UNIVERSIDADE DE SÃO PAULO
ESCOLA POLITÉCNICA

TAINÁ ANDREOLI BITTENCOURT

DESIGUALDADES DE CLASSE, RAÇA E GÊNERO NO ACESSO AO TRANSPORTE E AO ESPAÇO URBANO EM CIDADES BRASILEIRAS: ANÁLISES EMPÍRICAS E MÉTODOS PARA POLÍTICAS E PLANEJAMENTO

CLASS, RACE AND GENDER INEQUALITIES IN THE ACCESS TO TRANSPORT AND TO URBAN SPACE IN BRAZILIAN CITIES: EMPIRICAL ANALYSES AND METHODS FOR POLICIES AND PLANNING

SÃO PAULO
2023

TAINÁ ANDREOLI BITTENCOURT

DESIGUALDADES DE CLASSE, RAÇA E GÊNERO NO ACESSO AO TRANSPORTE E AO ESPAÇO URBANO EM CIDADES BRASILEIRAS: ANÁLISES EMPÍRICAS E MÉTODOS PARA POLÍTICAS E PLANEJAMENTO

CLASS, RACE AND GENDER INEQUALITIES IN THE ACCESS TO TRANSPORT AND TO URBAN SPACE IN BRAZILIAN CITIES: EMPIRICAL ANALYSES AND METHODS FOR POLICIES AND PLANNING

Versão Corrigida

Tese apresentada à Escola Politécnica da Universidade de São Paulo para obtenção do título de Doutora em Ciências.

Área de Concentração: Engenharia de Transportes

Orientadora: Professora Doutora Mariana Giannotti

SÃO PAULO
2023

Este exemplar foi revisado e corrigido em relação à versão original, sob responsabilidade única do autor e com a anuência de seu orientador.

São Paulo, ______ de ____________________ de __________

Assinatura do autor: ________________________

Assinatura do orientador: ________________________

Catalogação-na-publicação

Bittencourt, Tainá A.
Desigualdades de classe, raça e gênero no acesso ao transporte e ao espaço urbano em cidades brasileiras: análises empíricas e métodos para políticas e planejamento / T. A. Bittencourt -- versão corr. -- São Paulo, 2023.
162 p.

Tese (Doutorado) - Escola Politécnica da Universidade de São Paulo. Departamento de Engenharia de Transportes.

1.acessibilidade 2.planejamento de transportes 3.classe social 4.raça 5.gênero I.Universidade de São Paulo. Escola Politécnica. Departamento de Engenharia de Transportes II.t.

Bittencourt, T.A. Desigualdades de classe, raça e gênero no acesso ao transporte e ao espaço urbano em cidades brasileiras: análises empíricas e métodos para políticas e planejamento. 2023. 162 p. Tese (Doutorado em Engenharia de Transportes) – Escola Politécnica, Universidade de São Paulo, São Paulo, 2023.

Aprovada em 06 de dezembro de 2023.

Banca examinadora

Dra. Bianca Bianchi Alves
World Bank Group

Prof. Dr. Eduardo César Leão Marques
Departamento de Ciência Política da Faculdade de Filosofia, Letras e Ciências Humanas, Universidade de São Paulo

Prof. Dra. Karen Lucas
Department of Geography within the School of Environment, Education and Development, University of Manchester

Dr. Rafael Henrique Moraes Pereira
Instituto de Pesquisa Econômica Aplicada

AGRADECIMENTOS

Ao longo de seis anos, essa tese foi pensada, repensada, escrita e reescrita diversas vezes. Ao tempo em que esteve em constante transformação, ela também concretiza diferentes momentos e maturidades enquanto pesquisadora, ativista e profissional. Atravessou cidades, governos e inquietações pessoais, sociais e políticas vividas coletivamente.

Por isso, agradeço à Universidade Pública, em especial à Universidade de São Paulo e Universidade Federal do Paraná, fundamentais para o avanço social e científico do país e que me permitiram tantos diálogos, construções e aprendizados – dentro e fora delas – nos últimos doze anos, e à CAPES e ao CNPq, que apoiaram parte dessa caminhada.

Agradeço à professora Mariana Giannotti, pela orientação livre, vibrante e cuidadosa e pela parceria que extrapola os muitos limites da produção acadêmica. Agradeço também a Eduardo Marques, Karen Lucas, Rafael Pereira, Orlando Strambi, Bianca Alves e Maria Peix, por serem referências imprescindíveis a esse trabalho e por tão gentilmente aceitarem contribuir com ele.

Agradeço à Frente Nacional de Prefeitas e Prefeitos, nos nomes de Gilberto Perre e Jeconias Júnior, pela oportunidade de navegar entre âmbitos técnicos e políticos, e ao Projeto AcessoCidades, que fecha seu ciclo junto ao fechamento desta tese. Ao César Medeiros, Isabela Barbosa, Amanda Vieira, Haydée Svab e todas as pessoas que tanto me ensinaram ao longo desta iniciativa tão potente, inovadora e necessária. Esta pesquisa não seria a mesma sem a contribuição de vocês.

Agradeço aos colegas de Geomove, da Escola Politécnica, que se tornaram amigos, coautores e críticos deste trabalho, em especial Germán Freiberg, Pedro Logiodice, Mateus Humberto, Beatriz Moura, Diego Tomasiello e Fernando Gomes. Aos pesquisadores do Centro de Estudos da Metrópole, da Faculdade de Letras, Ciências e Humanidades, que expandiram os olhares e horizontes da pesquisa, entre eles Jonathan Phillips e Renata Bichir. À Bruna Pizzol e Matheus Barboza, pelo compartilhamento essencial das angústias, ideias, palpites, risos e respiros entre as muitas viagens a pé, de bicicleta, transporte público, carro e avião.

Agradeço às amigas e aos amigos que viveram comigo essa trajetória em São Paulo, Lucianna Shinye, Catherine Myazaki, Olívia Gil, Naomi Yamada, Caio Yuzo, Tiago Martinelli, Juliana Ballardie, e os muitos outros que fizeram mais colorida essa cidade cinza. E a Rafael Breternitz, pelas trilhas, bares e carnavais em tantas cidades pelo Brasil.

Agradeço à minha mãe, Cléa, e ao meu pai, Carlos, por estarem tão próximos mesmo a centenas de quilômetros de distância. Obrigada pelas referências históricas de amor e luta e pelo apoio constante nos momentos felizes e também nos de irritação. Agradeço à Naiara, irmã que compartilha de tantas semelhanças nas nossas enormes diferenças, pela inspiração, impulso e companheirismo desde que me entendo por gente.

E agradeço sobretudo a todas as pessoas que se dispuseram a compartilhar um pouquinho de suas histórias, percepções e vivências materializadas ao longo desta tese e às gestoras e gestores de todo o país que trabalham na construção de cidades mais sustentáveis, seguras e equitativas.

RESUMO

Existem desigualdades cumulativas e que se auto reforçam na sociedade e no espaço urbano. Os sistemas de transporte público, cuja função ideal seria a integração entre pessoas e atividades, estão intrinsecamente relacionados com o uso e ocupação do solo e muitas vezes acabam por reforçar desigualdades socioespaciais, sendo uma dimensão adicional ao precário acesso ao emprego, à saúde, à educação e ao lazer para grande parte da população. Nesse sentido, a presente pesquisa visa contribuir para a compreensão das desigualdades relacionadas aos transportes em espaços urbanos e sociedades altamente desiguais, particularmente no Brasil, e a partir de uma perspectiva comparada. Isto é atingido através de uma combinação de métodos quantitativos e de análise empírica dos desafios de acesso ao transporte e a serviços e atividades urbanos em cidades selecionadas, reunindo diferentes contextos nacionais e internacionais em relação à estrutura social (classe, raça e gênero) e estrutura espacial (uso e ocupação do solo e sistemas de transporte). Ao todo, a pesquisa apresentada em cinco capítulos abrange quatro cidades brasileiras (Curitiba, Fortaleza, Rio de Janeiro e São Paulo) e duas cidades localizadas no Reino Unido (Londres) e nos Estados Unidos (Nova York). As análises mostram que as classes mais baixas têm sistematicamente menor acesso às oportunidades de emprego do que as classes mais altas e pessoas negras têm menor acessibilidade do que as brancas, mesmo quando pertencem à mesma classe social. Essas desigualdades são maiores nas grandes cidades, nos países de menor renda e em sociedades pós-coloniais, especialmente quando são considerados os custos de viagem. Isto acontece porque as classes mais baixas e pessoas negras não somente estão sobrerepresentadas entre os mais pobres, mas também nas periferias urbanas, longe das oportunidades de emprego. As escolas públicas, as instalações de saúde e, em certa medida, os espaços verdes abertos estão melhor distribuídos espacialmente, mas a falta de capacidade e qualidade dos serviços ainda constituem grandes barreiras à acessibilidade e à mobilidade quotidiana, com um impacto maior sobre as mulheres. Além das contribuições em termos de análise dos fenômenos sociais, urbanos e de transportes, o presente trabalho contribui metodologicamente ao propor formas de cruzamento de dados de diferentes fontes censitárias, governamentais e colaborativas para ampliar a capacidade de análise do acesso a oportunidades urbanas pelos diferentes grupos sociais, bem como métricas de acessibilidade aderentes aos diversos contextos locais e nacionais e aos tipos de atividades e serviços públicos, considerando a capacidade de provisão dos serviços e competividade pelas mesmas oportunidades.

Palavras-chave: acessibilidade, planejamento de transporte, classe social, raça, gênero.

ABSTRACT

There are cumulative and self-reinforcing inequalities in society and urban space. Public transport systems, whose ideal function would be the integration between people and activities, are intrinsically related to land use and occupation and often end up reinforcing socio-spatial inequalities, being an additional dimension to the precarious access to employment, healthcare, education, and leisure for a large part of the urban population. In this sense, this research aims to contribute to understanding transport-related inequalities in highly unequal urban spaces and societies, particularly in Brazil, and from a comparative perspective. This is achieved by quantitative empirical analysis of accessibility and transport challenges in selected cities, gathering different national and international contexts regarding social structure (class, race, and gender) and spatial structure (land use and occupation and transport systems). In total, the research presented in three chapters covers four Brazilian cities (Curitiba, Fortaleza, Rio de Janeiro, and São Paulo) and two cities located in the United Kingdom (London) and the United States (New York City). The analyses show that lower classes have systematically lower access to job opportunities than upper classes, and blacks have lower accessibility than whites, even when they belong to the same social class. Those inequalities are higher in larger cities, middle-income countries, and post-colonial societies, especially when considering travel costs. This is because lower class and blacks are not only overrepresented among people experiencing poverty but also in urban peripheries, far from job opportunities. Public schools, healthcare facilities, and, to some extent, open greenspaces are better spatially distributed. However, the lack of service capacity and quality are still significant barriers to accessibility and everyday mobility, with a higher burden on women. In addition to the contributions in terms of analysis of social, urban, and transport phenomena, the present work contributes methodologically by proposing ways of crossing data from different datasets, including demographic census, governmental and collaborative data, to expand the possibilities of analysis of the access to opportunities by social groups, as well as accessibility metrics that adhere to different local and national contexts and types of activities and public services, considering service capacity and the competitiveness for the same opportunities.

Keywords: accessibility, transport planning, social class, race, gender

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

INDEX

1 Introduction

1.1 Background

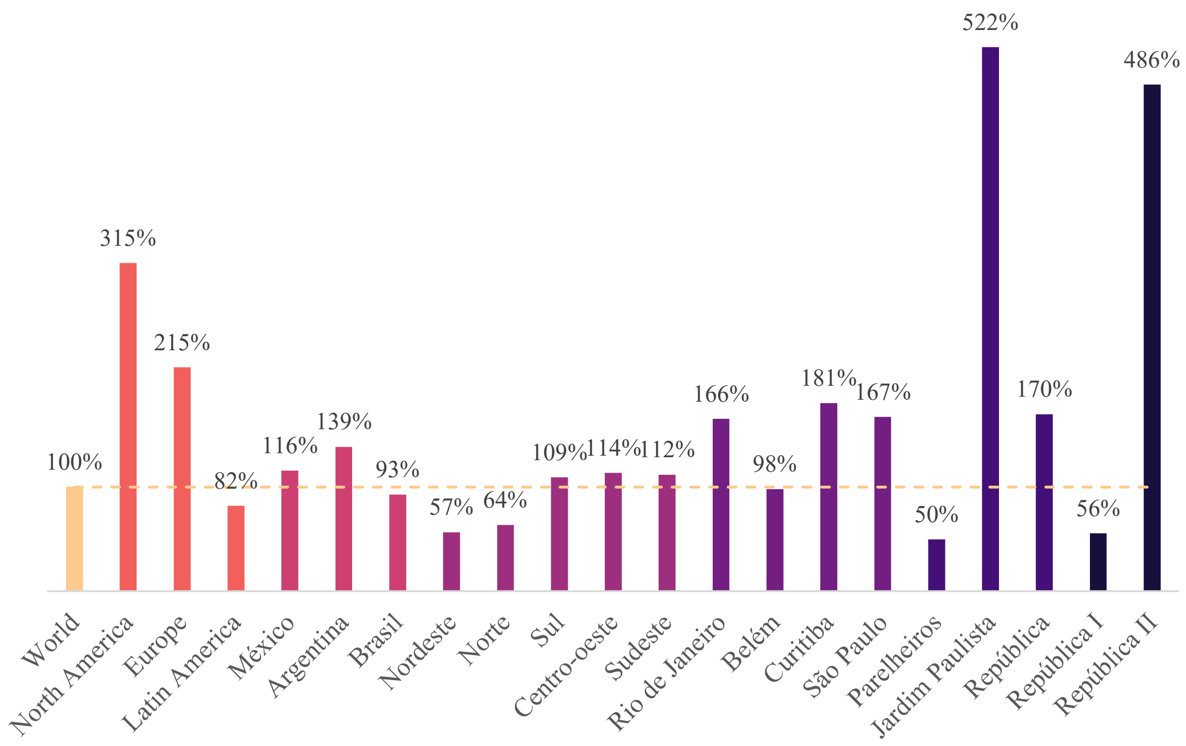
Inequality refers to the unequal distribution of resources, opportunities, or outcomes among individuals or groups. It can manifest in various forms and across different dimensions, including income, wealth, education, health, employment, etc. Social inequalities, however, are not created by chance. They result from structural aspects that form each society or context and systematically put some individuals and groups in better positions than others (Young, 2001). Those aspects in capitalist, racist, and patriarchal societies are mainly marked by social class, race, and gender (Davis, 1982).

Considering that more than half of the world's population is now urban, cities have become the primary locus for such inequalities, exemplified by precarious settlements, poor urban infrastructure, and insufficient and inadequate essential services (Davis, 2017). Nevertheless, more than only manifesting unequal patterns and distributions, space also has the power of structure and reinforcing inequalities translated by the socio-spatial dialectic (Lefèbvre, 2000) and the social production of space (Harvey, 1988).

The patterns of inequality propagate on different territorial units, which put on evidence another fundamental aspect of socio-spatial inequalities: its multiscalarity. From countries to neighborhoods, the historical processes of exploitation and dependence shaped even more substantial forms of inequality in low- and middle-income countries, aggravated by low levels of political representation and social participation of lower classes (Marini, 1973). In cities, peripheral occupations contrast with urban voids in central areas, commonly analyzed as part of intense competition for urbanized land inserted in the dynamics of real estate markets (Maricato, 2017).

Indeed, taking only income as a proxy for inequalities, although they have been massive over the years, with the top 10% income share oscillating around 50-60% of total global income between 1820 and 2020, while the bottom 50% share has generally remained around 5-15% (WID, 2022), there are critical geographical disparities. The average per capita income in Sub-Saharan Africa is 31% of the global average and 82% in Latin America. On the other hand, the average income in Europe is more than twice the global average (215%) and three times that in North America (315%). Moreover, the Brazilian average income is slightly smaller than the global average. However, people living in the northeast earn half the earnings of people from the southeast, but similar to someone living in Parelheiros, in the periphery of the city of São Paulo (Figure 1-1).

Figure 1-1: Average income per capita (in percentage from the global average)



Source: adapted from the World Inequality Database (2022) and IBGE (2010), corrected by inflation.

This process is deeply associated with locational accessibility (Villaça, 1998), and thus the organization of transport systems, which has a fundamental role in urban development and growth (Santos, 2008), as well as in perpetuating socio-spatial inequalities, alongside inequalities of income and power, modifying and remodeling spaces (Harvey, 2001). Large peripheral neighborhoods, for instance, inhabited by lower classes only exist because public transportation is available to get workers to production sites, independently of the quality and regularity of the service (Vuchic, 1984). Whether the different forms of land use and occupation induce travel demand, investments in transport also have the power to transform urban space in processes that feed back into each other (Hansen, 1959).

Although recognized by the Brazilian Constitution as a social right, transport systems vary significantly in terms of planning and operation. In addition to the unequal spatial distribution of households, social groups, activities, and services, which in turn leads to the concentration of transit networks, public transport systems are usually planned to follow optimization goals based on actual and future demand, giving less importance to people's needs and desires (Martens, 2006). Moreover, they are usually poorly regulated and financed by public authorities, giving private operators more power to reduce costs and maximize the number of passengers transported daily, usually at the expense of service quality (Vasconcellos, 2000)

As a result, many people are denied their right to access transportation, leading to the denial of the right to participate in urban life, with social, cultural, and economic consequences, especially for people experiencing poverty (Lucas, 2012). This is because transport is a means for access to other fundamental human and social rights, such as employment, education, healthcare, leisure, and other activities that may contribute to one's basic needs and well-being (Delbosc, 2012).

Public transport investments are, therefore, part of a much broader spectrum of public policies that mobilize groups with distinct and specific interests over the territory. Politicians, public administrators, policymakers, bureaucrats, private operators, developers, landowners, activists, citizens, and many other actors act inside and through the state, generating conflicts and influencing public decisions and actions, which may assume specific characteristics according to institutional capacity, traditional forms of organization, and the contexts in which policies take place (Marques, 2016).

In this sense, the present research is situated together with recent studies that propose to contribute to developing more accessible and equitable cities through urban and transport policies and planning.

Firstly, it is part of a potential and growing set of comparative analyses between cities (Pritchard et al., 2019; Giannotti et al., 2021; Geurs et al., 2021) in the movement to understand everyday experiences in different social and urban contexts, but also their differences and specificities, which are imperative to the formulation of contextualized policies. It is based on the combined and intersectional evaluation of social structure, urban space, and public transport systems' physical, temporal, and financial supply.

Second, if discussions about social inequalities and injustices are recently growing in the transport sector through theoretical and empirical perspectives (Lucas et al., 2015; Martens, 2012; Pereira et al., 2016), they are predominantly centered on high-income countries with a smaller set of investigations on cities in highly unequal contexts (Guzman et al., 2017; Pereira, 2019; Pizzol et al., 2021). Their profound inequalities can offer new empirical and theoretical tools for understanding and measuring socio-spatial and transport phenomena in their most diverse aspects.

1.2 Research questions

The overarching goal of this research is to contribute to the understanding and measurement of transport-related inequalities in the urban space of highly unequal cities through the dimensions of social class, race, and gender as a tool for urban and transport planning. Although there are multiple aspects of inequality in transportation, including transport emissions, congestion, road safety, and road space distribution, to name a few, we focus on access to transportation and urban opportunities. In Table 1-1, we summarize the specific objectives and research questions for each research paper.

Table 1-1: Specific objectives and research questions of the thesis

Specific objectives	Research questions
1. Understand how residential segregation by social class and race relates to accessibility.	1.1 How do scale, geography, class, and race differences relate to spatial segregation? 1.2 Where do spatial segregation and transport systems produce cumulative and self-reinforcing inequalities? 1.3 What are the effects of different spatial and temporal units on segregation and accessibility measurements?
2. Understand how local and global inequalities of income affect the affordability and accessibility by social class and race.	2.1 How do global and local inequalities in cities with different levels of maturity and connectivity of transport systems manifest in the accessibility of social and racial groups? 2.2 How do fare policies in interaction with income result in differential affordability and accessibility levels?
3. Identify tools for evaluating the accessibility of public services with limited capacity	3.1 What are the measures for the identification and prioritization of urban areas and populations in the distribution and qualification of public services with limited capacity?

> 3.2 What are the social, racial, and gender inequalities of accessibility to non-work activities?

These research questions aim to fill essential gaps in the academic literature on urban and transport studies.

First, although there is consistent literature on residential segregation by social class (Torres, 2003; Ribeiro, 2003) and a smaller number of studies on race (Telles, 1992; França, 2016), no previous study, to the best of our knowledge, was able to combine those two dimensions in the intraurban scale, allowing for a more robust analysis of how segregation limits or enable access to opportunities to different social and racial groups in different social and urban contexts.

Second, while the dimension of travel time is widely adopted in accessibility studies, few incorporate the dimensions of travel costs (El-Geneidy et al., 2016; Guzman & Oviedo, 2018) and transfers (Guo & Wilson, 2011). Furthermore, even when they do so, studies are primarily limited to study cases, which prevents analysis of how those two dimensions – partly structured by public transport networks and fare policies -- contribute to the inaccessibility of the city, despite the many studies highlighting the unaffordability of public transportation particularly in low and middle-income countries (Carruthers et al., 2005).

Third, although many accessibility metrics have been proposed over the years, including the most traditional (minimum travel time, cumulative and gravitational) to the most complex ones -- Shen's index (Shen, 1998), 2SFCA (Luo and Whi) and other balanced float catchment areas (Paez et al., 2019) --, and many others in between, only a few of them adequately dealt with the issues of the location of public facilities, service capacity and quality by keeping it simple to understand and use as a support for policy formulation.

1.3 Analytical dimensions

This is primarily empirical research drawn from quantitative methods and conducted mainly in Brazilian cities -- although it punctually incorporates cities from high-income countries to emphasize differences in social and urban contexts when needed.

The methodological choices, procedures, and data adopted will be described in Chapter 2. For now, the goal of the following subsections is to present a brief overview of the main concepts and analytical dimensions that guide this thesis.

1.3.1 The social structure: class, race, and gender

Economic resources are imperative to access services and goods in a capitalist society (Harvey, 1988). Nevertheless, other than economic resources, usually assessed by income levels in most transport studies, there are many other structuring dimensions of society. In addition to the economic, social - given by relations of domination and control - and cultural capitals - through the concentration of knowledge – a symbolic capital of power and prestige also plays an essential role in positioning individuals and groups in the social structure (Bourdieu, 1991).

Among those other symbolic and cultural dimensions that also reflect the economic dimension in a hierarchical society are race and gender (Davis, 1982). Even though those elements are socially constructed and receive different meanings and characteristics in each context, they usually result in substantial inequalities among social groups (Belkhir & Barnett, 2001).

On race, the legacy of colonization, slavery, and whitening goals across the centuries have shaped several forms of discrimination in Brazilian society, built on definitions of physical, intellectual, moral, and psychological capacities based on biological and geographical characteristics. Those discriminations are embedded in individual and institutional practices that reaffirm relations of power and contribute to the hegemony of the white population in social, economic, and political terms (Almeida, 2019).

The miscegenation and the myth of racial democracy in Brazil have contributed to creating different layers and social hierarchies among the black population, entrenched in the idea of white superiority (Devulsky, 2021). However, pardos have income levels and residential locations similar to pretos, mainly concentrated in peripheral areas (França, 2016). In other cities around the world, racial discrimination and inequalities manifest in different ways. In the United States, for instance, the black population is far less representative of the total population than it is in Brazil, and dynamic processes of discrimination through legal norms and informal practices led to the formation of highly segregated ghettos, usually structured by a distinct class gradient (Massey & Tannen, 2017). Moreover, racial discrimination is also present against immigrants of some specific ethnic origins and heritage, such as Latinos and Asians.

On gender, the social and sexual division of labor delegated to women activities related to household and family care (Hirata, 2004), which resulted in them having lower salaries and less time available to perform productive, educational, and self-care activities (Madariaga, 2013) and contributed to the loss of their autonomy and well-being. As a result, women tend to make multiple trips throughout the day, including trips to work, healthcare, education, shopping, etc. (Jirón et al., 2020). Also, due to economic and cultural aspects, a smaller proportion of women use private cars or bicycles (Vance & Rich, 2007). Instead, they mostly walk and use public transportation (Hanson, 2010).

At the same time, class, race, and gender interact with each other and structure different forms of power and oppression within the framework of capitalism, racism, and patriarchy (Crenshaw, 1989). The intersectionality of different and inseparable social structures provides a theoretical-methodological instrument to overcome mere overlaps or binary simplifications of men/women, white/black, rich/poor, and advance in the analysis of how the dimensions of class, race, and gender entangle specific forms of inequality and violence suffered by different social groups (Davis, 1982).

Those three structural dimensions of inequalities (social class, race, and gender) are transversal to this thesis. However, they are mobilized with a stronger or weaker emphasis depending on the goals and methods of each chapter. Since the first two chapters are based on locational accessibility analyses, we focus on the social dimensions of class and race. This is because women and men tend to inhabit the same places, and the employed metrics do not adequately capture gender inequalities. The gender dimension is more evident in the third chapter, when we discuss access to opportunities related to the mobility of care, and more strongly in the fourth chapter, based mostly on qualitative data from focus groups and interviews.

1.3.2 The spatial structure and the socio-spatial dialectics

According to Lefèbvre (2000), space is a social product, result, and condition of social production and reproduction. Therefore, it is relational and specific to each society and fundamentally historical, built from social practices and supporting future practices. Therefore, the urban environment is built under the conflicts of the many groups that structure society and have distinct interests over the territory (Harvey, 2001). The many inequalities among those groups may result in the separation in space, assuming different forms and patterns in cities in different regions of the world. Residential segregation, in this sense, is structured from feedback mechanisms in economic and social terms, mediated by institutional influences and historical legacies, which impose some degree of inertia on space and social relations (Fujita & Maloutas, 2012).

In general, most studies analyze socio-spatial segregation in Brazil from the center-periphery model, associated with the process of urban sprawl and the differential value of urban land (Maricato, 2017). Thus, high-income classes mostly occupy better-located and equipped areas, and peripheral areas are left to low-income people. The urban space, however, is more complex. There are segregated regions occupied by high-income groups in areas far from the city center and gated communities (Caldeira, 2001), precarious settlements in central areas (Berenguer, 2014), and very heterogeneous peripheral spaces (Torres & Bichir, 2009), with different conditions of access to adequate housing, affordable public transport, and access to jobs, healthcare, education, leisure, etc. (Maricato, 2017; França, 2016).

The concept of accessibility is thus of particular importance in discussions about residential segregation and land use. Although first proposed by Hansen (1959) as "potential of opportunities for interaction", the more commonly adopted definition was proposed by Geurs and Van Wee (2004) as "the extent to which land-use and transport systems enable (groups of) individuals to reach activities or destinations by means of a (combination of) transport mode(s)".

This relationship between residential segregation and accessibility is the focus of the first chapter of this thesis, establishing the foundations for all subsequent analyses. Although also based on accessibility, the second and third chapters look at each of the two main dimensions of accessibility in the definition proposed by Cervero (2005), who is mainly concerned with urban and transportation policies. According to this author, accessibility is a "product of mobility and proximity, enhanced by either increasing the speed of getting between point A and point B (mobility), or by bringing points A and B closer together (proximity), or some combination thereof." While mobility, and more specifically, public transport systems, is the focus of the second chapter, proximity to basic public services facilities is the focus of the third.

It is important to emphasize that even though all accessibility studies focus on the physical separation of residences and activities assessed according to a degree of impedance or resistance to urban trips in terms of monetary and temporal costs, its implementation varies substantially depending on the research or policy need, mode of transport and data availability (Wu & Levinson, 2020). They also vary according to the type of activity since work, education, health, and leisure activities provide different gains and are considered differently by people when planning their transport (Ramos et al., 2020). This is important since each chapter employs different accessibility metrics to best suit the object and purpose of the analysis.

1.3.3 Transport equity and justice

There has been substantial progress in transport equity and justice literature in recent decades. Though sharing some common elements, the multiple streams of research or trends in transport studies differ in terms of conceptual background, methodological approach, the transport dimension used to evaluate poverty or inequality, and the institutional focus on who can and should act upon transport-related injustices. Since concepts of transport disadvantage, transport poverty, transport exclusion, transport accessibility, transport connectivity, and transport stress, among others, are usually not consistent among studies, with different sets of contributing factors (Currie & Delbosc, 2011), it is worth summarizing some of those concepts that serve as the foundation for this thesis.

The first thing to highlight about transport disadvantage is its multidimensional character. Murray and Davis (2001) list three main elements that create transport disadvantage or, in other words, the inability or difficulty of people to access transport services: residential location (housing affordability and family ties), dispersed services (healthcare, education, employment, etc.) and inadequate transport (mainly focusing on public transportation in areas with low car ownership).

Wixey et al. (2005) gather six contributing factors of transport disadvantage: spatial, temporal, personal, financial, environmental, infrastructural, and institutional. Jirón and Carrasco's framework (2019) incorporates some of these factors but also makes explicit elements of the organization of travels and coordination with other people, information and traveling know-how, familiarity and capacity to use technologies increasingly adopted by transport systems, and embodied and affective attributes, which are related to personal characteristics.

Transport poverty aggregates multiple dimensions of transport disadvantage (Lucas, 2016), including i) not having adequate transport options within reach related to the lack of services or infrastructure; ii) not having a reasonable quality of life due to a lack of transportation options to perform key social or economic activities, iii) having to spend much of the already limited income in mobility needs, iv) having to invest excessive time in daily journeys, or v) having to travel regularly in dangerous, unsafe or unhealthy conditions.

When associated with social disadvantage, transport disadvantage or transport poverty may contribute to a process of transport-related social exclusion, understood as a condition of lack of resources, goods, and rights leading to the inability to participate in social interactions and activities, whether in economic, social, cultural or political arenas (Levitas et al., 2007). The social groups identified by transport literature to be the most vulnerable to experience transport-related social exclusion are associated with age (children and elderly), income (poor, unemployed), ethnicity (migrants), gender (women), household configuration (single-parent families), car ownership (no car), and disability (disabled) (Murray & Davis, 2001; Clifton & Lucas, 2004; Wixey et al., 2005).

In this context of transport-related social exclusion and profound transport-related socio-spatial inequalities, some studies focus on the need for transport equity and justice associated with the socio-spatial distribution of the benefits and burdens of transportation. In general, achieving equity in transportation means ensuring all citizens' access to services and goods — and consequently transportation — while mitigating social and environmental impacts such as pollution and eviction (Karner et al., 2016). This is regardless of their social class, race, gender, age, diverse functionalities, or other factors, but considering that those characteristics may imply the need for specific attention and policies (Lucas, 2004).

However, acting upon inequalities and inequities is not consensual among the social justice theories most applied to transportation; neither is how they deal with inequalities among individuals. Although we recognize the many divergences within each group, egalitarians defend minimizing disparities between individuals and providing equal access for all people to certain goods and services (Pereira et al., 2016). Sufficientarianists would prefer providing everyone with a minimum level of accessibility, which is aligned with what is considered sufficient to meet one's basic needs (Martens, 2017). The theory of the capability approach is concerned with creating conditions in which individuals can expand their capabilities and make meaningful choices, putting evidence on people's diverse goals and resources (Luz & Portugal, 2022). Their ideas oppose those of utilitarianists, whose goal is to maximize benefits for society while minimizing the costs of interventions (Lucas et al., 2015).

Nonetheless, social justice theories aiming for a more equal and just society have some practical limitations. As Harvey (1992) puts it, injustice is such a fundamental aspect of the capitalist system that any attempt to achieve a just city within the bounds of this political-economic system and its relations of power is doomed to failure. Although we align with that perspective, we also agree with Fainstein (2005) that a realistic acceptance of power structures does not simply imply that they cannot be changed or that inequalities cannot be mitigated. Instead, it accepts that changes are difficult and that any participatory or political decision holds mobilization biases and self-interests. Following Marcuse (2009), spatial remedies and distributions through urban (and transport) planning and policies are necessary and may significantly reduce social injustices and improve people's lives. However, they will always have limits unless the causes of social injustice -- embedded in historical and social, political, and economic contexts – are addressed.

1.3.4 Transport planning and policies

From a broad perspective, public policies and planning are the outputs of the operation of politics inside and through the State, which involves prioritizing sectors, populations, and territories. They reflect the conflicts of diverse groups with distinct interests, resources, and power and the constraints that characterize the context in which they are inserted (Marques, 2000). Multidimensional and structural inequalities are thus profoundly embedded in institutional practices (Young, 2001; Seth & Santos, 2020).

In urban transportation, public policies have a vital role in the allocation of spatial, financial, energetic, and human resources, which are essential to the operation of different transport modes and have the power to influence travel demand as well as the spatial distribution of people and activities (Hansen, 1959). Policies are usually linked to a regulatory framework and legal instruments that can act upon social and public issues through public ownership, subsidies, regulations, research, development, and safety and quality standards that guide transport operations (Rodrigue, 2020). Using those instruments is connected to target goals and promotes differential positive and negative impacts on the population and the territory, which are not always rigorously evaluated.

The field of analysis of public policies, including transport policies, has grown in recent decades and gained legitimacy and institutionality in the academic, governmental, and societal spheres (Marques & Faria, 2013). The main goal of such studies was not only to understand the functioning of the State and its actions but also to create a closer relationship between academics and decision-makers to support public policy design (Fisher, 2003). Although this discourse often resulted in a technocratic view that overlooked social and political conflicts (Marques & Bichir, 2001; Sanchez, 2003), it provided a scientific basis for public debate and government action.

Indeed, several transport studies have put some effort into ex-ante and ex-post analyses of infrastructural works (Pereira et al., 2016; Guzman et al., 2018), fare subsidies (Guzman & Oviedo, 2018; Matas, 2007; Barra & Nassi, 2002), and housing development (Martinez et al., 2018). Others focus on the constraints of public policy design, formulation, implementation, and evaluation, affected by aspects of governance and politics (Marsden & Rye, 2010).

As stated by Krahmann (2003), a complex universe of governmental and nongovernmental actors with various degrees of interdependence from each other may need to coordinate their needs and interests through the making and implementation of public policies. This process is even more critical in areas such as transportation, where State actions progressively shift from service provider to coordinator of public services provided by usually private actors (Pollitt & Bouckaert, 2011) and open to the participation of civil society organizations (Mayntz, 2003).

Although many previous studies have denounced the utilitarian character of transport planning and policies (Lucas et al., 2015; Pereira et al., 2016) and criticized it because of its role in perpetuating and reinforcing privileges and inequalities (Martens, 2006), few studies analyze how accessibility and socio-spatial inequalities associated with social class, race, and gender are explicitly present in urban mobility planning instruments and practices (Manaugh et al, 2015; Boisjoly & El-Geneidy, 2017). Even when they do so, the focus is usually on public administrators, ignoring other relevant actors in formulating and implementing public policies, particularly in contexts of low technical capacity and political power in the public administration.

1.4 Overview

This thesis is organized into three main chapters besides this introduction and final remarks. They are all theoretical and empirical, which refer to research papers published in scientific journals.

First, in **Chapter 1: Cumulative (and self-reinforcing) spatial inequalities: interactions between accessibility and segregation in four Brazilian metropolises**, we aim to understand the relationship between urban segregation and accessibility by public transport in Brazil, considering inequalities by class and race in different scales and geographies. From empirical evidence of four socially and spatially distinct Brazilian cities – São Paulo, Rio de Janeiro, Curitiba, and Fortaleza – we show that social class and race are intrinsically associated with each other in society and space, leading to black people having to travel longer to access the same number of jobs than whites, even when they belong to the same social class.

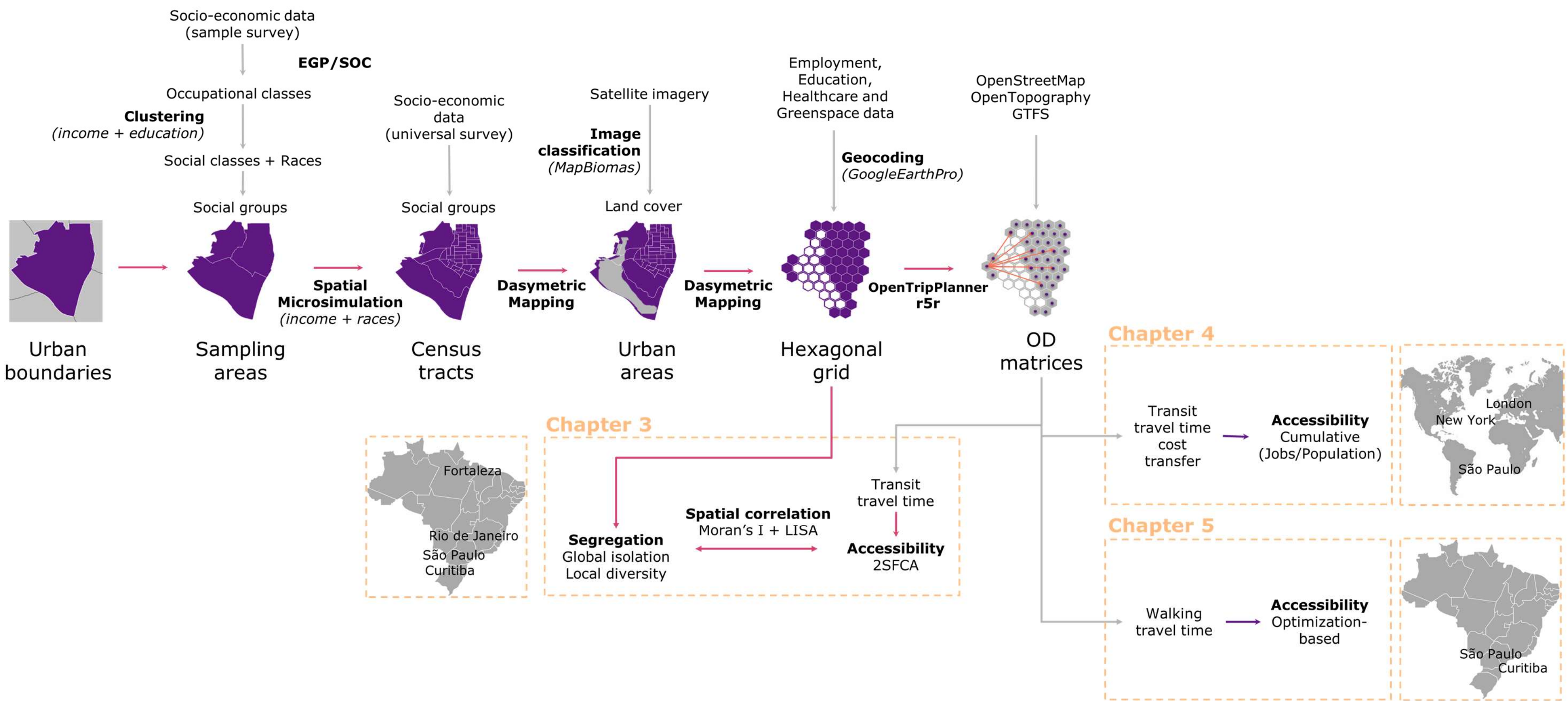
However, travel time is just one dimension of public transportation, adding to aspects of network connectivity and transport affordability. In **Chapter 2: The unequal impacts of time, cost, and transfer accessibility on cities, classes, and races**, we aim to understand how income levels among social and racial groups interact with public transport fare policies, resulting in additional constraints for accessibility. From the understanding that the conditions of income, infrastructure, and regulation in low and middle-income countries are undissociated from the global structure of dependence and exploitation in relation to high-income countries, we explore the many differences (and some similarities) among social, urban, and transport structures in cities with distinct positions in the globalized world - São Paulo, New York City, and London. By positioning Brazil in the international context, we show that the lower income in low- and middle-income countries, associated with expensive public transport fares, disproportionately burden lower classes and black populations.

Despite the usual focus on work trips, various other activities are essential to social reproduction and access to the city from a broader perspective, including education, healthcare, and leisure. In **Chapter 3: Evaluating the accessibility and availability of public services and inequalities in everyday mobility**, we focus on access to primary schools, basic healthcare facilities, and open greenspaces in two Brazilian cities - São Paulo and Curitiba. This presupposes not only the use of a diverse set of metrics and variables considering service capacity but also the incorporation of gender since women are the most burdened with care activities and perform more trips by walking and public transportation.

2 Methodology

The research methods used in this thesis and the advantages and limitations of the procedures adopted in each chapter are discussed below. Figure 2-1 illustrates a summary of the procedures and steps of data processing and quantitative analysis carried out in QGIS and R. All scripts are available on a GitHub page (github.com/tainabittencourt).

Figure 2-1: Graphical abstract of the methodology



2.1 The sociospatial structure

2.1.1 Urban boundaries

A significant limitation of this research is that public transport data is only available for some Brazilian cities, including municipalities in metropolitan regions. Therefore, while we recognize the metropolitan dynamics and their effects on transport-related inequalities, accessibility is measured and discussed only for the central city. Moreover, even when it is possible to look at the metropolitan scale, there is no unified national criterion for the definition of metropolitan regions (Firkowski, 2012), resulting in significant heterogeneity across the country.

In **Chapter 3**, we start our analysis by looking at the sociospatial structure at the metropolitan and central city levels, highlighting the complexity of urban occupation and setting the basis for future analyses. To do so, we redefined the metropolitan regions based on contiguity, density, urbanization, and integration, ensuring a minimum comparability between cities. As part of the metropolitan region, we considered municipalities with a contiguous urban area or more than 60 inhabitants/km², 70% of workers employed in non-agricultural occupations, and at least 10% commuting daily to work or study in the central city. These parameters were applied following the literature (Branco et al., 2013; Ingram, 2014). As a result, the redefined metropolitan region of São Paulo rose from 39 to 36 municipalities, while Rio dropped from 22 to 17, Curitiba from 29 to 13, and Fortaleza from 19 to 8.

In **Chapter 4**, since we are working with cities from different countries and legislations, we adopted different parameters for each city according to the urban context and data availability. In LON, we study the Greater London Authority (GLA), which includes the Inner, Center, and Outer London. Although we acknowledge the evolution of the exurban ring in recent decades and the growth of regional commuter flows (Eurostat, 2018), we limited our analysis to the contiguous urban area inside the Greenbelt for comparative reasons. In NYC, we include New York, Kings, Bronx, Richmond, and Queens counties. Even though these boundaries do not consider the super commuters, mostly from upstate New York, less than 15% of all work trips within the region other than New York City are to the city, and most daily commutes happen within the county (NYMTC, 2011).

The lack of transit data at the metropolitan level limited the study to the central city of São Paulo. While this limitation excludes an important share of the population (half of all people living in 39 municipalities) and activities, 90% of all motorized trips in the city of Sao Paulo are internal; that is, they are from and to the central city (METRO-SP, 2018). Other studies have shown that the metropolitan area of SP reproduces the socio-spatial patterns of the city, with some specificities. Generally, groups with the worst socioeconomic conditions tend to live outside the central city, but there are also heterogeneous spaces, including upper-classes living in neighboring municipalities (Marques, 2016; Moreno-Monroy et al, 2018).

In **Chapter 5**, analyses for Curitiba and São Paulo are also limited to the city boundaries, mainly because basic healthcare facilities, primary schools, and most of the greenspaces in Brazil are administrated at the municipal level.

2.1.2 Socio-demographic data

For Brazilian cities, demographic, social, and economic data came from the 2010 demographic census conducted by the Brazilian Institute of Geography and Statistics. The data is collected using two complementary surveys: universal and sample.

The universal survey is characterized by a short questionnaire applied to all households in Brazil, except for those in which residents refused to participate in the survey or who could not be reached after multiple visits. The collected data is then aggregated by census tract, a small territorial unit formed by a continuous area, located in a single urban or rural framework, with a size and number of households that allow a survey by a census taker. From this survey, we can know the total population, the average income, and the number of people belonging to each income level or race by census tract.

Although all households are asked to participate in the universal survey, some are randomly selected to participate in the sample survey according to some criteria to ensure the data is representative of the population. The questionnaire is considerably longer than the universal one, allowing for more information, and the microdata is available at the individual level. However, to ensure representativeness and anonymity, the data is attached to a sampling area, a territorial unit identified by the set of contiguous census sectors, usually belonging to the same district. From census sample data, we know the number of people by occupation, race, and income.

For New York City and London, analyzed in **Chapter 4**, we also use data from the national demographic census (IPUMS/USCB, 2018; ONS, 2011).

2.1.3 Social and racial classes

Many studies of urban inequalities consider income as a descriptor of social structure due to its direct and intuitive character. The problem is that income substantially diminishes our precision since many elements that stratify societies are not reducible to income, such as degrees of labor market protection, work skills, education, and autonomy in the work process, as well as symbolic and cultural features (Connelly et al., 2016) – not to mention the fact that economic cycles and crises produce effects on income, masquerading analyses with conjunctural dynamics. To avoid this problem, social stratification studies have developed empirical methods to classify individuals and social groups into social classes.

In **Chapter 3**, we used demographic census sample data to classify workers according to a classification that departs from EGP classes, a scheme initially proposed by Erikson, Goldthorpe, and Portocarrero (1979) and later adapted to the labor markets of many countries, including Brazil (Erickson & Goldthorpe, 1993; Scalon, 2013). We then regrouped the eight resulting classes of urban workers into three groups through hierarchical cluster analysis, considering income and years of schooling.

The following original classes were grouped: (1) Employers and owners with higher- and lower-rank professionals; (2) Technicians and supervisors of manual work with higher- and lower-rank routine non-manual workers; and (3) Skilled, semi-skilled, and unskilled manual workers. We removed three agricultural classes that represented less than 1% of the populations of the studied cities.

Additionally, the three groups of occupations were divided into two racial groups: (1) white (including Asian) and (2) black (including self-declared black, mixed race and indigenous). The racial information available in the Brazilian census is self-declared skin color, expressing racial identities far more than ancestry (Petruccelli & Saboia, 2013).

In **chapters 4 and 5**, we decided to use a different class scheme to classify urban workers based on demographic census sample data. Instead of using the EGP classes, we employ the revised version of the Standard Occupational Classification (SOC), the most recent update in the original SOC introduced in 1990.

The change in the socio-occupational classification system is because the revised version of SOC was only made available in 2020, after the conclusion of the previous analysis, and better portrays the changes in relations between labor, education, and skills, correcting distortions particularly related to professional and information technologies occupations (ONS, 2020).

In summary, the upper class corresponds to managers, directors, and professionals; the middle class corresponds to technicians and services and sales occupations; and the lower class corresponds to process and machine operatives and elementary occupations.

In addition, we divided the three social classes into three self-declared ethnic-racial groups: whites, blacks (and pardos, in Brazil), and non-whites/non-blacks, which included Asians, Hispanics, and other ethnicities. The addition of a third group was to better tackle the different social structures of the United States and the United Kingdom in relation to Brazil.

2.1.4 Spatial microsimulation and dasymetric mapping

The classification of urban workers by social class and race poses an additional challenge as the occupation variable is unavailable at the census tract level, only the sampling area. As mentioned, the census tract is a more disaggregated territorial unit designed to consider the operational capacity for data collection. The sampling area corresponds to a larger area where a longer questionnaire is applied to a household sample.

To identify the racial and social composition at more minor scales, we applied the iterative proportional fitting (IPF) method of spatial microsimulation (Lovelace & Dumont, 2017) based on income and race controls (or constraints). That is, by using the individual data provided by the census sample and the aggregated data collected by the universal census, we can calculate the maximum likelihood of a given individual being in specific census tracts (Lovelace & Dumont, 2017).

Using this methodology, individual data containing race, income, and occupation information available at the sampling area level were disaggregated into census tracts, which only contained the number of people by race and income. In simple terms, we assume that, according to the pattern observed in the census sample, census tracts with a higher presence of white people and higher income groups have a higher probability of concentrating white upper-class groups, and so on.

Using satellite imagery (MapBiomas, 2019), we corrected the census tracts' data to correspond to areas of urban occupation, removing green areas. This step is crucial in urban peripheries, where census tracts are more extensive than in central locations, and people are often concentrated in a small territory.

The same steps used to analyze Brazilian cities throughout the three main chapters were also used in New York City in **Chapter 4**, given that in the United States, the combined variable of detailed occupation and race is also only available at the sampling areas level (PUMAs). In London, the data was already available at the Lower layer Super Output Areas (LSOAs) and Middle Super Output Areas (MSOAs) levels.

2.1.5 Spatial grid

Multiple spatial grids and scales can be used to analyze a specific territory. Urban and transport studies commonly analyze mobility and accessibility levels by census tracts, origin-destination zones, or regular grids. In this thesis, we adopt regular hexagonal grids to standardize the size and shape of spatial units, thus reducing spatial bias (Shoman et al., 2018).

First, in **Chapter 3**, to check the robustness of our results against the modifiable areal unit problem (MAUP), which was proven to impact accessibility metrics in previous studies (Pereira et al., 2018), we adopted hexagons with diameters of 500, 1000, 2500 and 5000 meters. In **Chapter 4**, our analysis was limited to hexagons of 1000 meters due to data processing limitations. In **Chapter 5**, we adopted hexagons with a 500-meter diameter, which has proven to be small enough to allow robust analyses while not exceeding the computer’s memory capacity.

By using the dasymetric mapping method (Mennis, 2003), which redistributes data based on overlapping areas, we were then able to redistribute the sociodemographic and social group’s data from census tracts to the hexagonal grid.

2.1.6 Spatially distributed opportunities

Chapter 3 focuses on access to jobs, taken from the Annual Social Information Report issued by the Ministry of Economics and geocoded according to their zip codes using Google Earth Pro. With each job's estimated latitude and longitude, we joined them with the previously defined spatial grid. Given the unavailability of national data on the informal economy, we only considered accessibility to formal jobs. The problem is relevant even if the location of formal and informal jobs is highly correlated (Pereira, 2019), and, more importantly, informal jobs are usually more insecure and lower paid, offering different assets to workers.

Although **Chapter 4** also focuses on jobs, the use of origin-destination surveys available for São Paulo, New York City, and London, and the greater focus on transport systems (rather than the sociospatial structure itself) allowed for a more comprehensive analysis, considering both formal and informal jobs (METRO-SP, 2018; NYMTC, 2011; ONS, 2011). The data on the number of work-related trips by destination zone was redistributed to the hexagonal grid using the same dasymetric mapping method previously mentioned. In São Paulo, the change from the RAIS database to the origin-destination survey was also motivated by the need to make the methodology compatible with the data available for London and New York City.

Chapter 5 analyzes access to three public services (or opportunities): primary schools, healthcare facilities, and open greenspaces, considering service capacity and quality.

The number of school openings in primary schools was defined by the number of enrolled children from the first to the 6th year of their primary education in each public school, according to 2022 INEP data. Quality was assessed by factors contributing to school quality, such as infrastructure, equipment, number of professionals and staff, etc.

Regarding healthcare, only facilities that provide basic assistance were included since they are the main entrance to public healthcare in Brazil (Unidades Básicas de Saúde or Centros de Atenção Básica). We defined the maximum service capacity of each facility by multiplying the number of doctors in each UBS by 1000/3.5, which is close to the average ratio of 3.53 per 1,000 inhabitants in OECD countries (OECD, 2021). Quality indicators included aspects of infrastructure and human resources.

Finally, data on the location and size of greenspaces was obtained from local authorities. There is no clear guideline on greenspace per capita, and parameters change depending on the methodology used and what is considered greenspace. While some studies consider that it should be accessible, safe, and functional (Maryanti et al., 2016), others are more flexible in terms of use and consider all green areas with at least 2 ha (Kabish et al., 2016), regardless of if they are open to the public or not. Also, it may comprise all vegetation that may add value to inhabitants (Friederich & Langer, 2010). Given that the purpose of this study is to provide access to leisure and health activities, we align with the first and more restrictive notion of greenspace, which only includes parks, gardens, and squares. Even so, the m² of public open spaces per person in cities varies immensely: 3.47 m² in Saudi Arabia (Addas et al., 2020) to 36.47 m² in Dublin (Dublin, 2022). In this paper, we considered a ratio of 4 square meters per person as a first threshold for evaluation, but which should be subject to local (and hopefully progressive) targets and goals socially and politically defined.

2.2 Residential segregation

Massey and Denton (1988) describe five primary conceptual dimensions of residential segregation: evenness, exposure, clustering, centralization, and concentration. In **Chapter 3**, residential segregation is measured at the metropolitan level by isolation and diversity indices, representing two dimensions (Harris & Owen, 2018). All six main social and racial groups were considered in the analysis: black and white lower classes, black and white middle classes, and black and white upper classes.

At the metropolitan level, the spatial isolation index indicates the potential contact between people in the same group. Following Feitosa et al. (2005), the spatial isolation index is given by Eq. 1.

$$Q_m = \sum \frac{N_{jm}}{N_m} \left(\frac{L_{jm}}{Lj} \right) \text{ (Eq.1)}$$

where:

Q_m is the spatial isolation index of group m;

N_{jm} is the population of group m in areal unit j;

N_m is the population of group m in the study region;

L_{jm} is the local population intensity of group m in locality j;

L_j is the local population intensity in locality j.

To capture local facets of segregation and compare them with accessibility, we use the local diversity measure, which evaluates the distribution of groups considering the population at the city level. Following Tivadar (2019), based on Theil (1972) and Reardon and O'Sullivan (2004), the local diversity index is given by Eq. 2.

$$L_{SW,i} = -\sum_{k=1}^{K} p_{k,i} \ln p_{k,i} \text{ (Eq. 2)}$$

where:

$L_{SW,i}$ is the local diversity in spatial unit i;

$p_{k,i}$ is the population k in spatial unit i.

2.3 Interaction between zones

In accessibility studies, the impedance of traveling between different locations within each city is usually measured by travel times. In **Chapter 3**, transit itineraries included walking, waiting, transfer, and in-vehicle travel times and were computed using the OpenTripPlanner platform for a typical weekday in 2020 and a peak time journey beginning at 7 am.

However, many other aspects are considered by people when deciding on their trips, such as travel costs, the need to transfer between multiple systems and vehicles, or crowdedness, for instance. In transport planning, the mix of those aspects is represented as generalized costs, which translate into the disutility of traveling (Ortúzar & Willumsen, 2011). Although we recognize the importance of such a concept, the weight each individual gives to each aspect in one's decision matrix changes according to personal preferences, the characteristics of the trip (motives, time of the day, transport mode, etc.), as well as urban and transport systems.

Therefore, in **Chapter 4**, we consider travel times, monetary costs, and transfers separately. The dimensions of travel time and transfers were easily obtained by running the OpenTripPlanner platform. The time dimension corresponds to the travel time between origins and destinations. The transfer dimension considers the number of transfers between vehicles needed to make that trip, regardless of the transit system.

The monetary costs dimension, however, is more challenging since, as opposed to time, people have different income resources, and using different transport systems may represent additional costs. This is particularly true in São Paulo, where the isolated use of the bus or rail system costs R$ 4,40, but the combined use of both systems costs R$ 7,65.

To deal with this issue, we adopted a 4-step process. First, we ran a travel matrix considering the possibility of people using any public transport system that resulted in the shortest travel time, including a combination of different systems. Second, we ran separate travel matrices for each transport system – one for buses and one for subway and trains. Third, we combined the matrices, getting the cheapest route between origin-destination pairs, and based on the routes (for New York City), zones (for London), and transport systems (for Sao Paulo) used, we were able to obtain the monetary travel cost. Finally, we calculated the share of the average income that would be committed to make the round trip (go and return) between each origin-destination pair by dividing the monetary cost by the daily average income at the hexagon at the origin.

A critical limitation of this method is that, since potential travel costs were calculated by area, transport vouchers (or the Vale-Transporte - VT in Brazil) were not considered in the analysis, which may overestimate the share of income compromised with transportation. However, the VT only applies to weekday trips, formal workers – roughly 60% of workers in Brazil (IBGE, 2023) – and 6% of the employee's salary is discounted if he/she receives the benefit.

As in **Chapter 3**, transit itineraries were also computed for a typical weekday (February 2020) and a journey beginning at 7 am. This departure time was chosen to represent the start of the morning peak, where most work-related trips happen in the studied cities (METRO-SP, 2018; NYMTC, 2011; TFL, 2019). A time-sensitivity analysis was also performed between 7 am and 8 am for travel time accessibility, and different starting times were found to have a minimal impact on accessibility results (Appendix B-10, Appendix B-11, Appendix B-12, Appendix B-13, Appendix B-14, and Appendix B-15).

In **Chapter 5**, walking travel time matrices were obtained from the new r5r R package developed by Pereira et al. (2021), which made the implementation of the code much faster when compared to the OpenTripPlanner.

For all chapters, road network data came from OpenStreetMap, transit data in the General Transit Feed Specification (GTFS) format came from transit agencies, and slope data came from OpenTopography.

2.4 Accessibility measures

As accessibility has received many definitions over the years, its implementation also varied substantially depending on the research or policy need, mode of transport, data availability, and the type of activity since work, education, health, and leisure activities are considered differently by people when planning their transport (Ramos et al., 2020).

In **Chapter 3**, accessibility to formal jobs was calculated through the two-step floating catchment area (2SFCA) method, which considers the number of opportunities and the people competing for them (Luo & Wang, 2003). The main limitations of this cumulative method are the non-differentiation between activities accessible at times close to the defined limit and the impossibility of establishing a unique optimal threshold suited to different cities. These limitations relate to the modifiable temporal unit problem (MTUP), which, similarly to MAUP, states that temporal cuts can bias space-time and transport-related analyses (Cöltekin et al., 2011; Pereira, 2019). These were partially tackled by adopting multiple time thresholds to evaluate job accessibility by public transport (30, 45, 60, 90, and 120 minutes).

Moreover, the 2SFCA considers that only people within the defined thresholds to opportunities compete for them, which is not 100% true in large and unequal cities with quite long commuting times.

The formulation for the 2SFCA metric is given by Eqs. 3 and 4.

$$D_{j,T} = \sum \frac{O_j f(t_{i,j})}{\sum P_k}, \;\; f(t_{i,j}) = \{1, if \; t_{i,j} \leq T \; and \; 0, if \;\; t_{i,j} > T\} \text{ (Eq.3)}$$

$$A_{i,T} = \sum D_{j,T} f(t_{i,j}), \;\; f(t_{i,j}) = \{1, if \; t_{i,j} \leq T \; and \; 0, if \;\; t_{i,j} > T\} \text{ (Eq.4)}$$

where:
T is the time threshold for each evaluation (30, 45, 60, 90 or 120 minutes);
O_j is the number of formal jobs at the destination j;
P_k is the population living in all cells for which tkj is smaller or equal to T;
t_{ij} is the travel time by public transport from origin i to destination j;
$f(t_{ij})$ is a binary function that relates the travel time between the origin-destination pair ij and the time threshold T;
$A_{i,T}$ is the accessibility at the origin cell i for the time threshold T;

In **Chapter 4**, we adopted a different metric of accessibility to jobs by public transport, an adaptation to the commonly used cumulative measure. This change was due to three main reasons. First, we wanted to incorporate that people living far away from opportunities in urban peripheries may compete for the same jobs as those living in the city center. This is important when we compare cities with very different urban occupations, such as North American, Latin American, and European cities. Second, compared to other metrics, cumulative accessibility is more easily interpreted by much of the population outside the transportation research field, especially policymakers. Third, the number of jobs in relation to the working-age population in New York City and London is much greater than in São Paulo, resulting in more accessible opportunities and weaker competition for the same jobs in those places, which impacts accessibility analyses.

Therefore, to account for the absolute differences in population and job opportunities among the three cities, we divided the total number of jobs within each zone by the total working-age population within the city (people between 18 and 64 years old) and calculated accessibility levels by summing up these ratios when the trip between the origin-destination hexagons fell within a chosen threshold (Eq. 5).

$$A_{i,T} = \sum \frac{O_j f(t_{i,j})}{\sum P_k}, \; f(t_{i,j}) = \{1, if \; t_{i,j} \leq T \; and \; 0, if \; t_{i,j} > T\} \text{ (Eq.5)}$$

where:

T is the threshold for each evaluation;

O_j is the number of jobs at the destination j;

P_k is the working age population living in the city;

t_{ij} is the travel time, number of transfers or relative cost between origin i and destination j by public transport;

$f(t_{ij})$ is a binary function that relates travel time, transfers or relative cost between the origin-destination pair ij and the threshold T;

$A_{i,T}$ is the accessibility at the origin cell i for the threshold T.

Multiple thresholds of time (30, 45, 60, and 90 minutes), the share of income spent on traveling (5, 10, 20, and 30%), and the number of transfers (0, 1, 2, and 3) were calculated with the aim to reduce the effects of threshold choice.

As work-related transit trips are considered differently by people than walk trips to public services, in **Chapter 5**, we developed a new metric of accessibility, which is an adaptation of the optimum landscapes proposed by Horner (2008). The optimization-based accessibility metric evaluates, for each location in the city, the minimum travel time needed to access a number of opportunities greater than or equal to the total number of individuals competing for those opportunities. It is calculated through an optimization function similar to the classical transportation problem, in which the objective is to minimize the total cost of travel in society. In other words, to minimize the total cost c (of time or money) spent by individuals (x) living in all origin zones (i) to reach the services they need, which are spatially distributed throughout all destination zones or locations (j) (Eq. 6).

$$min \sum_{i=1}^{n} \sum_{j=1}^{n} x_{ij} c_{ij} \text{ (Eq. 6)}$$

where:

x_{ij} is the number of individuals living in spatial unit i matched to the opportunities in spatial unit j;

c_{ij} is the travel cost (time, money, …) from spatial unit i to spatial unit j;

n is the number of OD pairs between i and j.

Two additional functions constrain the objective function. The first constraint represents the supply side and guarantees that the service capacity (S) in each location will be reached (Eq. 7). The second constraint represents the demand side and guarantees that the total number of people (P) reaching all spatially distributed services cannot exceed the total population (Eq. 8). In cases of exceeding capacity, it is possible to make a mathematical adaptation and invert supply and demand in the algorithm implementation, using a transposed travel time matrix. Instead of matching opportunities to people, we would be matching people to opportunities.

$$\sum_{i=1}^{n} x_{ij} = S_j \ for\ all\ j = 1, 2, \dots, n \text{ (Eq. 7)}$$

$$\sum_{j=1}^{n} x_{ij} \leq P_i \ for\ all\ i = 1, 2, \dots, n \text{ (Eq. 8)}$$

where:

S_j is the number of opportunities in spatial unit j;

P_i is the population in spatial unit j.

The algorithm's output is the number of people matched to each opportunity (school, healthcare facility, or park/square, for instance). Once we merge this data with the travel time (or cost) matrix between origins (i) and destinations (j), we can determine the accessibility (A) of each zone by calculating the average time needed for all people within a zone to reach the services they need (Eq. 9).

$$A_i = \frac{\sum_{j=1}^{n} x_{ij} c_{ij}}{\sum_{j=1}^{n} x_{ij}} \text{ (Eq. 9)}$$

where:

A_i is the average accessibility (in minimum travel time or cost) in spatial unit i.

However, the population living in the urban area may exceed the total capacity of service, considering all spatially distributed opportunities. In this case, some people would be left out of the healthcare or education system and would not have access to enough school seats, doctors, or green areas. According to an accessibility perspective, they are located far away from public equipment and would need longer travel times or higher travel costs to reach them compared with their fellow citizens. The number of unattended people in each origin (i) is given by its population minus the number of people who were matched to an opportunity (Eq. 10). Differently to the original optimum accessibility landscapes, in this application, we overlap two different layers in the same map to better inform public policies: access times to the assigned opportunity and number of people left out of the optimum allocation due to longer travel times.

$$U_i = P_i - \sum_{j=1}^{n} x_{ij} \text{ (Eq. 10)}$$

where:

U_i is the number of people not matched to any opportunity in spatial unit i.

The supply side of these equations is described in section 2.1.6. The demand side depends on each service. For public schools, only children from middle and lower-class families from 6-11 years old were considered part of the demand for public services since the majority of upper-class families opt to enroll their children in private schools. According to national statistics, 80.7% of the Brazilian children who are enrolled in education from nursery to high school go to public schools (INEP, 2019), which is similar to the percentage of the lower and middle-class population in São Paulo (78.3%) and Curitiba (76.4%). The estimation of children per socio-occupational class was based on the workforce distribution and the number of children in each hexagon.

Regarding healthcare, we consider all the lower and middle-class populations living in the city, regardless of their age, as part of the demand for public healthcare facilities. As for greenspaces, we accounted for the whole population, regardless of their socio-occupational status or age.

2.5 Spatial correlation

In **Chapter 3**, to analyze the spatial correlation between accessibility and the lower-class population and then between accessibility and segregation, we used Global Bivariate

Moran's I scatter plots and their local disaggregation represented by LISA maps (Anselin et al., 2006).

Moran's I, initially proposed by Moran (1984), is a cross-product statistic between a chosen variable and its spatial lag, expressed in deviations from its mean. In our case, we will use the bivariate adaptation of Moran's I statistic, in which we measure the degree to which the value for a given variable at a specific location is correlated with the value of a different variable in its neighbors. Following Anselin (1996), the formulation for the Bivariate Moran's I is given by Eqs. 11, 12 and 13.

$$I_B = \frac{\sum_i(\sum_j w_{ij} y_j \times x_i)}{\sum_i x_i^2} \text{ (Eq. 11)}$$

where:

x_i is the variable value in spatial unit i;

y_j is the second variable value in the neighbors j of spatial unit i;

w_{ij} is the elements of the spatial weights matrix.

The spatial weights matrix refers to the neighbor structure between the observations, indicating degrees of spatial dependence. The spatial weights wij are non-zero when i and j are neighbors and zero otherwise. Here, the identification of neighbors was based on the criterion of queen contiguity, that is, the two neighbors share a common edge or vertex.

The bivariate Moran's I scatter plot is a plot with the original variable on the x-axis and the spatially lagged second variable on the y-axis. The value of Moran's I statistic corresponds to the slope of the linear fit to the scatter plot.

Moran's I, however, is designed to evaluate the null hypothesis of spatial randomness against the alternative hypothesis of spatial clustering. The Local Indicator of Spatial Association (LISA), suggested by Anselin (1995), allows the identification of the location of those clusters according to degrees of confidence (or significance). Its formulation, adapted to its bivariate implementation, is given by Eq. 14.

$$I_{B,i} = \frac{\sum_j w_{ij} z_{1,i} z_{2,j}}{\sum_i z_{1,i}^2} \text{ (Eq. 14)}$$

where:

I_i is the local Moran's I in spatial unit i;

$z_{1,i}$ is the standardized first variable in deviations from the mean in spatial unit i;

$z_{2,j}$ is the standardized second variable in deviations from the mean in the neighbors j from spatial unit i.

Consequently, we study the degree to which accessibility in a specific location is correlated with segregation in its neighboring cells. The same interpretation is valid between accessibility and the lower-class population. The stronger this correlation, the higher the absolute value of Moran's I.

In **Chapter 5**, we also use LISA maps to illustrate applications of the optimization-based accessibility metric to identify and prioritize public policies in the territory.

3 Cumulative (and self-reinforcing) spatial inequalities: interactions between accessibility and segregation in four Brazilian metropolises

Accessibility literature and practice emphasize three ways of promoting access to opportunities in the urban environment: distributing residence spaces, improving transport systems, and distributing and diversifying activities. In this first paper, we will focus on the first mechanism by exploring how differences in scale, geography, class, and race are related to residential segregation, leading to distinct levels of access to jobs by public transport in Brazil. These juxtaposed and combined inequalities create highly unfair and powerfully cumulative effects on some social groups, contributing to the reproduction of inequality.

From empirical evidence of four socially and spatially distinct Brazilian cities – São Paulo, Rio de Janeiro, Curitiba, and Fortaleza - and combining methodologies of spatial analysis to enhance comparability and reproducibility based on open data, we explore different areal units, time thresholds, and metrics in order to examine the transport inequalities present in different urban contexts and refine our results.

As discussed in the following few pages, upper classes have higher accessibility than lower classes, whites have higher accessibility than blacks, and large cities are more unequal than smaller ones. However, racial inequalities combine and overlap with class and city inequalities, changing these dichotomic notions when considering multiple dimensions of inequality. The groups that polarize social structure also polarize the urban space since the white upper class, and the black lower class are more segregated, but the way segregation interacts with accessibility is not straightforward and varies according to the socio-spatial structure.

3.1 Introduction

In analyzing the socio-spatial structure of cities, even contrasting approaches recognize the centrality of transport systems in relation to land use and occupations, and vice-versa. Classical models from urban economics that emphasize the role of markets in urbanization focus on the impact of transportation on the spatial organization of production, supply, and land prices (Fujita et al., 1999). Critical urban theories emphasize the political and social character of each location in the city, permeated by conflicts between actors over access to urban goods and services (Préteceille, 2000). In both cases, transport systems are considered capable of restructuring workplaces, housing, markets, and consumption, associating space and time (Harvey, 2001). The spatial distribution of individuals and activities presupposes trips via transportation systems. In turn, transport infrastructure produces differential locational advantages and disadvantages that modify how social groups are distributed in space (Hansen, 1959).

Social inequalities materialize in the urban environment and are redefined by it, assuming different spatial forms through contextualized mechanisms. In low- and middle-income countries, where consumer goods and services such as sanitation, health, and education are not universal, access to essential services becomes central to socio-spatial inequalities (Marques, 2019).

Despite the growing number of studies linking social and accessibility inequalities theoretically (Martens, 2012; Schwanen et al., 2015) and empirically (Currie, 2010; Nieuwenhuis et al., 2019), income, and more rarely race, are studied separately or taken as sole definers of social inequalities, reducing their complexity. Few studies focus on multiple dimensions of social and spatial structures (Bullard & Johnson, 1997; Sanchez & Brenman, 2017).

On race, Karner and Niemeier (2013) and Golub et al. (2013) highlight the need for racially focused analyses of equity, resulting in limited transport plans. Farber et al. (2015) have shown different patterns of interaction between races, while Tammaru et al. (2016) found an increasing segregation of immigrants over time. Although the studies above stress the need for research on the link between transport, minorities, and low-income individuals, they do not refer to accessibility. On the economic dimension, a few studies include other elements besides income to identify gaps between accessibility and socially disadvantaged neighborhoods, such as age, unemployment (Fransen et al., 2015), and schooling (Currie, 2010).

Although primarily concentrated in high-income countries, some studies on Uruguay (Hernandez, 2018), Colombia (Delmelle & Casas, 2012; Guzman et al., 2017), and Brazil (Slovic et al., 2018; Pereira, 2019) discuss transport-related inequalities in middle-income countries. Most of these works, however, focus on single cities. Looking at multiple Brazilian cities, Boisjoly et al. (2020) study access to jobs and public transport networks considering only income. Pereira et al. (2020) provide a broader analysis of accessibility to jobs, healthcare facilities, and schools, considering income and race. Our aim in this paper is to delve deeper into these discussions, exploring methods for generating comparability and enhancing our understanding of how inequalities in accessibility connect to inequalities in scales, geographies, social structures, and segregation.

Given the profound social and urban inequalities observed in global peripheral contexts, the proposed comparison addresses socio-spatial inequalities related to public transport rather than presenting a juxtaposition of case studies. We use clustering techniques, spatial microsimulation, satellite imagery, and dasymetric mapping to refine our comparative socio-spatial analysis through multiple areal and temporal units, taking four major Brazilian metropolises as empirical evidence. The methodology for the analysis is explained in section 2.

3.2 Urban socio-spatial inequalities and public transportation

Inequalities relate to social and spatial differentiations between individuals and social groups. Rather than being the product of random distribution, however, they derive from social processes that systematically place some individuals in more favorable conditions than others (Young, 2001), resulting in the accumulation of advantages or disadvantages in economic, political, and cultural spheres (Seth & Santos, 2020). The internal dynamics of societies reproduce both positions and dispositions, contributing to the formation and perpetuation of structures of social inequality (Bourdieu, 1989). Finally, land markets, housing policies, and State regulations add spatial dimensions to these stratification systems, connecting spatial and social inequalities and giving rise to segregation patterns (Arbaci, 2019).

Accessibility associates transport systems with land use, indicating the extent to which these enable individuals or groups to reach opportunities and activities (Geurs & Van-Wee, 2004). Several studies have linked a lack of accessibility and lengthy and unreliable daily commutes to difficulties in obtaining access to formal labor markets, creating disadvantages for people experiencing poverty (Ong & Houston, 2002). This has a particular effect on gender (Matas et al., 2010), given the larger burden of domestic work faced by women and ethnic and racial minorities (Hellerstein et al., 2008).

Spatial segregation of the poor and low accessibility thus tends to increase job precariousness and labor insecurity, reducing family income and contributing to the persistence of spaces of poverty (Sanchez, 2002). The increased accessibility provided by urban policies, such as transit infrastructures or the spatial redistribution of households and activities, not only has the potential to reduce inequalities but may also reduce unemployment and improve household income (Jin & Paulsen, 2018). Moreover, shortened travel times can minimize the disutility experienced by people during commutes and allow them to use this time more productively or creatively (Mackie et al., 2001).

In contrast, poor accessibility by public transport among segregated upper classes produces different outcomes. Due to more significant power resources to influence the production of urban infrastructure and more considerable monetary resources to access real estate markets (Pinçon-Charlot & Pinçon, 1989), elites can segregate themselves with the services and goods of most interest to them, creating a monopoly over opportunities, in parallel with Tilly's work on social networks (Tilly, 1998). Thus, the effect of segregation on access to opportunities has different meanings for different social groups.

In this context, many studies have applied accessibility metrics to measure the relationship between transport and social inequality (Lucas, 2012). Some of the remaining challenges concern how to compare different social and urban contexts and how to identify priority groups targeted by public policies. Despite the attractiveness of a 30-minute city, as discussed in North America, Europe, and Australia (Wu & Levinson, 2019), many people in low- and middle-income countries have exceptionally low cumulative accessibility, even in a 90 or 120-minute commute. This reflects the larger size of Asian, African, and Latin American cities and the historical processes of socioeconomic growth, urbanization, and the stage of transport structure development. Thus, a single time threshold fails to capture inequalities or fit every urban context, just as the average time spent commuting to work or the 60-minute threshold widely adopted in the literature and transportation plans (Palmateer & Levinson, 2017). This paper aims to further this effort by providing methodological and substantive contributions. First, it introduces a methodological framework for comparative analysis of social, racial, and spatial inequalities. Second, it advances discussions on transport-related inequalities, revealing complex patterns of interactions between accessibility and segregation.

3.3 São Paulo, Rio de Janeiro, Curitiba and Fortaleza

Brazil is one of the largest industrialized countries in the world and is notorious for its inequalities. Despite the magnitude of its metropolitan regions and urban disparities, substantial transportation systems were developed across the country, sparser but no different in nature from those found in the high-income countries studied by the literature. The study of Brazilian cities offers empirical insights to better understand the relationship between transit structures and social vulnerabilities. We focus on four major metropolises: São Paulo, Rio de Janeiro, Curitiba, and Fortaleza, intentionally choosing cities with different scales and distinct social and transport contexts. Their main characteristics are described below.

São Paulo is the largest urban agglomeration in South America, with 19.6 million inhabitants and an urban density of 6,320 inhabitants/km². It is also the continent's largest economic and financial center and has a socially unequal urban space (Marques, 2017).

Rio de Janeiro constitutes the second largest metropolitan region in the country, with 11.3 million inhabitants and 4,910 inhabitants/km². Much of its territory comprises a rugged and vegetated topography, which impacts its urban occupation (Préteceille & Cardoso, 2008) and accessibility levels (Pereira et al., 2018).

Curitiba's metropolitan region contains 3 million people and is also less dense with 2,730 inhabitants/km². It has been identified as a positive example of urban and transport planning. However, this model-city image is set against inequalities in urban occupation and infrastructure (Garcia, 1997).

Positioned in the country's poorest region, the northeast, Fortaleza is one of the densest cities in Brazil, with 3.3 million people and 4,400 inhabitants/km². Studies have highlighted its recent economic and urban growth, accompanied by increasing housing precariousness (Garmany, 2011).

Our cases include the largest and richest Brazilian cities, São Paulo and Rio de Janeiro, but also highly unequal in income. In fact, Gini coefficients for São Paulo, Rio de Janeiro, and Fortaleza are remarkably similar, ranging between 0.62 and 0.63. However, income levels are much lower in Fortaleza (U$ 170), while São Paulo and Rio have average incomes of U$ 280 and U$ 250, respectively. Curitiba has a slightly higher average income, U$ 285, and lower inequality (Gini of 0.53). Therefore, while São Paulo, Rio de Janeiro, and Curitiba are all richer, the latter is less unequal. Fortaleza is both poorer and unequal. On the other hand, both São Paulo and Rio de Janeiro are much larger and denser, while Curitiba is smaller and sparser, and Fortaleza is smaller but presents medium density.

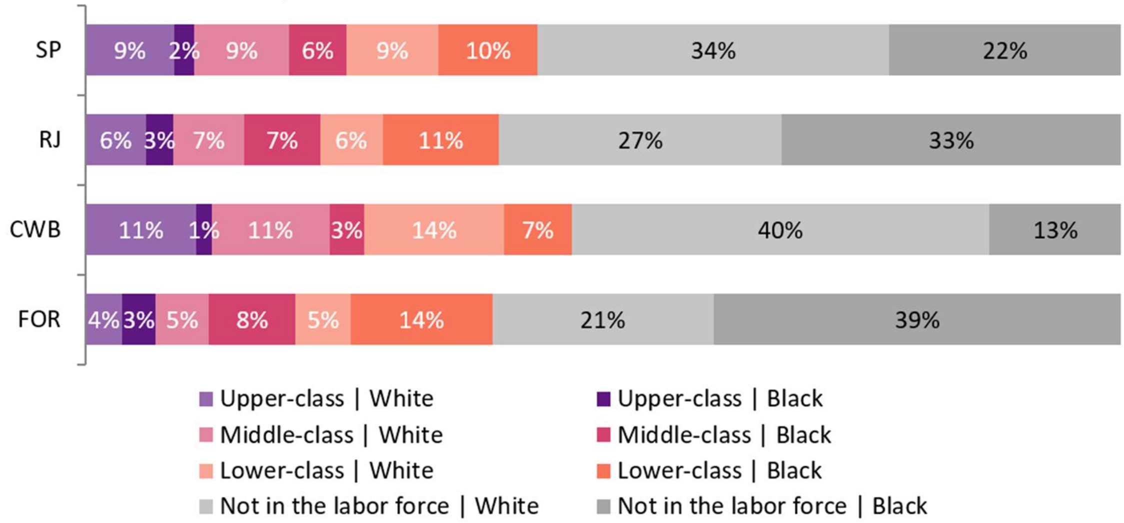
3.4 *Socio-spatial and accessibility inequalities*

Since different mechanisms contribute to urban segregation, this socio-spatial inequality is not unique to a particular economic, social, and political system. However, it assumes different patterns according to the society that forms it (Maloutas, 2008). In Brazilian cities, segregation is highly correlated with class and race (França, 2016), which constitute one focal point of the present study.

Social categories are generally similar across the cities, especially between São Paulo and Rio Janeiro, as discussed in previous studies (Marques et al., 2008; Préteceille & Cardoso, 2008). Curitiba has the highest proportion of employed workers, partly related to lower informality in work, which is lower in the south of the country (IBGE, 2010).

Nonetheless, there are substantial differences in racial composition, primarily associated with Brazil's colonial history. The northeast and southeast regions had export-oriented sugar economies based on large rural properties and slave labor. This contrasted with the southern region, characterized by greater agricultural diversification and a specific policy of attracting migrant European workers, combined with the eugenicist goal of whitening the population from the late nineteenth to early twentieth centuries (Seyferth, 2002). Moreover, the relative denial of African heritages, as well as the ideology of racial miscegenation (Telles, 2004), contributes to the underestimation of the country's black population. As a result, the respective proportions of white and black populations are 61%-39% in São Paulo, 46%-54% in Rio de Janeiro, 76%-24% in Curitiba, and 35%-65% in Fortaleza (Figure 3-1).

Figure 3-1: Social structure by class and race in São Paulo, Rio de Janeiro, Curitiba and Fortaleza.



In all cases, however, the proportion of black people is inversely correlated to social class. In Fortaleza, where black residents form the majority of the population, they represent 48% of the upper class, 62% of the middle class, and 72% of the lower class. The same trend is present in the other cities, although at lower levels. Moreover, the earned income gaps between white and black inhabitants provide eloquent evidence of racial inequalities, being on average 17% in the lower class, 33% in the middle class, and 93% in the upper class (Appendix A-1)

In comparative terms, São Paulo and Curitiba are the most segregated cities, presenting the highest dissimilarity indices – 0.252 and 0.247 – in contrast to Fortaleza, the least segregated city, with 0.187, and Rio de Janeiro, with 0.233. The dissimilarity rate decreases when spatial unit size increases but maintains the same pattern among metropolitan regions for each unit (Krupka, 2007; Sarkar, 2019).

The groups at the two extremes of the social structure – white upper class and black lower class – are more segregated and inhabit opposite spaces, probably interacting less with each other. In cities with fewer black people, like Curitiba and São Paulo, the white lower classes tend to be comparatively more segregated. Conversely, black upper classes, middle classes, and white lower classes are more spatially distributed in all cities (Figure 3-2). Isolation indices were calculated for all grids (500, 1000, 2500 and 5000m), resulting in one value for each combination of city, social group and grid size, standardized by grid size. In Figure 3-2, dots correspond to values for the 500m grid, while values for other grid sizes fall within the error bars.

Figure 3-2: Spatial isolation index by city and social group, considering the main cities (top) and their metropolitan regions (bottom).

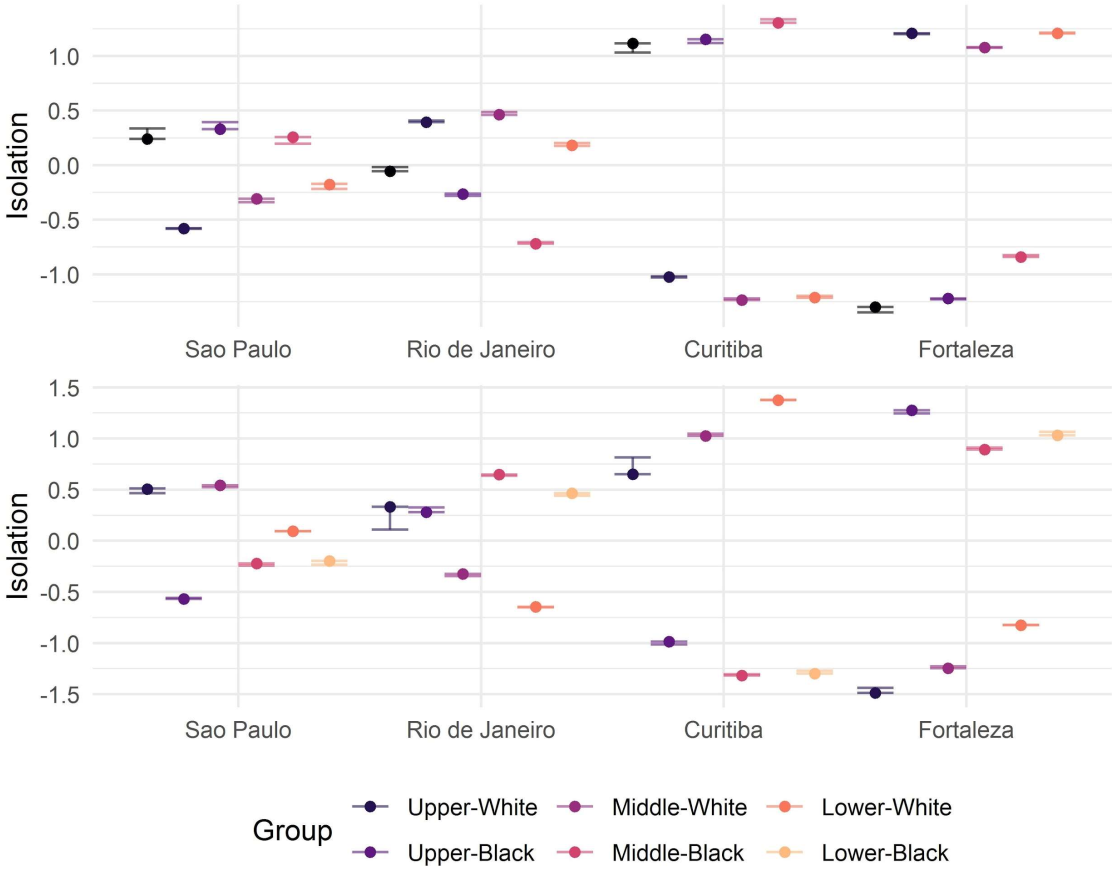
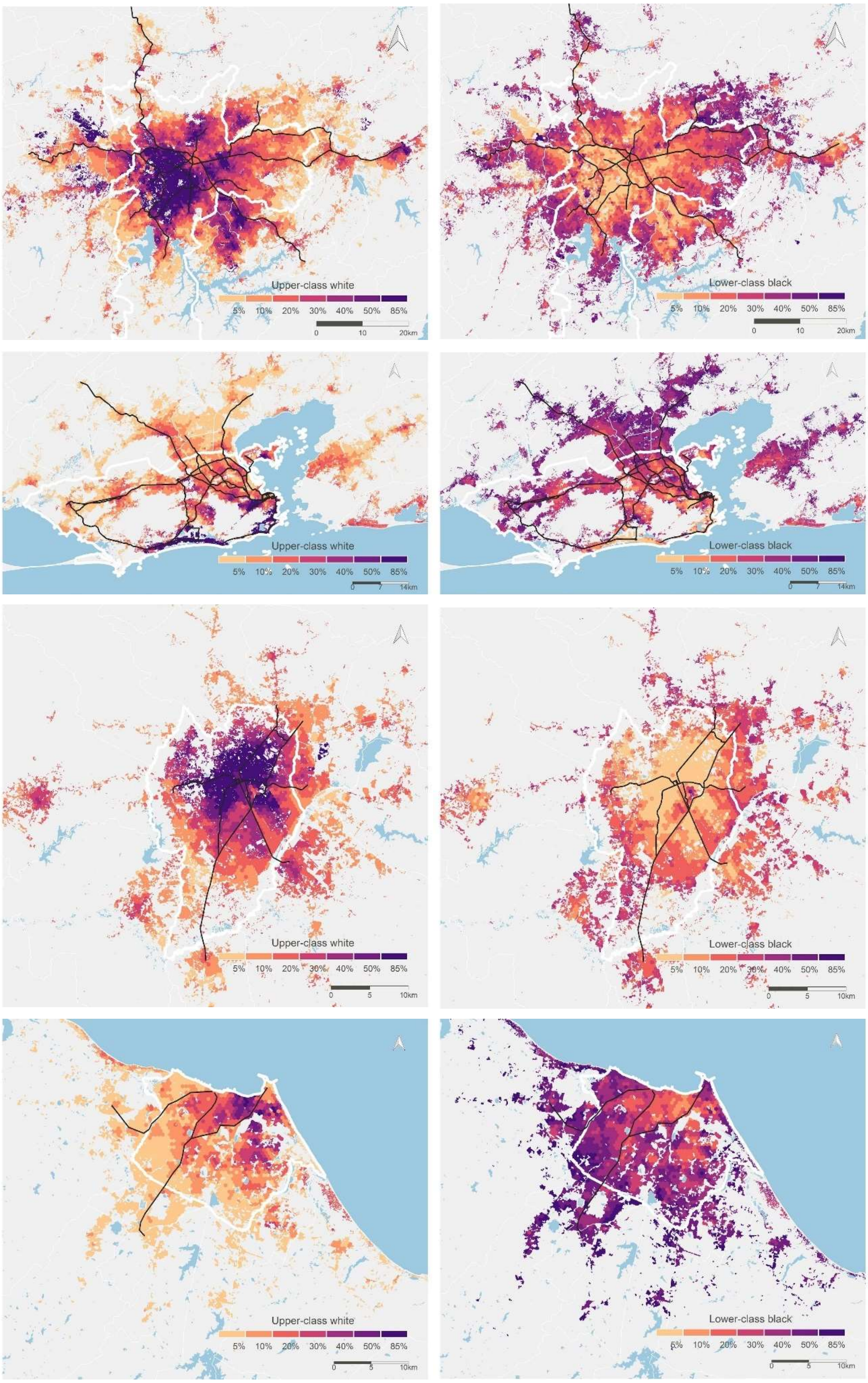


Figure 3-3 maps the distribution of the white upper class and black lower class, which together polarize the social structure (the distribution of other groups is shown in Appendix A-2, Appendix A-3, Appendix A-4, Appendix A-5). While the upper class inhabits the wealthiest areas of the cities – the southwest region of São Paulo, the coastlines of Rio and Fortaleza, and surrounding downtown areas of Curitiba – manual workers primarily occupy distant urban fringes, closer to non-urbanized areas. This reflects the center-periphery model widely adopted throughout the country. Segregation is associated with urban sprawl, an expression of the dispute for the built environment and differential land values (Rolnik, 2019), with the voluntary separation of the rich as the defining element (Villaça, 1998).

Figure 3-3: Spatial distribution of the white upper class and black lower class in São Paulo, Rio de Janeiro, Curitiba and Fortaleza.

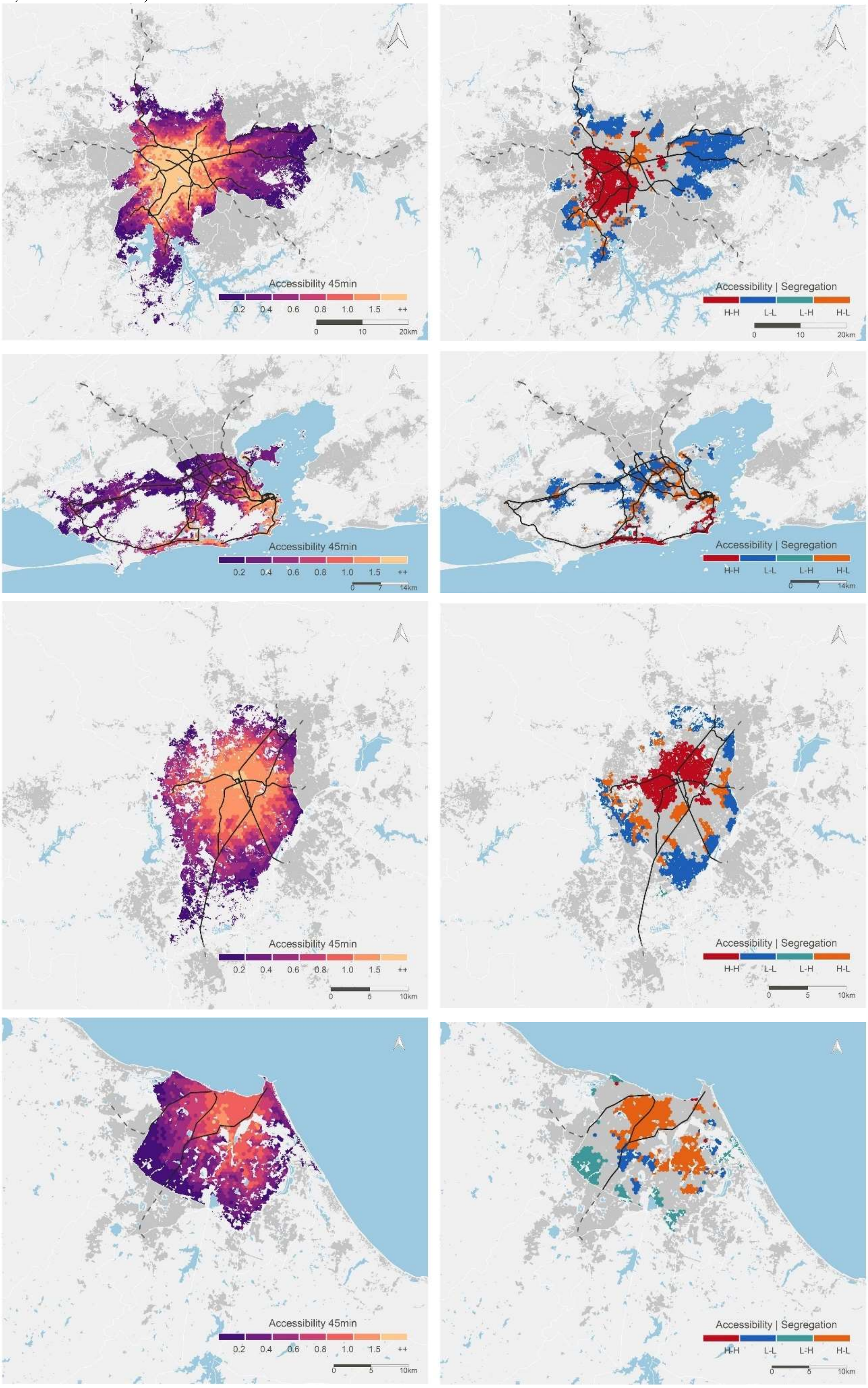


Metropolitan spaces are far more complex and heterogeneous than just center-periphery, however. Auto-segregation of elites happens in city centers, but also in gated condominiums (Caldeira, 2001). This is particularly true in São Paulo, where upper classes occupy spaces beyond the metropolis itself, mainly in the west and in the ABC region, a traditional industrial zone in the southeast. Among the lower classes, the white population lives closer to other groups while black residents live mostly in precarious settlements. Most of the central spots where black manual workers are concentrated in Figure 3-3 correspond to slums in all cities.

Similar spatial patterns can be seen in Figure 3-4, considering accessibility at a 45-minutes threshold. This threshold represents correspond to the highest accessibility inequalities between groups, in relation to 30, 60 and 90-minute thresholds. In all cities, central areas present higher accessibility than peripheral regions, given that jobs and transit lines are spatially concentrated in the urban core. These areas with greater levels of accessibility spread out through the city, following expansion vectors near to high and medium capacity transit lines. The most vulnerable areas are those largely populated by manual workers, more dependent on public transport (Appendix A-6). Small spots of lower-class concentration with high accessibility can be found in historical urban centers or surrounding areas.

Evidently, given their differences in size and stage of socio-economic development, job accessibility in the four cities differs in absolute and relative terms. São Paulo has more than four million formal jobs, compared to two million in Rio de Janeiro, 700,000 in Curitiba and 600,000 in Fortaleza. Due to its higher population and number of jobs, São Paulo is the city with the highest percentage of workers living at the extremes: around 15% have the highest accessibility levels and more than 20% of the population have the lowest. This pattern is followed by Rio de Janeiro, but with less people with high accessibility, just 4%. More employment opportunities, accessible jobs, and greater competition at the top of the social pyramid contribute to higher wages. The opposite happens at the bottom, where competition tends to decrease wages and widen disparities between rich and poor (Appendix A-1).

Figure 3-4: Job accessibility by transit within 45 minutes and LISA map of accessibility and segregation in São Paulo, Rio de Janeiro, Curitiba and Fortaleza.



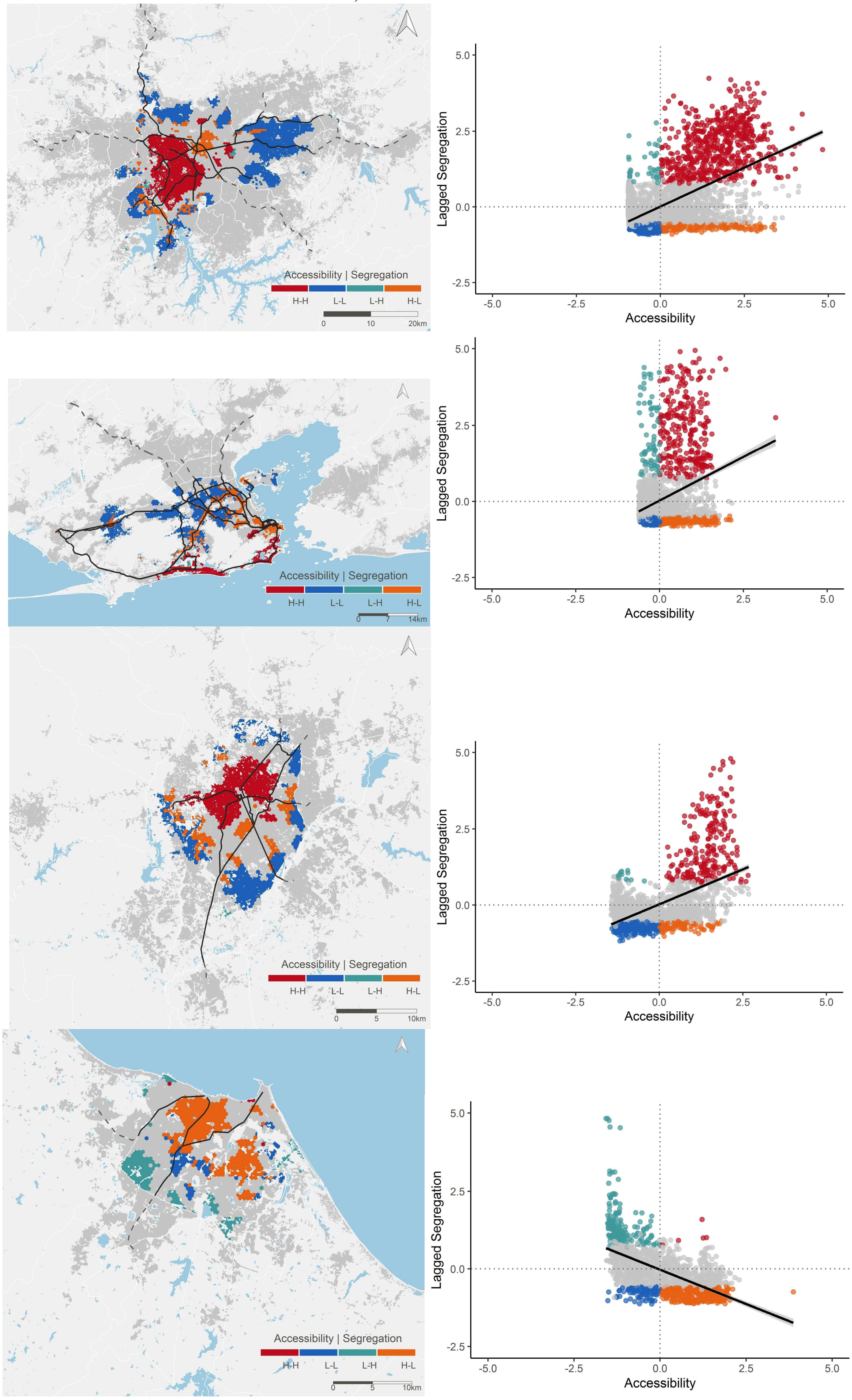
This difference relates to city sizes, differently to what was argued by Krupka (2007) in relation to segregation, but also to geographical aspects of urban and transport structures. Rio de Janeiro has half the population of São Paulo and is 20% smaller in area, but due to the location of the city center on the coast and topographical discontinuities, the network distance between the central region and the populated outer edge of the city is more than double (65km in Rio and 30km in São Paulo). In other words, geographical barriers combined with few rapid transit lines give the urban space characteristics comparable to a much bigger city.

Socio-spatial inequalities and segregation are associated with different levels of spatial and temporal supply of public transport, restricting interactions between social groups. Figure 3-4 also shows the spatial correlation between accessibility and segregation. The LISA maps on the right show the location of clusters of high-low accessibility and segregation. Moran's I scatter plots show the strength and direction of this correlation (Figure 3-5).

In São Paulo (Moran 0.512) and Curitiba (Moran 0.456), the auto-segregation of elites is prominent and represents higher access to opportunities in the urban space. By contrast, in Fortaleza (Moran -0.464), the involuntary segregation of the poor represents a much smaller accessibility. In all cases, however, the relationship between these two dimensions is far from straightforward, and the city of Rio de Janeiro (Moran 0.113) is a good example of this phenomenon. Since segregation is related to the spatial concentration of social groups (Barros & Feitosa, 2018), very often, when the political and financial power of elites combines with the desire for particular services, segregation of the upper classes means higher access to opportunities (Pinçon-Charlot & Pinçon, 1989). However, it may also create highly segregated neighborhoods in distant parts of the city (Caldeira, 2001).

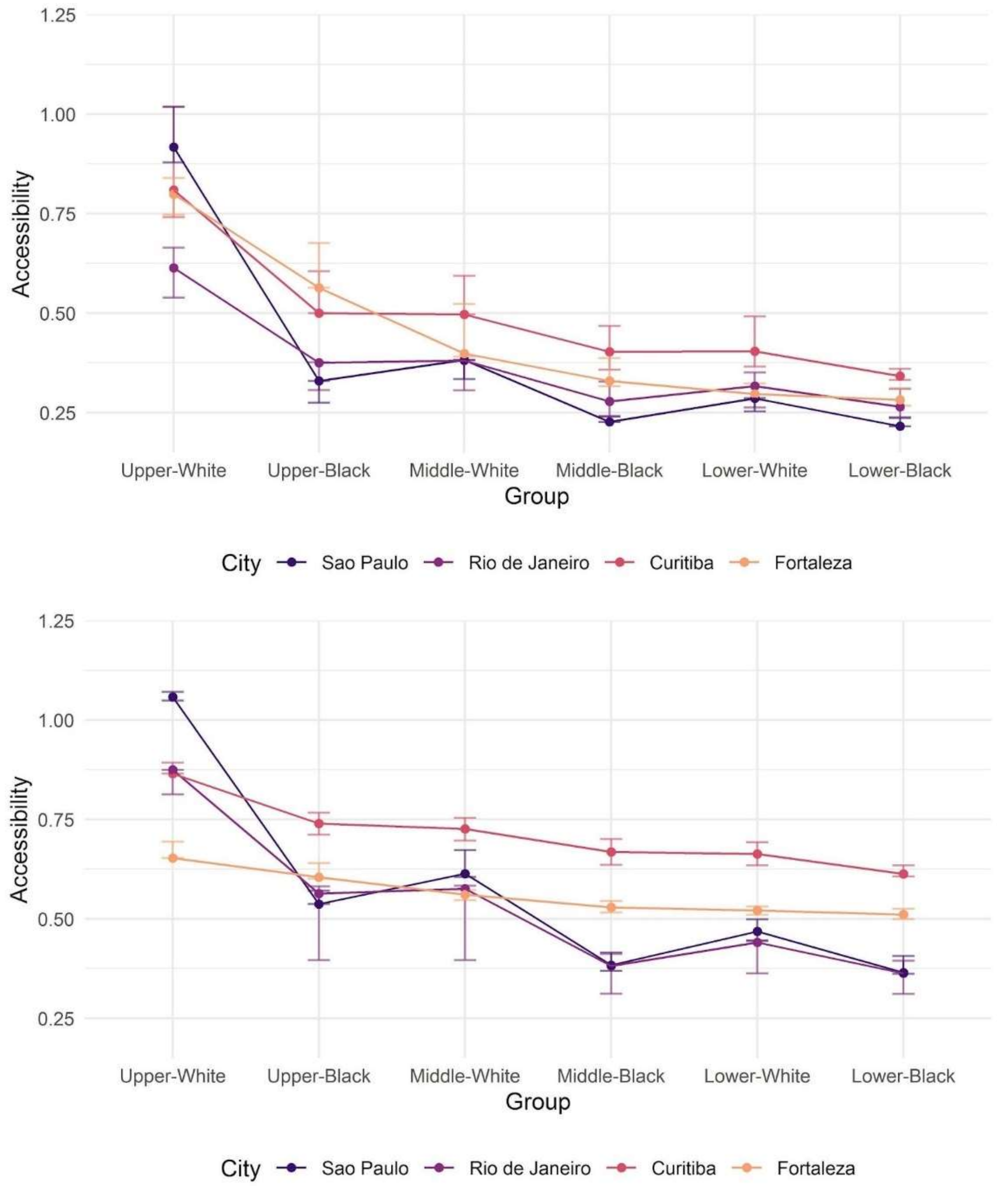
In the opposite scenario, the spatial concentration of poverty significantly affects living conditions and social and spatial mobility by imposing difficulties and barriers to accessing jobs, income, education, cultural repertoire (Marques, 2017), and political empowerment (Ribeiro & Santos Junior, 2003). In other words, besides physical distance, there are other obstacles to the access of social groups to opportunities in the urban space, and the multiple patterns across cities indicate that the interaction between accessibility and segregation changes according to social, spatial, and transport structures, themselves related to historical processes of land use and occupation.

Figure 3-5 Bivariate LISA Clusters and Moran's I plot of accessibility and segregation in São Paulo, Rio de Janeiro, Curitiba and Fortaleza.



A comparable analysis can be achieved with the use of median accessibility levels for each social group, as shown in Figure 3-6 (different time thresholds in Appendix A-7). Dots and lines correspond to accessibility for 500m cells and values for other grid sizes fall within the error bars.

Figure 3-6: Median job accessibility levels within 30 (top) and 60 (bottom) minutes by public transport.



First, the upper class has greater accessibility to formal jobs than the middle class, who have better accessibility levels than the lower class. There is thus a correlation between social structure and access to opportunities. However, this structure changes when we also consider race. Black upper-class people have accessibility levels more similar to (and sometimes lower than) those presented by the white middle class than those presented by the white upper class. This pattern is consistent among all three social classes and all four cities. In the two biggest cities, the difference between races is even sharper. This suggests that racial inequalities combine and overlap with class and city inequalities.

In general, accessibility levels in Curitiba are higher than in Fortaleza. Nonetheless, in terms of access to jobs, white upper classes are similar, but the black upper classes are considerably better off in Fortaleza, since they are more numerous and better located. Comparing the two biggest cities, accessibility in Rio and Sao Paulo are quite similar with the latter slightly lower.

However, although the smaller cities tend to have higher relative accessibility levels than the larger ones, this is not always true. Being a white upper-class worker in a large city means having higher access to opportunities than in any smaller city. The opposite occurs if you are a black lower-class worker, for whom distances between home and work in big cities tend to be larger and transit systems worse. In other words, since economic activities are clustered near wealthier households, the best possible scenario is to be an upper-class worker in a large city and the worst scenario is to be a manual worker also in a large city, due to the longer commuting times. Inequalities in urban occupation and transit accessibility among social classes are big enough to accentuate or diminish influences from city size and geographical barriers.

Finally, changes in areal units, though significant, did not produce substantive changes in segregation or job accessibility inequalities among groups. Although median values of accessibility and segregation vary in changing spatial units, the structure of inequality among groups and cities remains constant. This finding suggests that socio-spatial and transport-related inequalities are largely structured at a macro-level, associated with segregation and the spatial concentration of employment and infrastructure. Micro-level heterogeneity is particularly present in Rio de Janeiro, indicated by the spatial distribution of social groups and reinforced by the greater distance between median values of accessibility and segregation for different hexagon sizes.

3.5 Conclusion

This article presents compelling evidence that class, race, and geography inequalities are related to segregation patterns and accessibility to public transport. Groups at the extremes of the social structure live in highly segregated spaces and have contrasting levels of access to opportunities. Race adds another layer since the black population not only receives lower wages but also has systematically worse physical access to jobs than white people from the same social class. This applies more strongly to elites than the lower classes, for whom racial differences in segregation are smaller.

Such inequalities vary in the studied cities, constituting heterogeneous and complex socio-spatial structures. In larger cities, commuting times needed for individuals to cross urban space are longer, and inequalities in accessibility are higher. In addition, geographical aspects and spatial discontinuities impact urban occupation and pose barriers and difficulties to travel. Indeed, regional inequalities change how social and racial inequalities manifest in the urban space. Cities with larger proportions of black residents tend to be more integrated and less unequal. Nevertheless, even where the black population comprises a majority, white residents are still better located and enjoy higher levels of accessibility.

In addition, segregation and accessibility interact in different ways, related to various social and spatial elements. Upper classes are not always more segregated than other groups. In contrast, the spatial separation of upper classes does not always translate as better access to jobs via public transport since other advantages may drive occupation, including the desire for exclusivity, natural landscapes, and other urban amenities.

Therefore, this study highlights the multiple and interactive dimensions of inequality that structure societies and cities. The effect of race on accessibility is not constant across social classes, nor are the gains and losses of belonging to a particular social group in different cities, as looking at these variables separately might suggest.

Lastly, there remain limitations to this study. Given the unavailability of data on the informal economy, it has considered only accessibility to formal jobs. The problem is relevant even if the location of formal and informal jobs is highly correlated (Pereira, 2019), and, more importantly, informal jobs are usually more insecure and lower paid, offering different assets to workers. However, in-depth research must be undertaken to account for these differences properly. Moreover, we have demonstrated the relationship between class, race, and city inequalities in distinct Brazilian metropolises. Further comparative studies between cities from different global contexts may show how and whether this pattern persists across countries and continents and how it interacts with different local contexts, segregation structures, and transportation systems.

4 The unequal impacts of time, cost and transfer accessibility on cities, classes and races

After we analyzed the interaction between geographies, scales, residential segregation by class and race, and accessibility inequalities, we can now move forward to the second pillar of accessibility: transport systems.

Although most accessibility studies focus on travel times, the connectivity of public transport systems and fare policies may also significantly impact how people access urban opportunities in the city. This is because they can prevent low-income people from moving due to financial restrictions or significantly increase their discomfort while traveling.

Moreover, inequalities are structured and reproduced in multiple dimensions and scales. From countries to neighborhoods, local and global socio-spatial structures interact with public transportation development, resulting in uneven access to opportunities in multiple terms. By looking at cities with distinct positions in the globalized world, São Paulo, New York City, and London, we show that travel times, costs, and transfers have different impacts on the job accessibility enjoyed by social classes and ethnic-racial groups living in different areas of cities in various parts of the world. As we will discuss, at the global scale, while the monetary cost of travel relative to income has a small impact on accessibility in high-income countries, it substantially diminishes the access to opportunities of a large share of the population in middle-income countries. Also, social class strongly influences accessibility levels among whites, and the upper classes are far better off than the middle and lower classes. Among blacks, however, historical development trajectories have a significant role in explaining accessibility.

The analysis of socio-spatial inequalities in multiple dimensions and scales highlights the centrality of the affordability dimension in transport studies and its importance in evaluating and formulating contextualized policies, particularly in low- and middle-income countries.

4.1 Introduction

The right to the city is a broad definition involving the right to actively engage in urban life (Lefèbvre, 1973). This means all people should have the right and power to participate in constantly (re)building the city and access spatially distributed opportunities (Harvey, 2012) in which transport systems play an essential role. In this sense, it is vital to think of spatial justice through an accessibility perspective. It simultaneously involves land use and occupation associated with transport infrastructure and operation, such as travel time, affordability, and connectivity.

This notion is fundamental in low- and middle-income countries, where activities and urban infrastructure are highly concentrated far from an extensive amount of people who live in distant, informal, and precarious areas of the cities and have low incomes (Maricato, 1996). In contrast, the political power of elites to demand public actions combines with the economic power to access urbanized and well-located urban land (Pinçon-Charlot & Pinçon, 1989) and to choose among transport modes in their daily commutes. This dynamic creates very unequal societies and spaces, with a more considerable burden on lower classes and some ethnic-racial groups.

The patterns of precariousness and segregation within underdeveloped or developing countries, however, relate to striking global inequalities, given the structure of dependence shaped on colonialism and exploitation (Santos, 1970). Underdevelopment is associated with economic, political, social, and cultural structures, also products of past and continuous relations with the developed world (Santos, 1979). This world system can thus be seen as a constellation of metropolises and satellites in which the metropolises tend to develop. In contrast, the satellites' development is structurally limited by their dependent status (Frank, 1966) with several socio-spatial effects for peripheral residents, including lower wages (Marini, 2000) and higher precariousness at work, at home and also during commuting (Kowarick, 1980). Socio-spatial structures, therefore, assume a fractal pattern, reproducing inequalities in different scales and social groups, from countries to neighborhoods.

This article seeks to analyze how socio-spatial inequalities of access to opportunities are structured in terms of class and race in three large cities with distinct positions in the globalized world: São Paulo, New York City, and London. We focus on accessibility to jobs, considering critical elements of access to public transport, such as transit networks and costs.

Given its multidimensionality and analytical clarity, several studies have used accessibility metrics to analyze socio-spatial inequalities related to public transport in high-income (Fransen et al., 2015; Jin & Paulsen, 2018) and some in middle-income (Pereira, 2018; Bocarejo & Oviedo, 2012) countries. Also, a few empirical studies incorporated dimensions of costs and transfers - which represent well-known disadvantages associated with aspects of affordability, comfort, safety, and reliability - in the evaluation of public transport systems and inequalities (Guo & Wilson, 2011; El-Geneidy et al., 2016; Vale, 2020), with very different findings. These studies, however, focus on single cities and ignore fundamental aspects of socio-spatial structure, such as class and race (Karner & Niemeier, 2013). They also disregard the discussion of how one's position in income distribution and location in the urban space offers superposing barriers to access to opportunities by public transport on different global and local scales.

Therefore, there is still a core gap in the understanding of how fare costs, besides travel time and the need for transfers, relate to socio-spatial structures and affect the access to urban elements for different social classes and races in different parts of the world, which is imperative to the formulation of contextualized policies (Marchetti et al., 2019) aiming to reduce inequalities. The methodology for the analysis is explained in section 2.

4.2 The multiple dimensions of accessibility inequalities

Given the importance of public transport for social interactions and access to opportunities in the urban space, the coverage, connectivity, and affordability of the transit network have significant effects on the way and the extent to which social groups physically engage in activities related to the different dimensions of human life, which are spatially and temporally distributed (Geurs & Van-Wee, 2004). The accessibility metrics reproduce this dynamic, portraying both the practical conditions of commuting in the city and the number of opportunities individuals can reach (Hansen, 1959). They simultaneously include considerations on origins (usually represented by households) and destinations (a variety of activities), accessed according to a degree of impedance (Cervero, 2005). However, this impedance is usually represented by travel times required to overcome geographical barriers between locations in the city, ignoring several other factors that influence the degree of resistance that spatial distances impose on urban trips and, ultimately, on individuals (Cui & Levinson, 2018).

The monetary costs represented by transit fares limit the use of specific transport systems and compromise household income (Lau, 2011), especially for the low-income population in suburban areas and low- and middle-income countries (Falavigna & Hernandez, 2016). In fact, in a world study on public transport affordability, comparing global indexes per city, Carruthers et al. (2005) found Brazilian cities to have the least affordable systems in the world, with São Paulo having a (un)affordability index of almost four times higher than New York City and six times higher than London. The cost of transport has been growing in recent years. Brazilians spend more on transportation than on food, with transport and housing costs intrinsically related, responding to over 60% of household expenditures, on average (IBGE, 2019). These elements represent 49% of household expenditures in the United States (USBLS, 2018) and 34% in the United Kingdom (ONS, 2018).

The cost of travel is strongly associated with public transport funding in each context. Fares represent the most significant single funding source of transit systems in most cities, including London, New York, and São Paulo, but in different proportions. Diverse forms of funding such as direct subsidies from governments, crossed fundings from the use of the road network by private vehicles (tolls and congestion charges, for example), commercial activities (advertisements and properties) and other types of revenues other than fares respond to around 62% of receipts of MTA in NYC, 53% of receipts of TfL in London and 46% of receipts of SPTrans/Metro/CPTM in SP (MTA, 2019; TFL, 2019; SPTRANS, 2019; METRO, 2019; CPTM, 2019). The share of various funding sources implies different means of improving transport services and covering the operation at more minor fares paid directly by passengers.

The financial burden of urban trips at the bottom of social structure, in turn, also relates to several other cumulative factors, such as fewer transportation options, more considerable distances to activities due to unequal land use patterns, and different transportation needs associated with social inequalities (Litman, 2020). As a result, faced with housing and transportation costs that often exceed their incomes and without enough supply and demand-side subsidies, low-income workers are left with the choice of foregoing more elastic goods (Paulley et al., 2006), exploiting free transfers, subversive behaviors such as fare evasion (Perrotta, 2016), or not traveling at all. These alternatives, however, usually mean longer travel times (Bocarejo & Oviedo, 2012) and significantly affect one's quality of life (Lucas, 2012).

In this sense, living close to transit networks or a few minutes away from urban activities does not necessarily mean high accessibility if people cannot afford transportation. Incorporating transport affordability into the accessibility measurement, however, is not an easy task, and different methodologies applied in different urban contexts resulted in very distinct findings. First, impedance coefficients based on desired or revealed mobilities (Bocarejo & Oviedo, 2012; Liu & Kwan, 2020) may hinder unequal patterns by considering non-optional mobilities while ignoring coerced immobilities. Second, eliminating differential incomes and budget constraints by simply converting fares into time expressions (or vice versa) using the hourly minimum wage (El-Geneidy et al., 2016) might bias accessibility evaluations due to income inequalities across groups and spaces. Third, although it is interesting to calculate the effective accessibility by also considering how much time an individual has to work to pay for transportation (Vale, 2020), time and cost are hardly compensatory and have different impacts on travel options.

Additionally, the comfort, safety, and reliability of transport systems have an essential weight in the quality of travel and the perception of accessible opportunities by individuals (Cheng & Chen, 2015). Multiple transfers represent additional costs for users, especially when combined with unreliable and non-punctual transit systems, and burden individuals in energetic and emotional terms, which are not easily measurable (Delbosc, 2012). The disutility caused by waiting for vehicles at unsafe stops or walking long distances between transfer locations is more significant according to the risks involved (Wardman, 2001). It has a particular effect on women and some ethnic-racial groups due to discrimination (Sheller, 2018).

Public transport systems are essential to urban movements. In large cities, such as São Paulo and London, they correspond to 35% of daily trips (METRO-SP, 2018; TFL, 2019). In New York City, public transport makes up 53% of all trips (NYMTC, 2011). Therefore, transit travel time, the percentage of income spent on transit fares, and the need for multiple transfers all have essential effects on the disutility experienced by people during urban commuting, making up barriers to access to opportunities in the urban space. Also, they hinder the possibility of people engaging in different activities that provide psychological, educational, and financial gains (Mackie et al., 2001), which could contribute to social mobility and reduce inequalities.

One paramount step towards more inclusive and equal cities involves acting upon transit infrastructure, which positively affects economic growth (Calderón & Servén, 2004) and mitigates the effects of income inequalities (Harvey, 2009) by also improving social mobility due to access to opportunities (Nieuwenhuis et al., 2020). The provision of infrastructure, however, has traditionally been a public matter and is highly concentrated on global, regional, and local scales. High-income countries and highly developed economies have historically had more financial and political resources to invest in urban policies (GIO, 2017). In low- and middle-income countries, the fast, unplanned, and relatively recent urbanization challenges the extensive and long-term investments needed to bridge the infrastructure gap (Easterly & Servén, 2003). This is also associated with more fragile democratic institutions (Easterling, 2016) and, in some perspectives, combined with the association between national and international elites, undermining the political power to promote nationwide infrastructural works and urban development (Fernandes, 1976; Deák, 2015). Consequently, in these countries, transit infrastructure has been primarily concentrated in central areas of large cities.

In short, multiple cumulative and self-reinforcing factors are associated with the access to spatially distributed opportunities by public transport that burden individuals differently from distinct cities, classes, and races. These factors belong to social, spatial, and economic spheres shaped during centuries of industrialization, urbanization, and public investments (Maricato, 1996). To some extent, they are represented in the dimensions of travel time, number of transfers, and monetary costs social groups potentially spend on transportation. This paper investigates this further.

4.3 Cities and societies

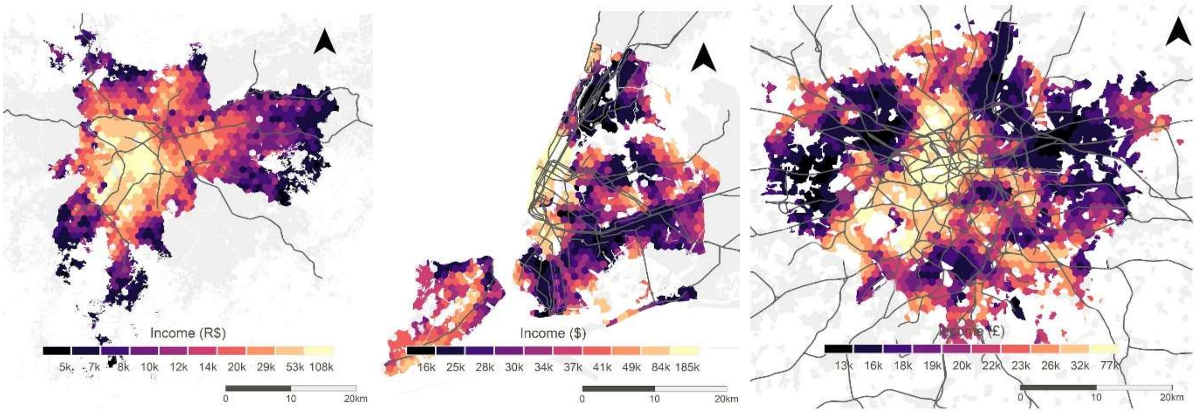
São Paulo (SP) is the largest city in South America, with a population of 11.7 million people in 1,521 km² of area. Despite the decline in industrial activities in the last decades (Marques, 2016), elementary occupations continue to represent an important share of urban workers (30%), mainly living in peripheral regions and near non-urbanized areas. In contrast, the upper class (22%) occupies the central and southwest regions of the city, while the middle classes (48%) live in intermediate spaces (Appendix B-2).

New York City (NYC) is the second largest city in North America, with 8.4 million inhabitants in 784 km² of area. Exemplifying an economy of services, middle-class workers are the vast majority of urban workers (54%), followed by the upper (26%) and manual working classes (20%). Unlike Brazil, where race adds a layer to spatial segregation by social class (França, 2016), the opposite happens in the United States. Dated back to the end of the 19th century, residential segregation by race in US cities became a structural element of the urban space after the First World War (Logan et al., 2015), and although it is not as strong as it was in the past, blacks still live in highly segregated and usually poorer neighborhoods, more so than any other ethnic group (Logan, 2013). In NYC, black workers mainly live in Harlem, in northern Brooklyn, in the western Bronx, or in the southern Queens, while whites live in other spaces, with the upper class primarily concentrated in the upper Manhattan (Appendix B-3).

London (LON) is the third largest city in Europe, and within the Greater London Area of 1,569 km², there is a population of 9 million people. Similar to New York City, most workers in London are engaged in administrative and service occupations (51%), but there is a higher percentage of workers in professional occupations (34%) and a lower percentage of workers in manual occupations (14%). Representing only a small share of the population, black workers mostly occupy some spots in the north, west, and south of London, while white workers, and particularly the middle class, are more spatially distributed in the city (Appendix B-4).

While the distribution of workers in the three social classes of the three cities reflects their positions in the international division of labor (Appendix B-1), the social inequalities between and within cities unfold the sharpest contours of the global structure. The yearly average of household expenditures in New York City is around $65.9k, compared to $44.1k (£34.2k) in London and only $14.7k (R$75.7k) in São Paulo (USBLS, 2019; ONS, 2019; IBGE, 2019). The poorest city, however, is also the most unequal in terms of income distribution: Gini indices are 0.63 in São Paulo, 0.49 in New York City, and 0.43 in London, which is reflected in the territory (Figure 4-1).

*Figure 4-1:*Deciles of yearly average household income in São Paulo, New York City and London (in Brazilian Reais, US Dollars and Pound Sterling, respectively).



Whites and blacks are the majority of the population in all studied cities and thus constitute the focus of this study. Whites are 66% of workers in São Paulo (SP), 52% in New York City (NYC), and 65% in London (LON); and blacks correspond to 33% of workers in SP, 23% in New York City, and 11% in London. Results for the non-white (and non-black) population are presented in Appendix B-1.

4.4 Time, cost and transfer inequalities of accessibility among classes and races

4.4.1 Inequalities in space

In all studied cities, economic activities and employment opportunities are largely concentrated in central areas, mainly occupied by the upper classes. Public transportation systems, however, differ in maturity. The London Underground is the oldest metro system in the world, opened in 1890 and was soon followed by the New York City Subway, which opened in 1904. The Sao Paulo Metro was only inaugurated decades later, in 1974. Years of transport development influence the organization and coverage of the transit network, which is also related to broader social, economic, political, and urban processes. There are 1,330 km of subway, train, and tram lines in London (a rate of 7 inhabitants for every meter of rail infrastructure), against 510 km in New York City (16 inhab/m) and only 220 km in SP (53 inhab/m). Despite the median coverage, New York City is denser in population and kilometers of rail infrastructure per area compared to the other cities (1.5 km²/km of infrastructure in New York City, 1.2 km²/m in London and 6.9 km²/km in São Paulo), which manifest on the time needed for people to achieve a significant amount of job opportunities (top of Figure 4-2). Within 45 minutes, only 12% of São Paulo's population can reach a ratio of jobs/working age population equal to 0.2 or higher. The exact ratio is reached by 25% of the population of London and 37% of New York City.

Mostly occupying urban fringes, social groups more dependable on public transport are also the ones who benefit less from high-speed transit systems, particularly in middle-income countries with scarce rail infrastructure. In São Paulo, for example, public transport is the primary mode to get to work among the lowest five income deciles, ranging from 57% in the first decile to 38% in the fifth. Most of these trips by public transport are made using only municipal and metropolitan buses (from 79% in the first to 61% in the fifth decile) (METRO-SP, 2018).

The higher coverage and technology of transport systems in New York City and London also allow a higher number of destinations to be reached with fewer transfers between vehicles (center of Figure 4-2). In New York City, smaller and with many structural subway lines, by leaving from almost anywhere in the city, it is possible to reach a relatively high amount of job opportunities with just one transfer. In contrast, in São Paulo, most people would need to transfer 2 or 3 times between vehicles or/and transport modes to get to qualified destinations. One or two transfers can be acceptable from the user's perspective and expected from an efficient and connected transit network (Walker, 2011) if transit systems are safe, punctual, and reliable, which is not always the case. In São Paulo, for example, a study on real-time data revealed that 18% of all planned bus trips are not fulfilled at the morning peak hour and 25% at the afternoon peak (Pons et al., 2015), increasing waiting time and reducing reliability.

While the analyses of travel time and transfers highlight the influence of public transport infrastructure on accessibility, the transit costs analysis highlights the striking disparities between cities, classes, and races, not fully captured by the previous dimensions (bottom of Figure 4-2). In other words, access to opportunities by public transport might present quite similar patterns in São Paulo, New York City, and London when we look at dimensions mainly influenced by city size. However, looking at travel costs, such socio-spatial inequalities become evident. First, relative cost analysis reveals significant income gaps worldwide, combined with the uneven fare policies applicable in these cities. The cost of accessibility in São Paulo is remarkably smaller than in London, especially in New York City. Transit costs seem to decrease accessibility in São Paulo and have little impact in New York City and London relative to time. Second, it reveals the spatial segregation by class and race and unfolds the social inequalities among groups. In São Paulo, there is a strong positive correlation between high accessibility and upper-class's spaces of residences, while in New York City, the strongest correlation is between low accessibility and the black population and low accessibility and lower classes (Appendix B-8). Also, results for all thresholds not shown in the main document are presented in Appendix B-5, Appendix B-6 and Appendix B-7.

On a global scale, the unequal transfer of value from low- and middle-income countries to high-income countries, given their position in the global system, also creates differential levels of wages and wealth (Santos, 1970). By reducing income and consumption, the share of transport expenditures is substantially higher, particularly the cost of commuting to work, which is an essential and relatively inelastic good (Martens, 2017; Litman, 2019). It is also important to note that lower wages are related to higher competition among workers and unemployment, particularly among manual working classes (Marini, 2000). Indeed, there are more jobs relative to the working-age population in London and New York City (ratio of 0.65) than in São Paulo (0.60), which also reflects lower levels of accessibility in the latter.

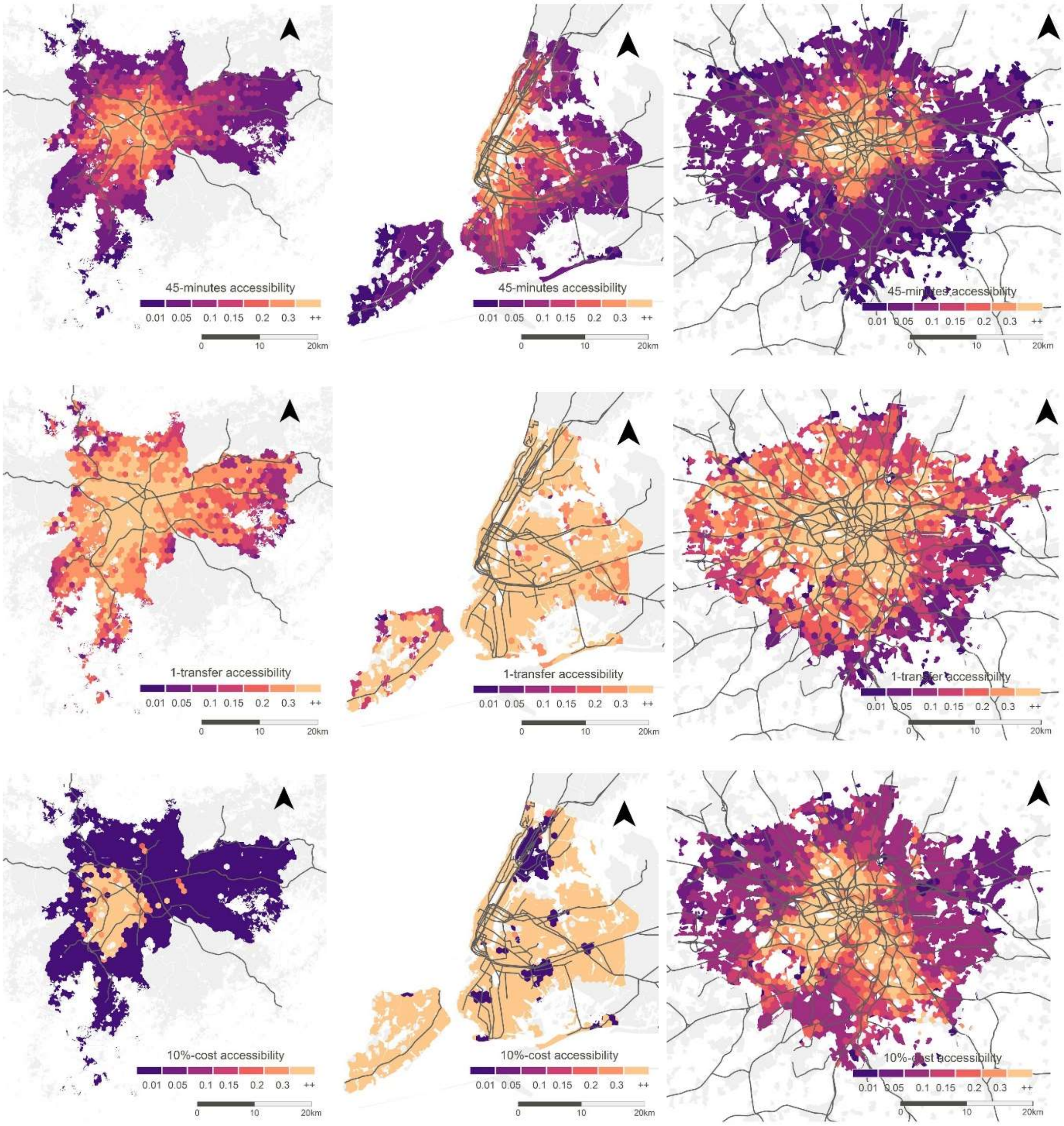
Fare policies enlarge such disparities and, along with income gaps, manifest locally. In New York City, there is no additional charge for integrating buses and subway; the transit fare costs $2.75. The combination of high incomes with relatively cheap fares means that people living in a large part of the city can access the most spatially distributed job opportunities for 5 or 10% of their incomes, considering a round trip. While cost accessibility is high for almost the entire city, however, the spots of low-cost accessibility are easily associated with the spots of black segregation (Appendix B-3), as they earn less, are over-represented in elementary occupations and are highly segregated in certain areas of the city.

In São Paulo, the fare policy that charges an additional 74% of the standard fare (of R$4.4 or $0.9) on the integration between the bus and rail systems burdens a large share of lower but also middle classes, whose incomes are low according to international standards. This burden is stronger for lower-class residents, who earn even less and spend relatively more because of the need for paid transfers. To achieve job opportunities comparable to the upper classes, the lower classes would have to spend 30% or 40% of their incomes to get to work and return home.

As a result, some strategies to avoid the additional payment on transfers involve using only one transit system or integrating it with long walks (METRO-SP, 2018).

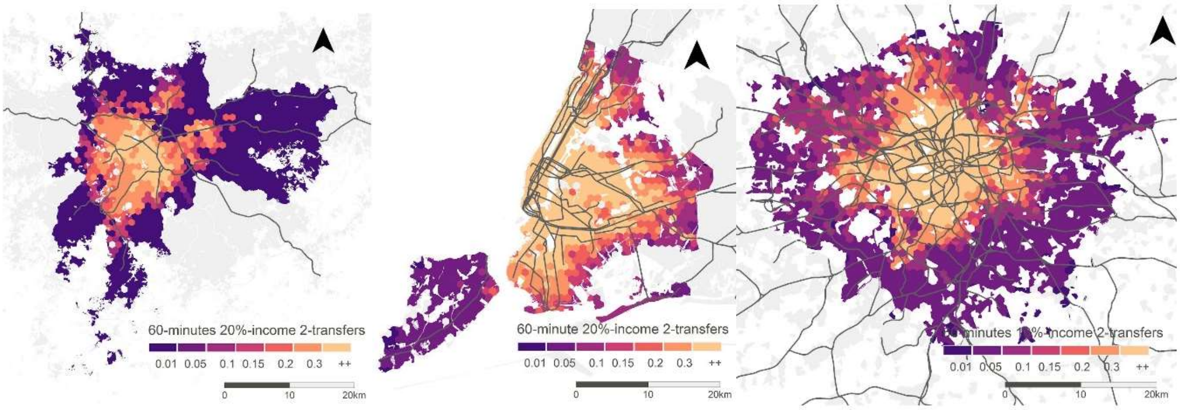
London is the middle ground in a discussion of opposites. The extensive metro-rail network significantly reduces travel times, but the zone-based fare model, in which the greater the distance, the greater the underground usage fare, has a more significant impact on the access of the peripheral population to the city center and most employment opportunities, given the coverage and high usage of the metro-rail system, used in 60% of transit trips (TFL, 2019).

Figure 4-2: Time, transfer and relative cost accessibility (number of reachable jobs by the working-age population) in São Paulo (left), New York City (center) and London (right).



Therefore, as lower classes are usually less sensitive to fares as they are more dependent on public transport (Taylor et al., 2009) and fare elasticity tends to be higher than service quality elasticity (Cervero, 1990), disposable incomes and transit fare structures burden the expenditures in transportation and limit travel and mode choice. Moreover, the restriction that monetary costs impose on the peripheries of the global system is so significant that it is more of a blocking issue than a constraint to the access of key urban opportunities by groups at the bottom of the social structure. This becomes clear in the combined analysis of accessibility considering both time, transfer, and affordability (*Figure 4-3*), considering the thresholds of 60 minutes, 20% of income dedicated to commuting to work, and 2 transfers. That is, for each origin zone, only jobs located in destination zones to which the travel costs do not exceed the thresholds in all three dimensions are considered accessible. Therefore, the combined accessibility maps reflect the most restrictive dimension for each location. In São Paulo, the cost of the transit fare relative to income is more restrictive to accessibility than travel time. In the other cities, as most of the population spends a small percentage of their incomes on commuting, time is the most restrictive dimension.

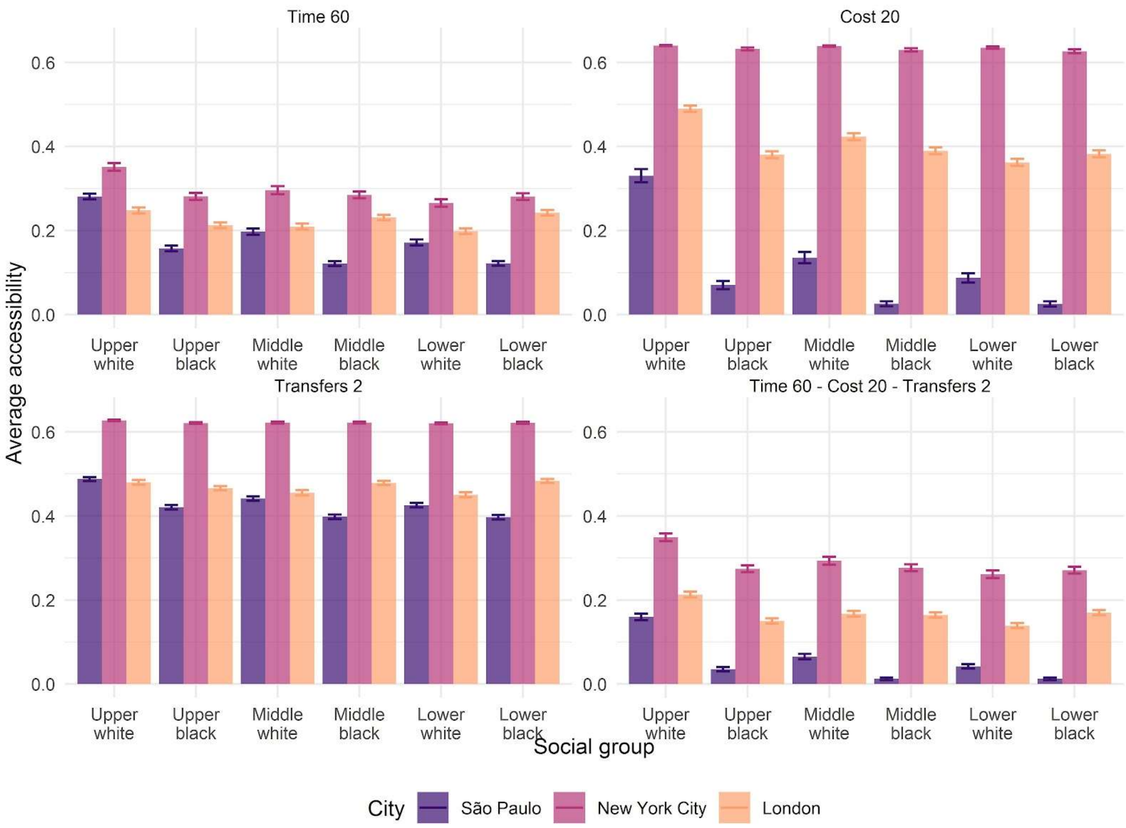
Figure 4-3: Time, transfer and relative cost combined accessibility in São Paulo (left), New York City (center) and London (right).



4.4.2 Inequalities by class and race

Despite the long trajectory of discussions on time and affordability in transport studies, these dimensions assume different degrees of importance in different countries, cities, and neighborhoods, playing distinct roles in structuring inequalities. Travel time analysis shows significant differences between the accessibility of people living in New York City, London, and São Paulo, which are related to the size of the cities but, more importantly, to the population density associated with the coverage of high-speed, particularly heavy rail and subway lines. Transfer analysis enlarges city inequalities and shows how connected and directed the transit networks are, an additional step in evaluating transit systems. It is in the cost analysis, however, that global inequalities are the most profound. In São Paulo, even at a high threshold of 20% of per capita household income dedicated to work trips, only the white upper class can access a reasonable ratio of job opportunities relative to the working-age population. To access an equivalent number, black lower classes would have to spend up to 50% of their daily income on transportation. On the global scale, black lower classes in New York City have an accessibility index almost two times higher than white upper classes in São Paulo (Figure 4-4).

Figure 4-4: Average accessibility by class and race (whites and blacks), considering dimensions of time, transfer and relative cost in São Paulo, New York City and London.



Although accessibility levels are higher in high-income cities, the uneven pattern between classes and races remains. Upper classes have greater accessibility than lower classes, and whites have greater accessibility than blacks. However, class and race matter differently regarding where people live in the urban space, the extent and quality of public transport infrastructure available to them, and the share of income they spend on transportation.

Among whites, social classes strongly influence accessibility, and inequalities are considerably sharper between the upper class and all the other groups than between the middle and lower classes. However, the difference between these last two is also evident. This relates to the widely discussed segregation of elites, who have more economic and political power to choose where they live, where they work, and how they commute (Villaça, 1998), but also a more significant influence on the implementation of infrastructure and the spatial distribution of activities and amenities in the urban environment (Pinçon-Charlot & Pinçon, 1989). White upper classes in São Paulo benefit from accessibility levels comparable to those in London and New York City, especially in terms of time and number of transfers, acknowledging the position of local elites. Global inequalities prevail over social inequalities within cities in high-income countries. In contrast, the striking socio-spatial inequalities in middle-income countries enable the upper classes to overcome the barriers imposed by city size and transit supply and to have accessibility levels comparable to the lower classes in other cities.

Among blacks, however, though the upper class seems to be in a better position in relation to physical access to opportunities, accessibility levels are not significantly different across social classes, as demonstrated by the overlapping confidence intervals in Figure 4-4. This indicates that, similarly to what was argued by Peach (1999) related to segregation, socio-economic class seems to have a more minor role in explaining accessibility inequalities among blacks than the contextual and historical trajectories of social and urban development, with way more severe effects in colonial societies, marked by slavery primarily based on ethnicity.

In the Americas, blacks from lower, middle, and upper classes are worse off than their white counterparts, but they tend to live close to each other and to have similar accessibility. In the United States, this phenomenon has its origins in the highly segregated ghettos from the 20th century, when the dynamic processes of discrimination through legal norms and informal practices led to a distinct class gradient within black settlement areas (Massey & Denton, 1993). Although the social and spatial mobility of the black upper classes softened this closed structure (Logan, 2013), this pattern is still present today and reflects the place of race over social class. In Brazil, while there was no race-based law that explicitly encouraged ethnic segregation after abolition, the whitening goals from the 19th century (Seyferth, 2002), the ideology of racial miscegenation, and the lack of public policies directed to racial integration, all contributed to socio-spatial segregation of the black population in slums and peripheries (Telles, 1992). As blacks are disproportionately represented at the bottom of the social structure, class, and race superpose and result in higher levels of inequalities in the cost dimension. That is, blacks live in more distant places, earn lower wages, and would pay higher transit fares to access the same number of opportunities as whites.

In the United Kingdom, ethnic migration is more recent and happened in multiple waves, with blacks also filling in jobs and spaces abandoned by the white population in the post-war

(Peach, 1999). As a result, black people are only a tiny part of the British population and mainly live in the city of London, which results in higher and more homogeneous levels of accessibility relative to white middle or lower classes, who are more distributed in the urban space, including the suburbs. The higher levels of accessibility of the black lower class compared to the white lower class is also true in New York City due to the size of the group and the heterogeneity of white spaces of residence, although to a smaller extent.

Accessibility levels of racial groups other than whites or blacks differ significantly across cities, mainly associated with the ethnicity that correspond to the majority of this group in each context (Appendix B-9). In São Paulo, most of the non-white and non-black population are Asians, particularly Japanese, who are very well placed in the social and spatial structures and have access to an even more significant number of opportunities than whites. In New York City, they are primarily Hispanic and, to a smaller extent, Asians from China, Korea, and Japan. While Hispanics tend to live in spaces between blacks and whites, having slightly higher accessibility than blacks, Asians in New York City have accessibility levels more similar to whites, which balances non-whites' aggregated levels of accessibility. In London, Indians, Pakistani, and Bangladeshi mainly live in the west and northeast, with accessibility levels similar to those experienced by the black population.

The centrality of class and race in structuring accessibility inequalities in these three very different social and urban contexts is highlighted when we compare inequality indices between individuals (top of Figure 4-5). London has the highest Gini indices for the time and transfer dimensions, probably due to the greater urban area and the fragmentation of urban occupation near the Greater London boundaries. On the other hand, São Paulo and New York City have similar inequality indices among individuals. However, lower inequalities happen in small accessibility in the former and high accessibility in the latter.

However, inequalities of cost and between social groups present a clearer view of socio-spatial inequalities. The ratios between accessibility levels of white upper classes and black lower classes, which polarize social structure, are far superior in São Paulo and inferior in London. That is, while in New York City and especially in London, urban space and transit infrastructure are more evenly distributed among groups, in São Paulo, black and lower classes are systematically worse off, suffering from cumulative conditions that offer superposing barriers to access to opportunities and socio-spatial mobility.

Figure 4-5: Gini indices and accessibility ratios of white upper class and black lower class, considering dimensions of time, transfer and relative cost in São Paulo, New York City and London.

4.5 Conclusion

The structural and overlapping inequalities in society and cities result in (and are reinforced by) uneven access levels to opportunities at global and local scales. This study highlights some of these spheres: socioeconomic, spatial, and infrastructural. At the socioeconomic level, the social and international division of labor imposes unequal levels of income, power, and wealth. This also contributes to an imbalance in public revenue and investment potentials in social and urban policies. These investments are fundamental to act upon the two crucial dimensions of accessibility: proximity between locals of residence and locals of activities and transit systems (Geurs & Van-Wee, 2004).

The first involves the decentralization of opportunities and the reduction of socio-spatial segregation, resulting in less monocentric and more socially mixed urban spaces. These outcomes are usually a product of long-term social cohesive policies related to urban occupation, involving housing and markets (Cassiers & Kesteloot, 2012), and are more challenging to tackle. The second involves the construction and operation of city-wide, integrated, connected, and affordable transit systems, which are even more necessary in large and unequal cities.

These two dimensions have different impacts on accessibility inequalities, which becomes evident in the comparative study between São Paulo, London, and New York City. White upper classes have accessibility far superior to lower classes. However, the difference is much higher in São Paulo -- where upper classes are highly segregated close to some few rapid transit lines and lower classes live far from opportunities and infrastructure -- than in London -- where housing policies have been more effective in bringing and maintaining lower classes in accessible places in the city -- and especially in New York City -- where social groups are highly segregated but transit infrastructure is more evenly distributed across the city.

These structural disparities between cities are present in all dimensions but are more robust when considering the monetary cost. This highlights the overlap between socioeconomic, spatial, and transportation inequalities from a global perspective and shows the centrality of the affordability dimension in transport and accessibility studies and in the formulation and evaluation of public policies, particularly in low- and middle-income countries. While the monetary cost of travel relative to income tends to have a minor impact on accessibility in high-income cities, in low- and middle-income cities, it substantially diminishes accessibility of a large share of the population, especially lower-class workers.

Among whites, social class contributes a lot to explaining accessibility levels in all cities. Most people from the upper classes live close to opportunities and transit infrastructure; middle classes occupy the intermediate spaces, and lower classes mainly live in peripheries far from jobs and rail transit systems. Among blacks, however, contextual and historical development trajectories have a significant role in explaining accessibility inequalities. In highly racially segregated cities, such as New York City, accessibility levels of upper, middle, and lower classes are not statistically different in most dimensions considered in this paper. In São Paulo, the upper-class black population has higher accessibility than blacks from the middle and lower classes. In London, however, where the black population is smaller and concentrated in the inner city, accessibility levels are even higher than whites of the middle and lower classes.

However, this difference is shortened when considering the share of income spent on transportation.

Investments in infrastructure and technology to expand and enhance transit systems can reduce travel times and reduce the perceived costs of transfers in the medium and long term, resulting in better mobility and also making public transportation more attractive to commuters, potentially increasing transit speed because of more road space, and fare revenues due to more users. Complementary, supply- and demand-side subsidies can reduce the burden of expenditures in transportation relative to income, removing some barriers to lower classes' access to opportunities in low- and middle-income countries and mitigating some effects of income inequality in the short term. Both actions are needed to reduce socio-spatial inequalities related to transport. However, different social and spatial contexts require different models of transport policies and prioritization, as transit networks and fares have distinct impacts according to classes, races, and cities.

Hopefully, unfolding inequalities beyond the usual travel time accessibility between income groups, including the analysis of classes and races within a robust empirical study from different global cities, will contribute as a new perspective to formulating contextualized policies to reduce inequalities on several fronts.

5 Evaluating the accessibility and availability of public services to reduce inequalities in everyday mobility

Finally, we now focus on the third and last mechanism driving accessibility in urban space: the spatial distribution of activities. Whether access to jobs is of the most importance for people's lives, there are many other activities people must access to fulfill their everyday needs, such as education, healthcare, and leisure. Those activities – or motives for travel – are constrained by their capacity and considered differently by individuals when planning their trips. Therefore, although accessibility encompasses similar dimensions across studies – again, the interaction among spaces of residences, transport systems, and location of activities --, its implementation varies substantially depending on the research or policy need, mode of transport, and data availability.

In this paper, we apply an optimization-based metric to analyze the accessibility and availability of public services -- schools, healthcare facilities, and greenspaces -- in the cities of São Paulo and Curitiba, in Brazil. Since it simultaneously captures supply and demand as endogenous variables in an optimization algorithm without losing communicability, we argue that the metric may be particularly useful to public policies that involve decisions at multiple territorial scales.

By identifying locations with no access to public services due to lack of proximity and service capacity, locations with low access to public services due to long distances and spatial barriers, and locations with access to poor quality services, it is possible to better inform the formulation and prioritization of public policies aiming at reducing inequalities in everyday mobility, with differential effects according to social class, race, and gender.

5.1 Introduction

Spatial accessibility is a fundamental aspect of social, economic, and cultural interactions in the city, which is a crucial dimension of the right to the city (Harvey, 2009). Transportation enables individuals and social groups to access various opportunities in the city and physically engage in activities related to the various dimensions of social life, which are spatially and temporally distributed. Despite the innumerable definitions over the years, accessibility is generally described as the 'potential of opportunities for interaction' (Hansen, 1959). It is usually operationalized by analyzing the physical separation of residences and activities, assessed according to a degree of impedance or resistance to travel in terms of monetary and temporal costs (Cervero, 2005).

Although the concept of accessibility encompasses similar dimensions across studies, its implementation varies substantially depending on the research or policy need, mode of transport, data availability (Wu & Levinson, 2020), and also the type of activity since work, education, health and leisure activities are considered differently by people when planning their transport (Ramos et al., 2020). Following Paez et al. (2012), positive implementations of accessibility, based on observed behaviors, may help assess actual levels of access to opportunities, allowing person-specific considerations. However, normative implementations based on desirable access levels may be particularly interesting to assessments of inequality and social exclusion and policy making.

Most accessibility analyses focus on evaluating the (uneven) access to employment opportunities as a proxy to multiple other types of urban opportunities or amenities, either because it is associated with many daily urban trips, according to many origin–destination surveys across the world, or because it is directly related to an individual's income and quality of life in the current political-economic system. Indeed, several studies have associated a lack of accessibility by public transport with greater difficulties in employment (Bastiaanssen et al., 2020), economic disadvantages, and social exclusion (Lucas, 2012; Lucas et al., 2016). Long and expensive daily commutes negatively impact the ability of people experiencing poverty to seek and keep themselves in formal occupations, with particular effect on women (Matas et al., 2010, Ong and Houston, 2002) and some racial groups (Cervero et al., 1995; Sanchez, 1999; Hellerstein et al., 2008).

However, there are a variety of other activities that people must reach to fulfill their basic needs, perform activities associated with care, and have a good quality of life, which are also permeated by social, racial, and gender dimensions. Only in São Paulo, for instance, studies have assessed the impact of school agglomeration (Moreno-Monroy et al., 2018), quality (Pizzol et al., 2021) and surroundings (Humberto et al., 2020) on educational and socio-spatial inequalities, the racial and income inequalities in access to healthcare (Tomasiello et al., 2023) and the different strategies poor residents take to overcome some of the many barriers to access good quality healthcare facilities (Guimarães et al., 2019), as well as the unequal accessibility to parks and cultural equipment (Tomasiello & Giannotti, 2022).

In this paper, we employ an optimization-based accessibility metric that combines the consideration of competitiveness with the ease of translating accessibility into policies since estimates are essentially based on potential travel times and population sizes. Based on the transportation problem, the optimal accessibility landscape measure previously proposed by Horner (2008) in analyzing the job-housing balance minimizes the total travel time citizens would have to spend to access destinations. The adaptation of this metric proposed in the present study provides a straightforward mechanism to spatially identify and quantify the unmet demand for activities, which may be an additional tool to support public policies.

We suggest that its use in accessibility analysis is potentialized when considering non-work activities (Horner & O'Kelly, 2007) and precisely the measurement of the differential levels of accessibility to public services with potentially limited capacity. Differently from employment opportunities, which have multiple differentiations according to socio-occupational status (Horner, 2010) and previous work experiences, are subject to the spatialization and specialization of firms (Rodrigue, 2020) and face the difficulty of matching job locations among family members, essential public services can be a lot easier to distribute in the urban space.

As it considers supply and demand as endogenous variables based on primary aspects of urban structure – such as population density, land use, and transportation systems – it does not require the definition of a specific threshold by the analyst. The normative aspect embedded into the model is the consideration that people prioritize travel time when accessing essential public services and would choose the nearest opportunity as long as there is enough capacity. Although this is not always true, and many other factors influence people's decisions, such as the quality of public services and the urban environment (Guimarães et al., 2019), providing spatially distributed opportunities may be the first step to increasing accessibility and reducing inequalities. That is precisely what the transportation problem is concerned about: a reallocation of services that minimizes the total cost within the urban system (Ma & Banister, 2006).

Consequently, this approach considers that people living closer to opportunities would have priority over those located farther away, following the literature on competitive accessibility measures (Van Eck & Jong, 1999; Van Wee et al., 2001). This is more evident in initiatives such as school admissions or affordable housing programs that may provide preferential benefits to individuals who live closer to opportunities. Nonetheless, although there is still some controversy about whether proximity to opportunities results in higher participation in activities, some studies suggest that proximity to schools can influence attendance rates (Shehu, 2018), as well as proximity to parks can result in higher usage and physical activity (Cohen et al., 2007), the opposite being also true.

If those assumptions are accepted, the model requires only the external parametrization of service capacity, that is, how many doctors or teachers per person should be available. These are usually the same indicators used at the country or city level to compare service provision against international standards or to decide upon resource distribution and allocation (Oecd, 2021; Who, 2023). Moreover, such as other accessibility metrics, including the optimal accessibility landscapes, by calculating a specific value of accessibility for each socio-occupational group, it is also possible to ensure that each group can only potentially access opportunities matching their respective social class (Horner, 2008; Korsu & Néchet, 2017). Those characteristics are essential to comparative studies and the formulation of public policies focused on different targeted groups.

The methodology for the analysis, including the optimization-based algorithm, is explained in section 2.

5.2 Accessibility and availability of public services

Accessibility is associated with how transport systems relate to land use and indicates how these two elements allow individuals or groups to reach different activities and destinations in the urban space (Geurs & Van-Wee, 2004). Accessibility is thus understood as a product of the mutual relationship between mobility and proximity (Cervero, 2005), and it may indicate the degree of freedom individuals have to decide to participate in spatially distributed activities (Burns, 1979).

Multiple ways of operationalizing the concept of accessibility have been proposed, either focusing on the transport infrastructure (Welch & Mishra, 2013), proximity to activities (Pajares et al., 2021), the uneven levels of access to opportunities among different locations (Guzman & Oviedo, 2018) or social groups (Pereira et al., 2019; Bittencourt et al., 2020), the potential of individuals to participate in urban activities (Allen & Farber, 2020), or the benefits (or utility) those activities and transport systems may provide (Nassir et al, 2016). All those approaches add interesting insights to public policy formulation and evaluation but at different levels and scales. Among location-based accessibility analyses to support urban policies intrinsically attached to territorial decisions, the most used metrics are the gravitational and cumulative-based ones (Handy & Niemeier, 1997).

Gravity-based metrics weigh opportunities based on their size and importance and the travel cost to reach them. Activities far away from a given area or point contribute less to its accessibility than closer ones (Southworth, 1978; Helling, 1998; Neutens et al., 2010). They are based on (usually exponential) weights assigned to each opportunity based on the travel impedance between different locations. Cumulative or boundary accessibility metrics, on the other hand, assess the relationship between the number of opportunities and the travel cost (distance, time, or money) to access them (Wachs & Kumagai, 1973; Frost & Spence, 1995). It requires the definition of thresholds for the number of opportunities to be reached or for the maximum travel cost to reach them.

Nonetheless, gravitational and cumulative metrics tend to underestimate access times and overestimate accessibility due to competition effects. Therefore, other metrics that do consider the level of competition for the same opportunities were proposed over the years, such as Shen's index (1998) or the 2-step floating catchment area (Luo & Wang, 2003; Luo & Whippo, 2012), but they often rely on very complex indicators that fall short in communicating differences in accessibility to communities and policymakers. More recently, other researchers suggested new adaptations for floating catchment areas by efficiently allocating the population into opportunities and communicating accessibility estimates as provider-to-population ratios (Paez et al., 2019) and access travel times (Barboza et al., 2021).

Another branch of accessibility metrics research focused on optimizing the jobs-housing balance, reducing wasteful commuting, as initially proposed by Hamilton (1982), re-examined by White (1988) with the use of linear programming algorithms, and replicated in different cities across the globe, most of them in high-income countries (Ma & Banister, 2006). The optimum accessibility landscapes fits into this category, measuring the amount of excess time people travel that cannot be explained by the locations of jobs and housing themselves but also testing better urban configurations (Horner, 2008), as well as the quadratic programming approach proposed by Wang and Tang (2013) to minimize the variance of accessibility scores across locations by readjusting jobs and also physicians supply. Indeed, although relatively timid compared to employment opportunities, some authors have applied optimization algorithms inspired by the transportation problem in public services, usually associated with healthcare, with different methodologies (Horner & Mascarenhas, 2007; Fredriksson, 2017).

The choice of the accessibility metric and the definition of thresholds or parameters of each model are not straightforward and include several assumptions about individuals' behavior and socio-spatial dynamics, as well as moral choices embedded in each decision (Paez et al., 2012). How many opportunities are enough to provide good accessibility? (Silva and Anders, 2019). How much time or money is it acceptable for people to spend on transportation to access everyday activities? Do people have the same willingness to travel, and if so, should it even be considered in inequality assessments? (Giannotti et al, 2022).

From a normative perspective, in a sustainable city, individuals would ideally have access to all basic activities within a short walk or transit ride to fulfill their everyday needs, consequently reducing transport's social, economic, and environmental impacts. This is aligned with recent discussions on the 15 or 30-minute city (Allam et al., 2021; Levinson, 2019) or, more comprehensively, chrono-urbanism ideas that gained particular attention in the political debate across the globe. The application of the concept, however, faces the challenges of the spatial concentration of activities and the spatial segregation of social groups, which may result in cumulative and self-reinforcing inequalities.

In any case, job accessibility measurement is quite different from access to public services. In education or healthcare, measuring the time it takes for children or people to get to the closest school or healthcare facility may be helpful to unfold inequalities, especially when households are linked to school or health districts. However, the number of people who can access them is constrained by the number of teachers or doctors available in each facility and its infrastructure (Paez et al., 2019; Soukhov et al., 2023). Also, the quality of the service provided in each location varies significantly in the territory (UNESCO, 2019), which may also play a role in accessibility levels (Pizzol et al., 2021).

Concerning access to non-regular leisure activities such as theaters and libraries, the variety of available options is a critical factor for human development, mental and physical health, and quality of life (Dadvand et al., 2016; Markevych et al., 2017). Therefore, measuring how many opportunities can be reached within a particular time limit may be useful (Hino et al., 2019; Zhang et al., 2011). Occasionally, people may be willing to travel longer or pay more to access some vital urban amenities they rarely do (Susilo & Dijst, 2010). Nonetheless, although variety and quality are essential to travel choices, particularly on weekends and holidays, proximity to a park or square is fundamental to ensure that people have access to greenspaces in their everyday lives, promoting health and quality of life (Holbrook, 2009), especially for children (McCracken, 2016).

It is also important to highlight that the spatial distribution of such activities is intrinsically attached to public and private decisions. Job locations are driven mainly by market dynamics (Duranton & Puga, 2004), although constrained by land use regulations to some extent, which usually results in a very city-center-concentrated spatial distribution. Public services do not follow the same logic.

Despite the many interpretations of the state, it is not a homogeneous structure. It is permeated by conflicts among multiple actors with different perspectives and power resources, primarily constrained by social and institutional contexts and the political debate (Marques, 1997). Either to ensure the production and reproduction of the workforce (Poulantzas, 1980; Lojkine, 1997; Castells, 1972), as a result of social conflicts and institutional arrangements (Skocpol, 1985; Hall & Taylor, 1996) or due to the pressure of social movements (Sader, 1988), the state may be pushed to prioritize peripheral or low-income areas, where there are higher concentrations of low-income populations or the ones that are more dependent on public services. Also, in contexts of high inequality, upper classes may opt out of public services by choosing self-finance private alternatives that can be perceived as of better quality (Motiram & Nugent, 2007). In this sense, they may exercise little or no influence over the location of public schools or basic healthcare facilities, and public services may be better distributed in the territory.

This does not apply to hospitals, universities, or parks and greenspaces used by all social classes. This is either because the private cost of the service is too expensive (even for most of the upper-class population), the public equipment offers a higher value service than its private alternative, or there are no (or very few) private substitutes to the public service (Epple et al., 2000; Araujo et al., 2008). Financial and political elites may then exercise their power to pressure public institutions to redirect investments toward those services (Karabarbounis, 2011; Kosec, 2010) with territorial facets (Vetter & Massena, 1981).

Finally, if social class and, more recently, race have been increasingly explored in accessibility studies (Horner, 2010; Gianotti et al., 2021), socio-spatial inequalities are also affected by gender. Although women and men tend to inhabit the same spaces, the unequal and persistent sexual division of labor makes women more involved in unpaid and often invisible activities (Hirata et al., 2000), which has an impact on their time and money budget, their use of public spaces (Lieber, 2008), as well as their mobility patterns (Gauvin et al., 2020; Jirón et al., 2021). Indeed, although separately analyzed by traditional mobility surveys, access to activities such as education, healthcare, and greenspaces are deeply associated with the mobility of care (Madariaga & Zucchini, 2020).

This includes caring for the family, the children, the elderly, etc., usually resulting in shorter and chained trips (Rosenbloom, 2006). Providing proximity to essential services by reducing travel times to nearby activities and guaranteeing enough seats in public schools, enough doctors in basic healthcare facilities, as well as enough public spaces for personal, child, and elderly care, may be one step to mitigate at least a little, the excessive workload women often face in everyday life. In this sense, the same public policy may act upon several dimensions of socio-spatial inequalities, which may be considered by policymakers in the decision of the location and maintenance of public equipment and services.

5.3 Socio-spatial structure and mobility patterns in São Paulo and Curitiba

Brazilian cities have seen massive demographic and economic growth during the 20th century (Rolnik, 2017). Those demographic booms were accompanied by selective urban policies associated with the political representation of traditional elites, which prioritized urban and transport infrastructure investments in the city center (Frugoli, 2000). The emergence of gated communities in distant spaces (Caldeira, 2000) and the deconcentration of some economic activities (Rolnik & Frugoli, 2001) increased the heterogeneity within the cities, as well as their metropolitan areas. However, they still carry some attributes of the simplified center-periphery model used to explain Brazilian cities in the past (Villaça, 1998).

This is seen by the spatial distribution of social classes and racial groups in Appendix A. There is an apparent concentration of the upper class close to the city center and traditional spaces of elites, with a few more distant and isolated hotspots. With the lack of solid and comprehensive urban policies during this rapid urbanization and the active action of the real estate sector (Maricato, 2017), cities expanded towards their borders and peripheries, leaving manual workers who do not have the financial resources to compete for the very disputed central locations. As a result, lower-class workers are mainly in the historic center of the city and in urban fringes. Social class, however, is not the only fundamental aspect of residential segregation. As discussed in previous studies (França, 2016), race also plays a structural role in social and spatial structure in Brazilian cities, and blacks tend to inhabit more peripheral locations in cities than whites, even when belonging to the same social class. While whites are more distributed across the territory, blacks are mainly in peripheral locations (Appendix C-1 and Appendix C-2).

The spatial distribution of the social and racial groups reflects on accessibility (Bittencourt et al., 2020) and mobility patterns since peripheral residents travel longer in their daily commutes and use more public transportation than central residents (METRO-SP, 2017; CURITIBA, 2017). Nonetheless, as previously discussed, another critical aspect of social structure, gender, is also a defining variable of accessibility and mobility. In São Paulo and many other cities, women travel proportionately less to work activities and more to activities associated with education, health, and shopping, which is most related to the mobility of care. Those differences between men's and women's mobility patterns are even more pronounced when they live with children and/or older adults.

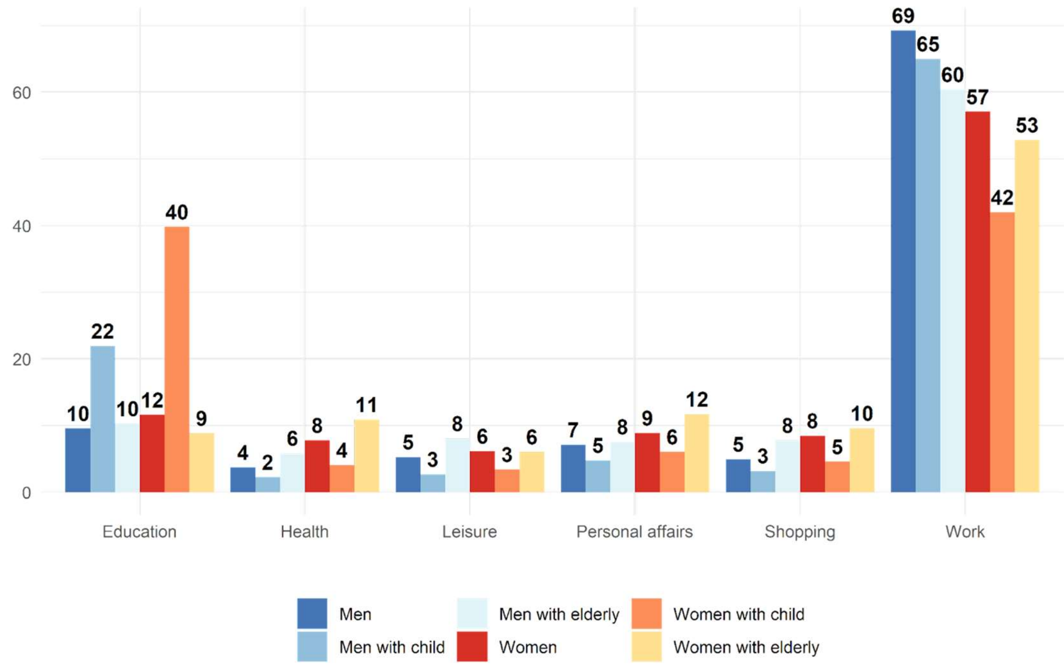
As seen in Figure 5-1 (top), the participation of work in the total number of trips drops when women live in households with at least one child younger than 12 years old. In contrast, the number of trips to educational activities substantially increases, probably indicating trips to accompany children to schools. Similarly, the percentage of trips to health-related activities grows (to a larger extent than men) when women live with someone older than 80.

Also, as seen in *Figure 5-1* (bottom), while most men with at least one child mostly use a car to access basic activities such as education, health, leisure, or visiting activities, women usually walk. Public transport is mainly used in families with older people, who face more difficulties walking. In Curitiba, although the available data does not allow such disaggregated analysis, women also travel more with the purpose of education (25% of all women's trips against 19% of men's), health (6% against 4%) and leisure or visits (7% against 6%). Similarly, to access those activities, they usually walk (28% against 15% of men) or take transit (21% against 16%) (CURITIBA, 2017).

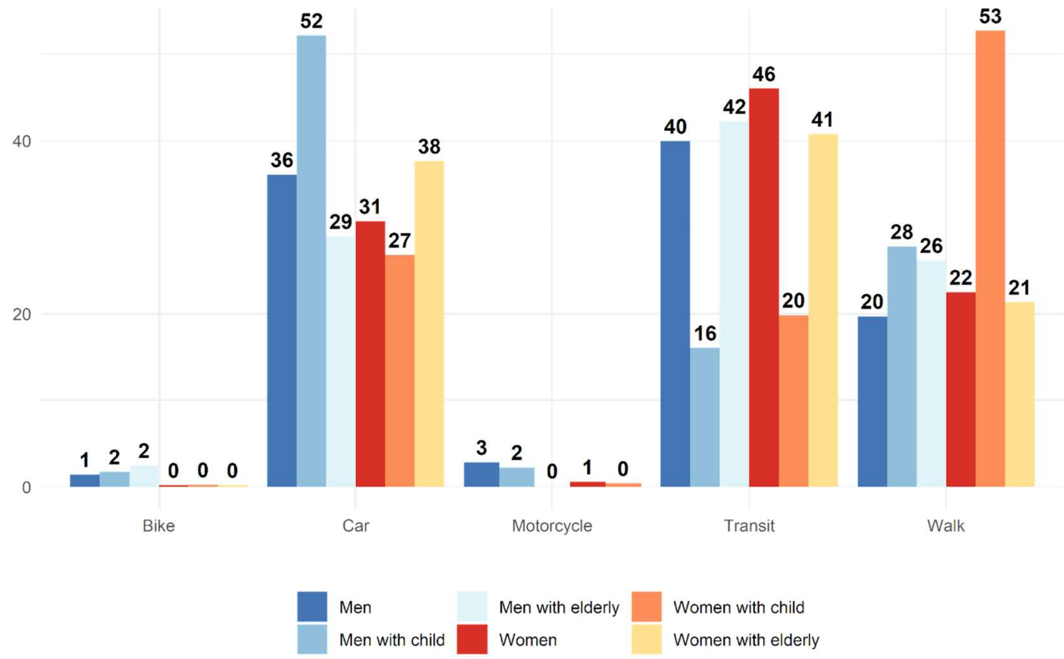
This indicates that, although women and men usually have the same physical (locational-based) accessibility, access to activities such as primary schools and healthcare facilities, especially by walking, may impact women's everyday mobility more than men's. On the contrary, difficulty accessing such activities may be a more significant burden on the time and money women spend on transport.

Figure 5-1: Main purpose of trips (top) and main transport mode to access education, health and leisure/visit activities (bottom) by men and women between 18 and 80 years old in São Paulo and the existence of children or elderly in the family, by percentage of each group's total number of trips.

Main purpose of trips on a typical weekday



Main transport mode to access education, health, and leisure/visit activities



5.4 *Accessibility to public services and equipment*

As extensively analyzed in multiple studies, formal jobs in São Paulo and Curitiba are primarily concentrated in the expanded city centers, ensuring that white upper classes have higher accessibility to employment opportunities. In contrast, most of the population, predominantly black lower classes, live in densely populated peripheral zones and enjoy much smaller accessibility (Bittencourt & Giannotti, 2021). As for public schools and healthcare facilities, their spatial distribution is much less concentrated and, at least in terms of infrastructure, can provide access to a larger share of the population within reasonable travel times. However, when considering service capacity, this changes a little (Pereira et al., 2021).

As the total primary school capacity, measured by the number of seats, is smaller than the actual number of children from middle and lower classes between the ages of 6 to 11 years old, 10.2% of children are left out of a public school due to lack of proximity in São Paulo and 18.4% in Curitiba. Those children are mainly in places mostly populated by upper classes and where only a few public schools are available in both cities. The children with physical access to public school seats would have to travel for 13 minutes, on average, to reach an available school seat.

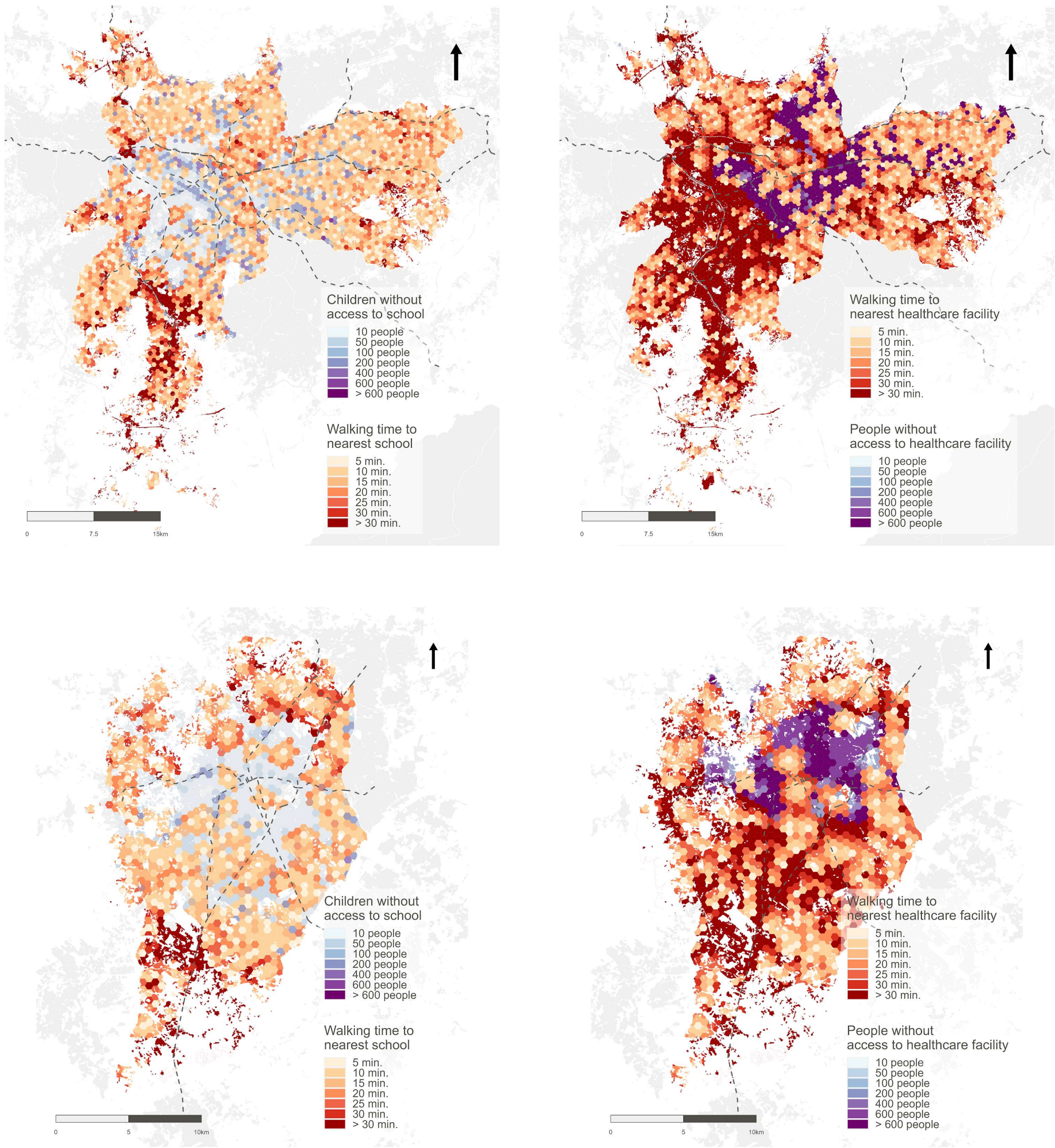
Healthcare capacity in São Paulo is also below international guidelines. Considering a ratio of 3.5 doctors for each one thousand inhabitants, the total demand from the middle and lower classes far exceeds what would be managed by the existing staff. About 8.7% of those groups' population in São Paulo and 9.3% in Curitiba would be left without care or would overcrowd the healthcare facility closest to them. On average, the others would have to travel for 53 minutes and 40 minutes in São Paulo and Curitiba, respectively, to access those activities, with large social and spatial inequalities.

In Figure 5-2, dark purple areas indicate that a significant amount of people (or, in the case of school seats, specifically children) do not have access to school seats or enough doctors, which is the result of a combination of lack of infrastructure (facility) and lack of service capacity (teachers and doctors). This is the most urgent problem to tackle through public policies, which depends on installing new infrastructure with additional service capacity. However, in both cities, most areas where residents do not have access to public services are occupied mainly by the middle classes, who have more financial resources to seek private alternatives. In fact, 13.9% of the white middle class do not have access to school seats in São

Paulo and 20.4% in Curitiba, against 7% and 15% of the black lower class in both cities, respectively. The same pattern is seen in the access to healthcare.

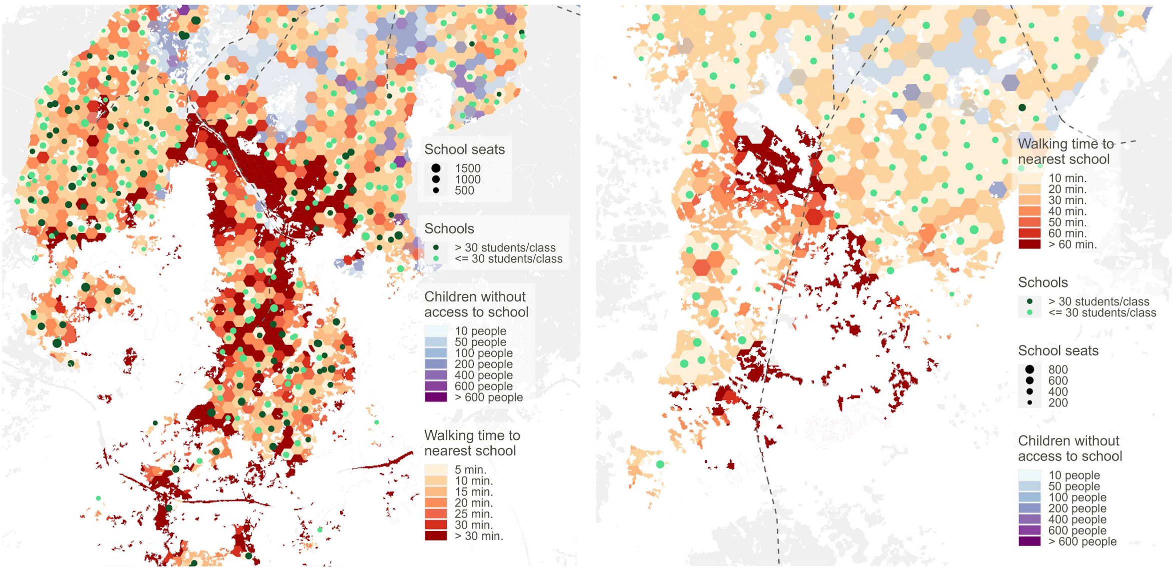
Dark red areas indicate that although there is enough capacity to meet population needs, people would have to travel for extended periods (more than 30 minutes of walking) to access public equipment. This can be mitigated by the decentralization of services and the supply of efficient and affordable public transportation linking those areas to nearby schools and healthcare facilities. It is interesting to note that physical barriers primarily affect the walkability and accessibility to schools and healthcare facilities, including railways, rivers, and also large vegetation areas, which must be the focus of micro-accessibility analysis and infrastructure interventions.

Figure 5-2: Accessibility to primary schools (left) and basic healthcare facilities (right) in São Paulo (top) and Curitiba (bottom).



Based on this panorama, we can then take a closer look at the territory, focusing on particular locations where the travel time to primary school seats exceeds the city average and where a large part of the population does not have access to enough school seats (*Figure 5-3*). Also, although many peripheral locations have access to school seats and doctors within a short walk (yellow and orange areas), the quality of such services may not always be adequate. Indeed, taking only the students per class/teacher ratio as a simplified proxy to school quality, for instance, we see that poor quality schools, particularly in São Paulo, are mainly in urban peripheries, contributing to enlarged educational inequalities. Therefore, dark green spots (poorer quality schools) should be the focus of public policies that increase service quality, either by reducing the number of students in classrooms, increasing the variety of services offered, or by many other necessary initiatives that may be subject to territorial evaluation.

Figure 5-3: Accessibility to primary schools in the south of São Paulo (left) and Curitiba (right).



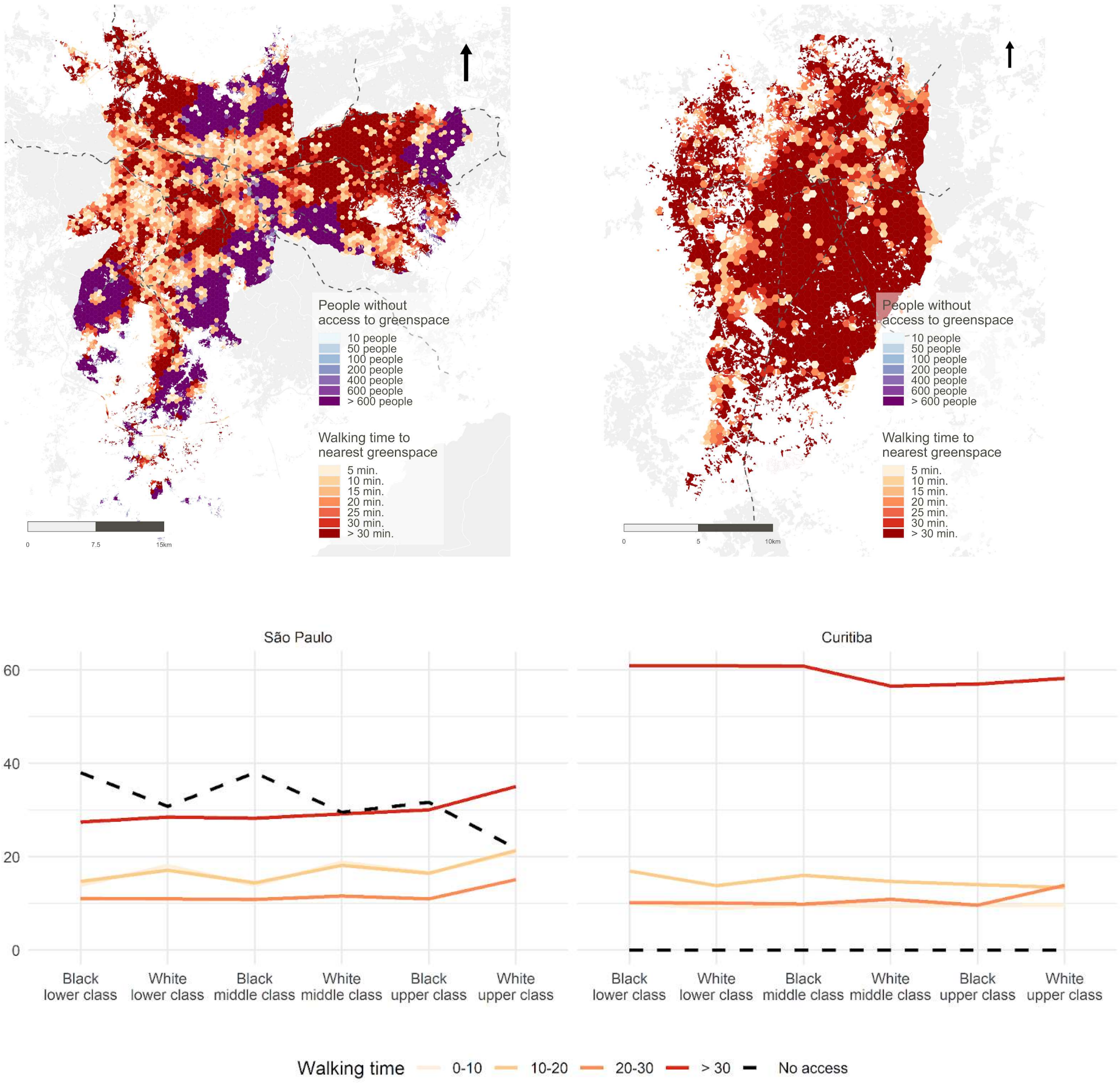
A few significant differences were identified in terms of access to good or bad healthcare and education according to social class and race, as shown in Appendix C-4. In Curitiba, white children tend to access schools with more multimedia equipment and computers per student, while in São Paulo, as previously described, they tend to access schools with smaller classrooms and a lower ratio of students per teacher. Concerning healthcare, in Curitiba and São Paulo, locations accessed by white people tend to be open for more hours during the week and to have more installations and services per inhabitant. However, there are fewer professionals and teams per person.

As previously mentioned, access to parks and greenspaces may assume very different characteristics. Leisure activities on holidays and weekends are submitted to a personal decision matrix in which factors related to environmental quality and the provision of cultural activities significantly affect travel decisions, more so than travel time or cost. On the other hand, access to parks in everyday life is submitted to another decision matrix with quite different weights and parameters. Low accessibility to parks and squares, which depend on long journeys on foot or the use of public transport, limit leisure and care activities daily, both due to the lack of available time, considering the various activities carried out during the day, and also due to transit fares, which is often a significant barrier especially for low-income people to make frequent non-mandatory trips.

São Paulo has, on average, 2.74 m² of public open space per capita, which results in 60% of the population without enough access to parks and squares in their everyday life. However, in opposition to the access to education and healthcare, most of them are blacks from lower and middle classes: 21.8% of the white upper class do not have access to open greenspaces, against 38% of the black lower class. This is in line with the existing literature on the political action of elites towards different public services, as previously discussed.

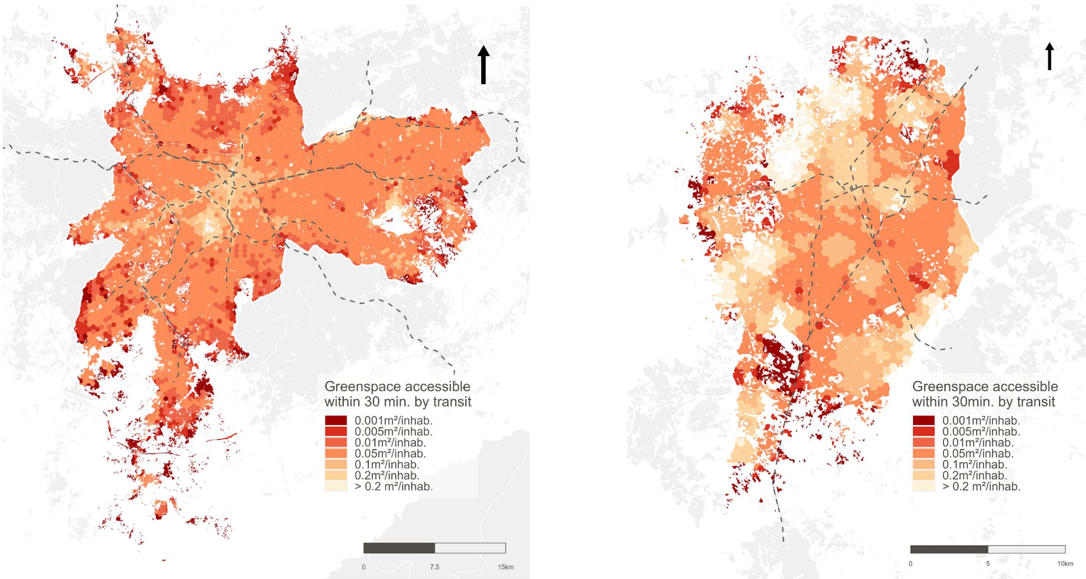
Evidently, it does not mean that people cannot access further and eventually more crowded locations. However, the accessibility indicator suggests large and populated areas with unmet demand for green areas. This is a very different scenario from Curitiba, which has 8.67 m² of public open greenspaces per inhabitant. In theory, although everyone could access enough parks and squares, they are mainly concentrated towards the northwest, which means the walking time needed for most people to access them far exceeds what would be considered walkable (Figure 5-4).

Figure 5-4: Accessibility to the closest park or square by walking in São Paulo (left) and Curitiba (right), in accessibility maps (top) and in percentage of people accessing (or not accessing) greenspaces by time interval.



Public transport can increase accessibility to parks and squares, especially on weekends and holidays, when the variety of options may matter more to individuals than being close to just one public open space. Within a 30-minute transit ride, many people from Curitiba can access a significant number of opportunities and, therefore, open greenspaces (*Figure 5-5*). In São Paulo, which has a much smaller ratio of m² per capita, most people would access a much smaller rate of greenspace than in Curitiba.

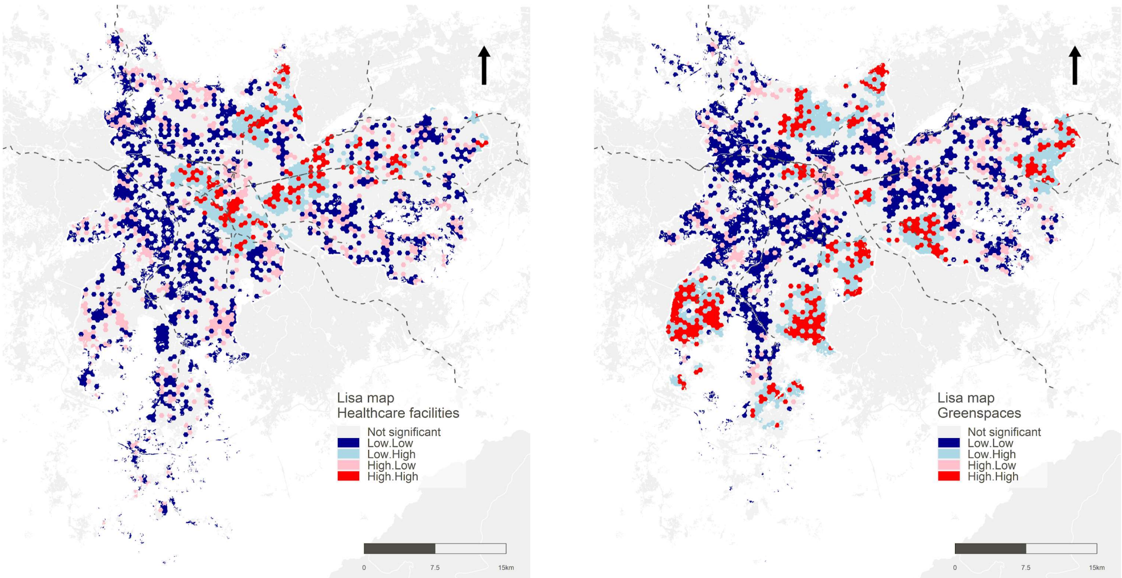
Figure 5-5: Cumulative accessibility to parks and squares by transit in São Paulo (top) and Curitiba (bottom).



Finally, once we have measured the accessibility and availability of public services, we can also match those areas with no or very little access to schools, healthcare facilities, and greenspaces with spaces of concentration of priority groups, the ones most impacted by low accessibility. The overlap of all those dimensions may be a helpful indicator of cumulative and self-reinforcing inequalities or even social exclusion. However, analyzing them separately may make formulating and evaluating public policies easier.

In this case, we focused on women living with children or elderly without a car. The bivariate Lisa maps, as proposed by Anselin (1998), allow the identification of the concentration of priority groups surrounded by locations with no access to public services, and it is presented in *Figure 5-6* for the city of São Paulo. Considering access to healthcare facilities, there are many spots with a high concentration of women living with children or elderly without a car and low accessibility in places mainly occupied by middle and upper classes, close to the city center. There are some hotspots, however, in the northeast, close to Guarulhos, one of the most populated neighboring municipalities. Considering parks, the most vulnerable places are close to the city border in the southern and eastern regions, namely Capão Redondo (southwest) and Itaim Paulista (east). It is interesting to note that although there are parks in the southeast and north, highways or few entrances make it more difficult for people to access those areas.

Figure 5-6: Bivariate Lisa maps of priority group and low accessibility to healthcare facilities (left) and greenspaces (right) in São Paulo.



Comparing the optimum accessibility landscapes metric to other largely employed metrics, such as the nearest opportunity, cumulative opportunities, and the 2SFCA, specifically to the analysis of the availability and accessibility to public services, there are some qualitative and quantitative differences (Appendix C-5 to Appendix C-16).

Notably, one fundamental aspect of public service delivery has enough capacity to meet the population's needs. This means that if insufficient school seats or doctors are available at the nearest public facility, people would have to travel to further destinations. Indeed, although the correlation is relatively high (around 0.8 to education and healthcare), the optimum accessibility landscapes provide travel time results up to four times greater than the simple nearest opportunity metric of accessibility. This difference is even more significant when considering public services with minimal capacity or high spatial concentration, such as open greenspaces in São Paulo and Curitiba. Also, although the 2SFCA also considers competition, and it is possible to parametrize the cumulative metric to consider the size of the population, people do not need multiple facilities of some public services to meet their needs adequately. They would only need one close to their home and providing adequate service. Moreover, the overlapping of the two main results from accessibility estimates – access travel times and the number of people without access due to longer travel times – allows for better identification and prioritization of policies that are profoundly attached to the territory.

5.5 *Conclusion*

Both the Master and Transportation Plans of the cities of São Paulo and Curitiba, as many other cities, envision a polycentric urban structure, distributing urban opportunities and services throughout the region and reducing the need for long-distance commutes. The reality, however, is more complex. Although public equipment, particularly public schools, and healthcare facilities, seem to be directed towards urban peripheries in both cities, the lack of service capacity or the unequal distribution of service quality may increase cumulative inequalities and should be carefully analyzed.

We also argue for including other markers of inequality in planning and evaluating the territorial dimensions of public policies. Although black populations and lower classes live closer to public healthcare facilities and schools, they have significantly lower levels of accessibility to greenspaces than white upper classes. In addition, even though women inhabit the same spaces as men, their mobility patterns and the activities they usually perform are pretty different, which significantly impacts how they deal with low accessibility and availability of public services and spaces. The existing and future research on this topic may contribute to a better understanding the multiple strategies those groups adopt when experiencing low accessibility in their everyday mobility.

Accessibility metrics should be theoretically and empirically consistent with the object of the study and attached to the socio-spatial context. The optimization-based accessibility may be one of the many other metrics and tools researchers and policymakers have to assess the accessibility and availability of public services and to design and evaluate public policies that are intrinsically attached to social, urban, and transport structures. This model implementation offers an easy-to-communicate way of identifying locations with no access to public services due to lack of proximity and service capacity, locations with low access to public services due to long distances and spatial barriers, and locations with access to poor-quality services. Linking those places to sociodemographic variables makes it possible to better prioritize public actions according to politically defined principles and goals, especially in contexts of limited resources. Moreover, as it only depends on the parametrization of service capacity and socio-spatial structure, it may benefit comparative studies and public policies defined at the national and local levels. This is because it allows us to treat the diversity of territorial contexts and apply joint targets and efforts to the intraurban scale.

6 Final remarks

Transport systems are structured according to spatial, temporal, and social dimensions that overlap and feed into one another. In spaces, people live, work, study, enjoy, protest, and travel through infrastructures and services, consuming limited time resources. Both space and time are not neutral and are differently experienced by people in objective and subjective terms associated with individual characteristics and structural aspects of society. Socioeconomic inequalities are fundamental principles of capitalist society and result in relations of power related to income, birth, literacy, and occupation, just as race and gender are fundamental aspects of socio-spatial inequalities in societies formed by racism and patriarchy.

In the three research papers that compose this thesis, we walk through the profound social, racial, and gender inequalities related to urban transportation as a part of a process of better understanding territories and societies to inform public policies aiming at building more equitable, safe, and sustainable cities. Due to the complexity of such a challenge, this can only be approached by a mix of research methods and techniques.

Transport and accessibility metrics should be theoretically and empirically consistent with the object of the study and attached to the socio-spatial context. Measuring access to employment opportunities substantially differs from measuring access to education, healthcare, or leisure activities. Comparing cities presupposes special attention to the effects of geographies, population size, and number of opportunities within the city and, evidently, within the metropolitan region — although metropolitan data and governance are so scarce in Brazil that they prevent most of the much-needed metropolitan analyses. That is the reason why the five chapters significantly differ in methodologies.

6.1 Summary of the thesis

In the third chapter, we focus on the unequal occupation of urban space by socio-occupational and racial groups and its effects on job accessibility. Groups at the extremes of the social and racial structure live in highly segregated spaces and have contrasting levels of access to opportunities. Lower classes are over-represented in urban peripheries and have lower levels of accessibility than upper classes. Black people have worse physical access to jobs than whites, even when they belong to the same social class. This applies more strongly to elites than to lower classes, for whom racial differences in residential segregation are smaller.

However, it is worth mentioning that the upper classes are not always more segregated than other groups, and they do not always have better access to jobs by public transport since other advantages may drive urban occupation, including the desire for exclusivity, natural landscapes, and other urban amenities.

Such inequalities also vary according to city size, geography, and other aspects that form urban spaces, constituting heterogeneous and complex socio-spatial structures. In larger cities, commuting times needed for individuals to cross urban space are longer, and inequalities in accessibility are higher. In addition, geographical aspects and spatial discontinuities impact urban occupation and pose barriers and difficulties to travel. Indeed, regional inequalities change how social and racial inequalities manifest in the urban space. Cities with larger proportions of black residents tend to be more integrated and less unequal. Nevertheless, even where the black population comprises a vast majority, white residents are still better located and enjoy higher levels of accessibility.

In the fourth chapter, we aimed to position accessibility inequalities associated with socio-occupational class and race in a broader perspective, investigating how local and global inequalities feedback into each other in complex relations between neighborhoods, cities, and countries. To do so, not only time is a core dimension of transport systems, but also network connectivity and travel costs.

These two dimensions have different impacts on accessibility inequalities, which becomes evident in the comparison between São Paulo, London, and New York City. As we have seen in the first chapter, white upper classes have accessibility that is far superior to that of lower classes. However, the difference is much higher in São Paulo -- where upper classes are highly segregated, close to some few rapid transit lines, and lower classes live far away from opportunities and infrastructure -- than in London -- where housing policies have been more effective in bringing and maintaining lower classes in accessible places in the city -- and especially in New York City -- where social groups are highly segregated but transit infrastructure is more evenly distributed across the city.

These structural disparities between cities are present in all dimensions but are more robust when considering the monetary cost. This highlights the overlap between socioeconomic, spatial, and transportation inequalities from a global perspective and shows the centrality of the affordability dimension in transport and accessibility studies and the formulation and evaluation of public policies, particularly in low- and middle-income countries with significant socioeconomic inequalities and poverty.

Among whites, social class contributes a lot to explaining accessibility levels in all cities. Most people from the upper classes live close to opportunities and transit infrastructure, middle classes occupy the intermediate spaces, and lower classes live in peripheries far from jobs and rail transit systems. Among blacks, however, results suggest that contextual and historical development trajectories may majorly explain accessibility inequalities.

In the sixth chapter, we expand our analysis beyond trips to work to incorporate access to activities essential to social reproduction, such as education, healthcare, and leisure. In this sense, if only the dimensions of social class and race were considered in the previous chapters — since women and men tend to inhabit the same places in the city — now gender becomes a fundamental dimension. This is because caring for others disproportionately relies on women's shoulders.

Public equipment, particularly public schools and healthcare facilities, seem to be directed towards urban peripheries, which contribute to reducing accessibility inequalities. However, the lack of service capacity or the unequal distribution of service quality may increase cumulative inequalities of social class, race, and gender. To tackle this limitation faced by many accessibility studies, we propose a new adaptation of an optimization-based accessibility metric that may help evaluate the accessibility and availability of public services and design public policies that are intrinsically attached to social, urban, and transport structures and subject to decisions at multiple territorial and government levels.

By applying this metric, we show that although black populations and lower classes live closer to public healthcare facilities and schools, they have significantly lower levels of accessibility to greenspaces than white upper classes. In addition, even though women inhabit the same spaces as men, their mobility patterns and the activities they usually perform are pretty different, which have a significant impact on how they deal with low accessibility and availability of public services and spaces.

6.2 Policy implications

The findings from this research have important implications for public policies at both local and national levels, not only in urban and transport policies but also in social assistance, health, education, and many other areas that intersect with transportation to ensure people's access to social rights and opportunities.

First, race is a fundamental dimension of social and urban policies interacting with social class. Although policies focused on lower classes may significantly improve the accessibility of black people, they do not necessarily equate access levels between groups. Therefore, social policies to increase income and guarantee affordable and accessible housing, in addition to income criteria, may include racial criteria for the prioritization and selection of projects and strategies.

This consideration is also essential to transport planning. In public transportation, for instance, accessibility evaluations disaggregated by social class and race may inform the prioritization of new infrastructures, bus or rail lines, and the definition of fare schemes. Since affordability is inherently relational, beyond the reduction of fare prices for all, the low levels of accessibility of black people and lower classes due to lower incomes may be a strong argument in favor of special fares and passes directed to those groups. The same applies to women and large low-income families, who spend more on transportation or avoid trips because of limited financial resources.

Moreover, if disaggregated accessibility indicators may benefit ex-ante evaluations of public policies since we can test the decrease (or increase) in inequalities in the potential access to opportunities, disaggregated data on mobility patterns may complement ex-post analyses. That is, how the benefits of a specific set of policies are being distributed among different social groups and may contribute to the mobility of lower classes, black people, and women, who face additional barriers to travel.

However, although there is an increasing use of data automatically collected by Intelligent Transport Systems, most indicators are calculated for the entire city or population, disregarding social, racial, and gender inequalities. Most electronic ticketing registrations gather data on income, occupation, gender (or sex), or age, and a smaller number of systems collect user data on race. The crossing of user data (from the registers) with ticketing data (from validations), for instance, substantially increases the possibilities to evaluate the effectiveness of public policies in the short and medium term, as well as the explanatory capacity of research on central problems in society, contributing to scientific advancement in the long term.

The same applies to other data sources available at the local or national level, which are still underutilized in urban mobility. This thesis used data from the national demographic census, the Ministers of Economy, Health and Education, satellite and remote sensing, collaborative and open-source platforms, etc. In the context of the lack of specific surveys on urban mobility, crossing social and spatial information from different databases can offer a relevant overview of significant mobility issues and even direct less costly and more targeted surveys.

The results of this thesis also call for systematic use of accessibility indicators in different spatial scales and domains. According to the Brazilian Constitution, many policies are discussed concomitantly at the local, regional, and national levels. This is the case of healthcare -- with the Sistema Único de Saúde (SUS) --, food security -- with the Sistema Nacional de Segurança Alimentar e Nutricional (SISAN) --, and education, which is not based on a unified system, but it is structured as integrated and nationally coordinated policies.

While at a national level, it is crucial to know the number of people without access to doctors, food, or school places, in order to distribute federal public resources to different cities, at a local level, it is essential to understand where and who the people without access to these services and rights are, in order to territorially direct policies to decentralize public facilities, increase service capacity or improve the quality of the services provided in those places.

Nonetheless, although we need a national standard parameter for accessibility to compare cities and prioritize investments and the distribution of resources, it is equally important that accessibility parameters and thresholds adhere to the reality of the local context. This presupposes participation and consensus within each community, which will decide its goals and targets. Therefore, national policies may combine with city-level policies and very local and community-based policies and practices, resulting in multiple thresholds and parameters defined from the bottom up and the top down.

Finally, in addition to multilevel cooperation, there is an urgent need for intersectoral collaborations. Although transport is a means to access other rights, its planning is often separate from other domains, which often reduces the effectiveness and efficiency of public policies.

6.3 Limitations

There are, however, significant limitations to the research presented in this thesis, with policy implications as well.

First, many academic studies and technical reports have highlighted the need for urban analysis and public policy formulation at the metropolitan scale, with a focus on issues of multi-level governance (Veneeman & Mulley, 2018) and public transportation planning and service provision (Rodrigues et al., 2013; Bray, 2022). This is particularly relevant in Brazil since roughly 60% of the population lives in the 82 metropolitan regions, urban agglomerations, or integrated development regions formally defined by national or state legislation, making those territories strategic to guaranteeing social and human rights.

The sociospatial inequalities presented across the main chapters of the thesis expand towards metropolitan fringes, putting pressure on local, regional, and national public authorities to provide quality infrastructure and public services that meet the population's needs. In the other direction, the scarce availability of resources for growing demands presupposes efficiency in public management and the prioritization of investments.

However, despite the federal legislation, and particularly the Statute of the Metropolis (Federal Law nº 13,089/2015) establishing general guidelines for the shared planning, management, and execution of strategic public policies in metropolitan regions, inter-federative relations in Brazil, they are marked by a lack of cooperation, adding up to the challenges of technical capacity, institutional arrangements, political disputes, and legal gaps. As a result, not only do we lack metropolitan governance, but we also lack metropolitan data.

Second, the unavailability of data in Brazil also applies to other domains, including urban mobility and public transportation. Despite being an international reference, the last available data from the national demographic census conducted by IBGE is from 2010. Fourteen years later, when this thesis is concluded, we still need more updated and disaggregated information on population and households, making many sociospatial analyses outdated. In addition, few Brazilian cities organize and open their transport data in the GTFS format, which is a crucial element to accessibility analyses, or conduct periodic origin-destination surveys that could allow more research on how accessibility interacts with actual mobility patterns.

Some limitations of data unavailability are being tackled using technology and automated data, such as smartphone data and call detail records. Researchers have been using mobile phone datasets to estimate land use (Caceres et al., 2020), mobility patterns (Yang et al., 2019; Barboza et al., 2020), and travel mode choices (Peng et al., 2021), among other topics. Nonetheless, the use of data in transport planning and practice still needs to be improved, and even the use of GPS and smartcard data is scarce in Brazil. According to a survey by the National Front of Mayors, in Brazil, only 77,5% of the medium and large-sized municipalities use ticketing data, and 66,3% use GPS data to plan and control their public transport systems. Less than 20% publish their data in open data portals (FNP, 2021).

The lack of transport data limits the possibilities of scalability and replicability of the analyses carried out in this thesis to other Brazilian cities and also reduces, to some extent, the application of the same concepts and phenomena throughout the national territory, given the variety of urban contexts in the country.

Third, in this thesis, we adopted a location-based approach to accessibility, measured through quantitative methods. Although some structural aspects of society are incorporated in the analysis based on where people live, we still need other fundamental aspects that influence people's perceptions of accessing opportunities and travel possibilities and preferences.

Indeed, people face many other challenges when accessing activities aside from spatial distances between residences and activities. Individual characteristics and abilities condition multiple challenges to mobility in the urban space, built, occupied, and experienced differently by people of diverse backgrounds.

This is a fundamental limitation to gender evaluations, for instance. Although men and women tend to inhabit the same places – which makes their locational accessibility similar – mobility patterns change significantly. Women's mobilities generally consist of diverse trips throughout the day (Rosenbloom, 2006), specially dedicated to care and social reproduction tasks – usually unpaid or low-paid activities – which are associated with the historically constructed sexual division of labor (Hirata, 2007a). The tight time and money budget to travel and perform daily activities often results in time-poverty-based exclusion (Church et al., 2000; Perez, 2019) or greater use of public transport and walking (Gonzalez et al., 2020).

In addition, the intersectionality of social class, race, and gender dimensions also brings out new features to social relations and everyday experiences and practices (Hirata, 2007b), which are often overlooked due to the difficulty of analyzing those mechanisms with the generally available quantitative data. Deepening the knowledge about the personal, social, spatial, and transport elements influencing travel decisions is fundamental for designing more effective public policies to build more sustainable and equitable cities.

Incorporating those aspects into transport literature and practice thus requires a mix of quantitative and qualitative methods. The use of combined methods allows for a better understanding of complex issues that either a quantitative or qualitative approach cannot address alone (Clark et al., 2008). Moreover, mixed methods can be used to inform one another; that is, a qualitative approach can be used before a quantitative approach when we know very little about the phenomena of analysis, or the opposite when findings from a quantitative approach can be better interpreted using qualitative techniques (Grosvenor, 1998). In transportation, qualitative studies have been increasingly applied to studies on travel behavior research (Clifton & Handy, 2001), to engineering changes in travel choices (Lucas, 2013; Humberto et al., 2021), as well as to the understanding of transport disadvantages and social exclusion processes (Perrotta, 2017; Guimarães et al., 2019).

6.4 Future research

Indeed, the findings and methods applied in this research are far from exhausting the multifaceted character of transport-related inequalities of class, race, and gender. Instead, they encourage reflections on important social, spatial, and transport issues, open many research paths, and have significant policy implications.

First, the new paradigm of accessibility, particularly accessibility by proximity (Pajares et al., 2021), is being progressively incorporated into the political debate, particularly with the 15- and 30-minute city (Levinson, 2019). The idea is to allow people to fulfill their basic needs within a short walk, bike ride, or transit ride from their homes and thus reduce the social, economic, and environmental impacts of transport. Similarly, the triad of avoid-shift-improve aims to reduce undesired vehicle commutes and increase the number of short trips by walking and public transportation (GIZ, 2011). However, applying these concepts faces the challenges of the spatial concentration and specialization of activities and the uneven spatial distribution of social groups. Moreover, avoiding urban trips may also represent reducing social interaction and increasing residential segregation, and cities may potentially lose the characteristics that made them thrive, such as being the space for encounters, creativity, and production (Harvey, 2012). Therefore, although access to a variety of opportunities closer to home is a fundamental aspect of everyday life, having the right to mobility and being able to get anywhere is just as essential to get us closer to the concept of the right to the city (Lefèbvre, 2000). Indeed, the right to the city involves enjoying, creating, and transforming urban and social life, not only our neighborhoods. Mobility and accessibility, therefore, are far from being contradictory or exclusive concepts.

Second, despite the cliché of the need for contextualized and evidence-based policies, exhaustively repeated by some academics and activists, this is often ignored in practice. Local and social priorities may clash against political interests and international guidelines on urban mobility, which often disregard the dissimilar stages in infrastructure development, regulation, and economic resources (Easterling, 2016). Exclusive public transport corridors, the conditions of buses and bus stops, information on transport systems, or the cost of transport in relation to people's income are essential elements of transport systems and quite precarious in low- and middle-income countries (Vasconcellos, 2000). Nonetheless, they may lose space in public investments in the face of new, less contradictory, and more attractive technologies to policymakers and international finance corporations, whose funding is still insufficient to tackle local and global inequalities.

Third, although the availability, reliability, and affordability of transport systems and their impacts on the differential levels of accessibility by social groups and territories have been the focus of several studies (Lucas et al., 2016), there is still little in-depth research on how multiple other aspects, including perceptions of safety, really affect people's mobility. Feminist geographers and sociologists have paid attention to the link between fear of crime and the occupation of public space by lower classes, black people, and women (Whitzman, 2007). However, given the naturalization of violence, little is known about how this profoundly affects the mobility strategies of those social groups, considering their interaction with other individual, social, and spatial aspects. This may be even more important in contexts of greater urban violence but also in places considered relatively safe by some groups and not by others.

Fourth, given the lack of data, especially in low and middle-income countries, there is still room for data crossings and for improving metrics and methods for assessing people's access to opportunities for activities and services and related inequalities. Beyond purely scientific discussions, such innovations can advance the incorporation of different dimensions and scales of public policy, contributing to multi-level governance and the public debate. We hope this work may provide some insights to other researchers, policymakers, and activists who believe in fairer, safer, and more sustainable cities in Brazil.

Publications

Bittencourt, T. A., Giannotti, M. and Marques, E. (2020) 'Cumulative (and self-reinforcing) spatial inequalities: Interactions between accessibility and segregation in four Brazilian metropolises', Environment and Planning B: Urban Analytics and City Science, 48 (7), 1989-2005. https://doi.org/10.1177/2399808320958426

Tainá Bittencourt: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data Curation, Writing – Original Draft

Mariana Giannotti: Conceptualization, Supervision, Writing – Review and Editing

Eduardo Marques: Conceptualization, Writing – Review and Editing

Bittencourt, T. A. and Giannotti, M. (2021) 'The unequal impacts of time, cost and transfer accessibility on cities, classes and races', Cities, 116, 103257. https://doi.org/10.1016/j.cities.2021.103257

Tainá Bittencourt: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data Curation, Writing – Original Draft

Mariana Giannotti: Conceptualization, Supervision, Writing – Review and Editing

Bittencourt, T. A. and Giannotti, M. (2023) 'Evaluating the accessibility and availability of public services to reduce inequalities in everyday mobility', Transportation Research Part A, 177, 103833. https://doi.org/10.1016/j.tra.2023.103833

Tainá Bittencourt: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data Curation, Writing – Original Draft

Mariana Giannotti: Conceptualization, Supervision, Writing – Review and Editing

References

Addas, A. & Alserayhi, G. (2020). Quantitative Evaluation of Public Open Space per Inhabitant in the Kingdom of Saudi Arabia: A Case Study of the City of Jeddah. *Sage Open*, 1-18.

Allam, Z., Moreno, C., Chabaud, D. & Pratlong, F. (2022). Proximity-Based Planning and the "15-Minute City": A Sustainable Model for the City of the Future. In. *The Palgrave Handbook of Global Sustainability*. Palgrave Macmillan.

Allen, J. & Farber, S. (2020). Planning transport for social inclusion: An accessibility-activity participation approach. *Transp. Res. Part D Transp. Environ.*, 78, 102212.

Almeida, S. (2019). *Racismo estrutural*. Coleção Feminismos Plurais. Ed. Sueli Carneiro e Jandaíra.

Anselin, L. (1995). Local Indicators of Spatial Association — LISA. *Geographical Analysis*, 27, 93–115.

Anselin, L. (1996). "The Moran Scatterplot as an ESDA Tool to Assess Local Instability in Spatial Association." In Spatial Analytical Perspectives on GIS in Environmental and Socio-Economic Sciences, edited by Manfred Fischer, Henk Scholten, and David Unwin, 111–25. London: Taylor; Francis.

Anselin. L., Syabri, I. & Kho, Y. (2006). GeoDa: An Introduction to Spatial Data Analysis. *Geographical Analysis*, 38, 5–22.

Araujo, M., Ferreira, F., Lanjouw, P. & Ozler, B. (2008). Local inequality and project choice: Theory and evidence from Ecuador. In. *Journal of Public Economics*, 92, 1022–1046.

Arbaci, S. (2019). *Paradoxes of Segregation: Urban and Migration in Europe*. Wiley Blackwell.

Barboza, M., Alencar, R., Chaves, J., Silva, M., Orrico, R., Evsukoff, A. (2020). Identifying Human Mobility Patterns in the Rio de Janeiro Metropolitan Area using Call Detail Records. *Transportation Research Record – Journal of the Transportation Research Board*, 2675(4).

Barboza, M., Carneiro, M., Falavigna, C., Luz, G. & Orrico, R. (2021). Balancing time: Using a new accessibility measure in Rio de Janeiro. *Journal of Transport Geography*, 90, 102924.

Barra, A. & Nassi, A. (2002). Considering poverty impact of fare policy studies for urban public transport. Urban Mobility for All. *Proceedings of the 10th International CODATU Conference*.

Barros, J. & Feitosa, F. (2018). Uneven geographies: Exploring the sensitivity of spatial indices of residential segregation. *Environment and Planning B: Urban Analytics and City Science,* 45(6), 1073–1089.

Bastiaanssen, J., Johnson, D. & Lucas, K. (2020). Does transport help people to gain employment? A systematic review and meta-analysis of the empirical evidence. *Transport Reviews*, 40, 607–628.

Belkhir, J. & Barnett, B. (2001). Race, Gender and Class Intersectionality. *Race, Gender & Class*, 8(3),157-174.

Berenguer, L. (2014). The Favelas of Rio de Janeiro: A study of socio-spatial segregation and racial discrimination. *Revista Iberoamericana de Estudios de Desarrollo*, 3(1), 104-134.

Bittencourt, T. & Giannotti, M. (2021). The unequal impacts of time, cost and transfer accessibility on cities, classes and races. *Cities*, 116, 103257.

Bittencourt, T. A., Giannotti, M. & Marques, E. (2020). Cumulative (and self-reinforcing) spatial inequalities: Interactions between accessibility and segregation in four Brazilian metropolises. *Environment and Planning B: Urban Analytics and City Science*, 48(7), 1989–2005.

Bocarejo, S. & Oviedo, H. (2012). Transport accessibility and social inequities: a tool for identification of mobility needs and evaluation of transport investments. *Journal of Transport Geography,* 24, 142-154.

Boisjoly, G. & El-Geneidy, A. (2017). The insider: a planners' perspective on accessibility, *Journal of Transport Geography*, 64, 33-43.

Boisjoly, G., Serra, B., Oliveira, G. & El-Geneidy, A. (2020). Accessibility measurements in São Paulo, Rio de Janeiro, Curitiba and Recife, Brazil. *Journal of Transport Geography*, 82(2020), 102551.

Bourdieu, P. (1989). Social Space and Symbolic Power. *Sociological Theory,* 7(1),14–25.

Bourdieu, P. (1991). *Language and symbolic power: The economy of linguistic exchanges*. Polity Press.

Branco, M., Pereira, R. & Nadalin, V. (2013). Rediscutindo a Delimitação das Regiões Metropolitanas no Brasil: Um Exercício a Partir dos Critérios da Década de 1970. *Ipea*, 1860(50).

Bray, J. (2022). *Transport authorities for metropolitan areas: The benefits and options in times of change.* International Association of Public Transport – UITP.

Bullard, R. & Johnson, G. (1997). *Just Transportation: Dismantling Race and Class Barriers to Mobility*. New Society Publishers.

Burns, L. (1979). *Transportation, temporal, and spatial components of accessibility*. Lexington Books.

Caceres, N., Benitez, F. & Romero, L. (2020). Land use inference from mobility mobile phone data and household travel surveys. *Transportation Research Procedia*, 47, 417-424.

Caldeira, T. (2001). *City of walls: crime, segregation, and citizenship in São Paulo.* University of California Press.

Calderón, C. & Servén, L. (2004). The Effects of Infrastructure Development on Growth and Income Distribution. *Central Bank of Chile Working Papers*, 270, 1-48.

Carruthers, R., Dick, M. & Saurkar, A. (2005). Affordability of public transport in developing countries. *The World Bank Group Transport Papers*, 3, 1-27.

Cassiers, T. & Kesteloot, C. (2012). Socio-spatial Inequalities and Social Cohesion in European Cities. *Urban Studies*, 49(9), 1909-1924.

Castells, M. (2019). *A questão urbana.* Editora Paz e Terra/Record.

Cervero, R. (1990). Transit pricing research. *Transportation,* 17(2), 117–139.

Cervero, R. (2005). Accessible Cities and Regions: A Framework for Sustainable Transport and Urbanism in the 21st Century. *UC Berkeley Center for Future Urban Transport Working Paper*, 3, 1-44.

Cervero, R., Rood, T. & Appleyard, B., (1995). Job Accessibility as a Performance Indicator: An Analysis of Trends and Their Social Policy Implications in the San Francisco Bay Area (No. 366). *University of California Transportation Center*.

Cheng, Y. & Chen, S. (2015). Perceived accessibility, mobility, and connectivity of public transportation systems. *Transportation Research Part A: Policy and Practice,* 77, 386-403.

Church, A., Frost, M. & Sullivan, K. (2000). Transport and social exclusion in London. *Transport Policy*, 7, 195-205.

Clark, V., Creswell, J., Green, D. & Shope, R. (2008). Mixing Quantitative and Qualitative Approaches: An Introduction to Emergent Mixed Methods Research. In. *Handbook of Emergent Methods*. The Guilford Press.

Clifton, K. & Handy, S. (2001). Qualitative Methods in Travel Behaviour Research. *International Conference on Transport Survey Quality and Innovation*, 2-20.

Cohen, D., McKenzie, T., Sehgal, A., Williamson, S., Golinelli, D. & Lurie, N. (2007). Contribution of public parks to physical activity. *American Journal of Public Health*, 97, 509-514.

Cöltekin, A., Sabbata, S. & Willi, C. (2011). Modifiable temporal unit problem. In: *Persistent problems in geographic visualization*. ICC2011.

Connelly, R., Gayle, V. & Lambert, P. (2016). A Review of occupation-based social classifications for social survey research. *Methodological Innovations*, 4, 1-14.

CPTM (2019). *Relatório Integrado da Administração*. Companhia Paulista de Trens Metropolitanos.

Crenshaw, K. (1989). Demarginalizing the Intersection of Race and Sex: A Black Feminist Critique of Antidiscrimination Doctrine, Feminist Theory and Antiracist Politics. *University of Chicago Legal Forum*, 1.

Cui, M. & Levinson, D. (2018). Full cost analysis of accessibility. *Journal of Transport and Land Use*, 11(1), 661-679.

CURITIBA (2017). *Pesquisa Origem e Destino na Região Metropolitana de Curitiba.*

Currie, G. & Delbosc, A. (2011). Transport Disadvantage: A Review. In. *New Perspectives and Methods in Transport and Social Exclusion Research*, Emerald Group Publishing Limited, 15-25.

Currie, G. (2010). Quantifying spatial gaps in public transport supply based on social needs. *Journal of Transport Geography,* 18(1), 31–41.

Dadvand, P., Bartoll, X., Basagaña, X., Dalmau-Bueno, A., Martinez, D., Ambros, A., Cirach, M., Triguero-Mas, M., Gascon, M., Borrell, C. & Nieuwenhuijsen, M. J. (2016). Green spaces and General Health: Roles of mental health status, social support, and physical activity. *Environ. Int.,* 91, 161–167.

Davis, A. (1982). *Women, race & class*. Women's Press.

Davis, M. (2017). *Planet of slums*. Verso.

Deák, C. (2015). Acumulação entravada no Brasil e a crise dos anos 80. In. *O processo de urbanização no Brasil*. FUPAM-Edusp, 19-48.

Delbosc, A. (2012). The role of well-being in transport policy. *Transport Policy*, 23, 25-33.

Delmelle, E. & Casas, I. (2012). Evaluating the spatial equity of bus rapid transit-based accessibility patterns in a developing country: The case of Cali, Colombia. *Transport Policy,* 20, 36–46.

Devulsky, A. (2021). *Colorismo*. Coleção Feminismos Plurais. Ed. Sueli Carneiro e Jandaíra.

Dublin (2022). Dublin City Parks Strategy. Available at: https://www.dublincity.ie/residential/parks/strategies-and-policies/parks-strategy

Duranton, G. & Puga, D. (2004). Chapter 48 - Micro-Foundations of Urban Agglomeration Economies. In. *Handbook of Regional and Urban Economics*, 4, 2063-2117.

Easterling, K. (2016). *Extrastatecraft: The Power of infrastructure space*. Verso Books.

Easterly, W. & Servén, L. (2003). *The limits of stabilization: infrastructure, public deficits, and growth in Latin America*. The World Bank Publications.

El-Geneidy, A., Levinson, D., Diab, E., Boisjoly, G., Verbich, D. & Loong, C. (2016). The cost of equity: Assessing transit accessibility and social disparity using total travel cost. *Transportation Research Part A: Policy and Practice,* 91, 302-316.

Epple, D., Figlio, D. & Romano, R. (2000). Competition between Private and Public Schools: Testing Stratification and Pricing Predictions. *Journal of Public Economics*, 88(7-8), 1215-1245.

Erikson, R. & Goldthorpe, J. (1993). *The Constant Flux: A Study of Class Mobility in Industrial Societies.* Oxford University Press.

Erikson, R., Goldthorpe, J. & Portocarero, L. (1979). Intergenerational Class Mobility in Three Western European Societies: England, France and Sweden. *The British Journal of Sociology,* 30(4), 415–441.

Fainstein, S. (2005). Planning Theory and the City. *Journal of Planning Education and Research*, 25, 121-130.

Falavigna, C. & Hernandez, D. (2015). Assessing inequalities on public transport affordability in two latin American cities: Montevideo (Uruguay) and Córdoba (Argentina). *Transport Policy*, 45, 145-155.

Farber, S., Kelly, M., Miller, H. & Neutens, T. (2015). Measuring segregation using patterns of daily travel behavior: A social interaction based model of exposure. *Journal of Transport Geography,* 49, 26–38.

Feitosa, F., Câmara, G., Monteiro, A., Koschitzki, T. & Silva, M. (2005). Global and Local Spatial Indices of Urban Segregation. *International Journal of Geographical Information Science*, 21(3), 299-323.

Fernandes, F. (1976). *A revolução burguesa no Brasil: ensaio de interpretação sociológica.* Zahar Editores.

Firkowski, O. (2012). Por que as Regiões Metropolitanas no Brasil são Regiões mas não são Metropolitanas. *Revista Paranaense de Desenvolvimento*, 122, 19–38.

FNP (2021). *Mapeamento do uso e abertura de dados para a gestão do transporte público coletivo nos municípios brasileiros*. Frente Nacional de Prefeitos - FNP.

França, D. (2016). Inequalities in residential segregation by race and class. In: Marques E *São Paulo in the Twenty-First Century: Spaces, Heterogeneities, Inequalities*. Routledge.

Frank, A. (1966). The Development of Underdevelopment. *Monthly Review*, 18(4), 17-31.

Fransen, K., Neutens, T., Farber, S., Maeyer, P., Deruyter, G. & Witlox, F. (2015). Identifying public transport gaps using time-dependent accessibility levels. *Journal of Transport Geography,* 48, 176–187.

Fredriksson, A. (2017). Location-allocation of public services e Citizen access, transparency and measurement. A method and evidence from Brazil and Sweden. *Socio-Economic Planning Sciences*, 59, 1-12.

Friederich, J. & Langer, H. (2010). *Latin American Green City Index: Assessing the environmental performance of Latin America's major cities*. Economist Intelligence Unit.

Frost, M. & Spence, N. (1995). The rediscovery of accessibility and economic potential: the critical issue of self-potential. *Environment and Planning A*, 27, 1833-1848.

Frúgoli Jr, H. & Rolnik, R. (2001). Reestruturação urbana da metrópole paulistana: a Zona Leste como território de rupturas e permanências. *Cad. Metrópole*, 43–66.

Frugoli Jr, H. (2000). *Centralidade em São Paulo*. Edusp.

Fujita, K. & Maloutas, T. (2012). *Residential Segregation in Comparative Perspective: Making Sense of Contextual Diversity.* Routledge.

Fujita, M., Krugman, P. & Venables, A. (1999). *The Spatial Economy: Cities, Regions, and International Trade*. MIT Press.

Garcia, F. (1997). *Cidade Espetáculo: Política, Planejamento e City Marketing*. Editora Palavra.

Garmany, J. (2011). Situating Fortaleza: Urban space and uneven development in northeastern Brazil. *Cities,* 28(1), 45–52.

Gauvin, L., Tizzoni, M., Piaggesi, S., Young, A., Adler, N., Verhulst, S., Ferres, L. & Cattuto, C. (2020). Gender gaps in urban mobility. *Humanities and Social Sciences Communications*, 7(11).

Geurs, K. & Van-Wee, B. (2004). Accessibility evaluation of land-use and transport strategies: review and research directions. *Journal of Transport Geography,* 12(2), 127–140.

Geurs, K. T., Niemeier, D., & Giannotti, M. (2021). The uneven geography of the accessibility and environmental quality in the global north and south: Introduction to the special issue. *Journal of Transport Geography*, 97, 103216.

Giannotti, M., Barros, J., Tomasiello, D. B., Smith, D., Pizzol, B., Santos, B. M. & Batty, M. (2021). Inequalities in transit accessibility: Contributions from a comparative study between Global South and North metropolitan regions. *Cities*, 109, 103016.

Giannotti, M., Tomasiello, D. & Bittencourt, T. (2022). The bias in estimating accessibility inequalities using gravity-based metrics. *Journal of Transport Geography*, 101, 103337.

GIO (2017). Global Infrastructure Outlook: infrastructure investment needs. *Global Infrastructure Outlook and Oxford Economics Report.*

GIZ (2011). Sustainable Urban Transport: Avoid-Shift-Improve (A-S-I). *Sustainable Urban Transport Project* - German Federal Ministry for Economic Cooperation and Development.

Golub, A., Marcantonio, R. & Sanchez, T. (2013). *Urban Geography*, 34(5), 699–728.

Gonzalez, L. (2020). *Por um feminismo afro-latino-americano: ensaios, intervenções e diálogos.* Zahar.

Grosvenor, T. (1998). Qualitative Research in the Transport Sector. Workshop on qualitative/quantitative methods. *TRB Transportation Research Circular*, E-C008: Transport Surveys: Raising the Standard.

Guimarães, T., Lucas, K. & Timms, P. (2019). Understanding how low-income communities gain access to healthcare services: A qualitative study in São Paulo, Brazil. *Journal of Transport & Health*, 15, 100658.

Guo, Z. & Wilson, N. (2011). Assessing the cost of transfer inconvenience in public transport systems: A case study of the London Underground. *Transportation Research Part A: Policy and Practice*, 45(2), 91-104.

Guzman, L. A. & Oviedo, D. (2018). Accessibility, affordability and equity: Assessing 'pro-poor' public transport subsidies in Bogotá. *Transport Policy*, 68, 37-51.

Guzman, L. A., Oviedo, D., & Rivera, C. (2017). Assessing equity in transport accessibility to work and study: The Bogotá region. *Journal of Transport Geography*, 58, 236-246.

Hall, P. & Taylor, R. (1996). Political Science and the Three New Institutionalisms. *Political studies*, 44 (5).

Hamilton, B. (1982). Wasteful Commuting. *Journal of Political Economy*, 90 (5), 1035-1053.

Handy, S. & Niemeier, D., (1997). Measuring accessibility: an exploration of issues and alternatives. *Environment and Planning A*, 29 (7).

Hansen, W. (1959). How Accessibility Shapes Land Use. *Journal of the American Institute of Planners,* 25(2), 73–76.

Hanson, S. (2010). Gender and mobility: new approaches for informing sustainability. *Gender, Place & Culture*, 17:1, 5-23.

Harris, R. & Owen, D. (2018). Implementing a Multilevel Index of Dissimilarity in R with a case study of the changing scales of residential ethnic segregation in England and Wales. *Environment and Planning B: Urban Analytics and City Science,* 45(6), 1003–1021.

Harvey, D. (1988). *Social justice and the city*. Basil Blackwell Scientific Publications.

Harvey, D. (1992). Social Justice, Postmodernism and the City. *International Journal of Urban and Regional Research*, 16(4), 588-601.

Harvey, D. (2001). *Spaces of capital: Towards a critical geography*. Routledge.

Harvey, D. (2009). *Social justice and the city*. University of Georgia Press.

Harvey, D. (2012). *Rebel cities: from the right to the city to the urban revolution.* Verso

Harvey., D. (2009). *Social justice and the city*. University of Georgia Press.

Hellerstein, J., Neumark, D. & McInerney, M. (2008). Spatial mismatch or racial mismatch? *Journal of Urban Economics,* 64(2), 464–479.

Helling, A. (1998). Changing intra-metropolitan accessibility in the U.S.: Evidence from Atlanta. *Progress in Planning*, 49 (2).

Hernandez, D. (2018). Uneven mobilities, uneven opportunities: Social distribution of public transport accessibility to jobs and education in Montevideo. *Journal of Transport Geography,* 67, 119–125.

Hino, A. A. F., Rech, C. R., Gonçalves, P. B. & Reis, R.S., (2019). Acessibilidade a espaços públicos de lazer e atividade física em adultos de Curitiba, Paraná, Brasil. *Cad. Saude Publica,* 35, e00020719.

Hirata, H., Laborie, F., Le Doaré, H. & Senotier, D. (2000). *Dictionnaire critique du féminisme.* Presses universitaires de France.

Hirata, H. (2004). *Dictionnaire critique du féminisme*. Presses universitaires de France.

Hirata, H. (2007a). A Precarização e a Divisão Internacional e Sexual do Trabalho. *Sociologias*, 11 (21), 24-41.

Hirata, H. (2007b). Gênero, classe e raça: Interseccionalidade e consubstancialidade das relações sociais. *Tempo Social*, 26 (1), 61-73.

Holbrook, A. (2009). *The green we need: an investigation of the benefits of green life and green spaces for urban dwellers' physical, mental and social health.* University of Newcastle.

Horner, M. & Mascarenhas, A. (2007). Analyzing Location-Based Accessibility to Dental Services: An Ohio Case Study. *Journal of Public Health Dentistry*, 67 (2), 113-118.

Horner, M. & O'Kelly, M. (2007). Is non-work travel excessive? *Journal of Transport Geography*, 15(6), 411-416.

Horner, M. (2008). 'Optimal' Accessibility Landscapes? Development of a New Methodology for Simulating and Assessing Jobs-Housing Relationships in Urban Regions. Journal Article. *Urban Studies*, 45 (8), 1583–1602.

Horner, M. (2010). How Does Ignoring Worker Class Affect Measuring the Jobs–Housing Balance? Exploratory Spatial Data Analysis. *Transportation Research Record*, 2163 (1), 57–64.

Humberto, M., Moura, F. & Giannotti, M. (2021) Can outdoor activities and inquiry sessions change the travel behavior of children and their caregivers? Empirical research in public preschools in São Paulo (Brazil). *Journal of Transport Geography*, 90, 102922.

Humberto, M., Pizzol, B., Moura, F., Giannotti, M. & Lucca-Silveira, M. (2020). Investigating the Mobility Capabilities and Functionings in Accessing Schools Through Walking: A Quantitative Assessment of Public and Private Schools in São Paulo (Brazil). *Journal of Human Development and Capabilities,* 21(2).

IBGE (2010). *Censo demográfico - 2010*. Rio de Janeiro: Instituto Brasileiro de Geografia e Estatística.

IBGE (2018). *Demographic census - 2010*. Instituto Brasileiro de Geografia e Estatística.

IBGE (2019). *Pesquisa de Orçamentos Familiares*. Instituto Brasileiro de Geografia e Estatística.

IBGE (2023). *Pesquisa Nacional por Amostra de Domicílios Contínua – PNAD Constínua*. Instituto Brasileiro de Geografia e Estatística.

INEP (2019). *Censo escolar da educação básica*. Instituto Nacional de Ensino e Pesquisas Educacionais Anísio Teixeira. Brasil.

Ingram, G. (2014). Defining Metropolitan and Megapolitan Areas. *Lincoln Institute of Land Policy Report.*

Jin, J. & Paulsen, K. (2018). Does accessibility matter? Understanding the effect of job accessibility on labour market outcomes. *Urban Studies,* 55(1), 91–115.

Jirón, P. & Carrasco, J. (2019). Understanding Daily Mobility Strategies through Ethnographic, Time Use, and Social Network Lenses. *Sustainability*, 12(312), 1-16.

Jirón, P., Carrasco, J. & Rebolledo, M. (2021). Observing gendered interdependent mobility barriers using an ethnographic and time use approach. *Transportation Research Part A: Policy and Practice*, 140, 204-214.

Kabish, N., Strohbach, M., Haase, D. & Kronenberg, J. (2016). Urban green space availability in European cities. *Ecological Indicators*, 70, 586-596.

Karabarbounis, L. (2011). "One Dollar, One Vote". *Economic Journal*. 121, 621–651.

Karner, A. & Niemeier, D. (2013). Civil rights guidance and equity analysis methods for regional transportation plans: a critical review of literature and practice. *Journal of Transport Geography*, 33, 126–134.

Karner, A., Rowangould, D & London, J. (2016). *We Can Get There from Here: New perspectives on Transportation Equity.* A White Paper from the National Center for Sustainable Transportation.

Korsu, E. & Néchet, F. (2017). Would fewer people drive to work in a city without excess commuting? Explorations in the Paris metropolitan area. *Transportation Research Part A*, 95, 259–274.

Kosec, K. (2010). Preschool and Politics: The Political Economy of Investment in Pre-Primary Education. *World Bank Policy Research Working Paper*, 5647.

Kowarick, L. (1980). *A espoliação urbana*. Paz e Terra.

Krahmann, E. (2003). National, regional and global governance: One phenomenon or many?. *Global Governance*, 9.

Krupka, D. (2007). Are big cities more segregated? Neighbourhood scale and the measurement of segregation. *Urban Studies,* 44(1), 187–197.

Lau, J. (2011). Spatial mismatch and the affordability of public transport for the poor in Singapore's new towns. *Cities*, 28(3), 230-237.

Lefebvre, H. (1973). *Le droit à la ville*. Anthropos.

Lefebvre, H. (2000). *Espace et politique: Le droit à la ville II*. Anthropos.

Levinson, D. (2019). The 30-Minute City: Designing for Access. *Network Design Lab*.

Levitas, R., Pantazis, C., Fahmy, E., Gordon, D., Lloyd, E. & Patsios, D. (2007). *The multidimensional analysis of social exclusion*. Department of Sociology and School for Social Policy, Townsend Centre for the International Study of Poverty and Bristol Institute for Public Affairs. University of Bristol.

Lieber, M. (2008). *Genre, violences et espaces publics. La vulnérabilité des femmes en question.* Les Presses de Sciences Po.

Litman T (2020). Transportation Affordability: Evaluation and Improvement Strategies. Vctoria: Victoria Transport Policy Institute.

Litman, T. (2019). Understanding Transport Demands and Elasticities. How Prices and Other Factors Affect Travel Behavior. *Victoria Transport Policy Institute*.

Liu, D. & Kwan, M. (2020). Measuring spatial mismatch and job access inequity based on transit-based job accessibility for poor job seekers. *Travel Behaviour and Society*, 19, 184-193.

Logan, J. (2013). The Persistence of Segregation in the 21st Century Metropolis. *City and Community,* 12(2), 160-168.

Logan, J., Zhang, W. & Chunyu, M. (2015). Emergent Ghettos: Black Neighborhoods in New York and Chicago, 1880–1940. *American Journal of Sociology*, 120(4), 1055-1094.

Lojkine, J. (1997). *O Estado capitalista e a questão urbana.* Martins Fontes.

Lovelace, R. & Ballas, D. (2013). 'Truncate, replicate, sample': A method for creating integer weights for spatial microsimulation. *Computers, Environment and Urban Systems*, 41, 1-11.

Lovelace, R. & Dumont, M. (2017). *Spatial microsimulation with R*. CRC Press.

Lucas, K. (2004). *Running on Empty: Transport, Social Exclusion, and Environmental Justice.* The Policy Press.

Lucas, K. (2012). Transport and social exclusion: Where are we now?. *Transport Policy*, 20, 105-113.

Lucas, K. (2013). Qualitative methods in transport research: the 'action research' approach. In. *Transport Survey Methods: Best practice for decision making*. Emerald Publishing.

Lucas, K., (2012). Transport and social exclusion: Where are we now? *Transport Policy*. 20, 105–113.

Lucas, K., Bates, J., Moore, J. & Carrasco, J. (2016). Modelling the relationship between travel behaviours and social disadvantage. *Transportation Research Part A*, 85, 157-173.

Lucas, K., Wee, B. V., & Maat, K. (2015). A method to evaluate equitable accessibility: Combining ethical theories and accessibility-based approaches. *Transportation*, 43(3), 473-490.

Luo, W. & Wang, F. (2003). Measures of spatial accessibility to health care in a GIS environment: synthesis and a case study in the Chicago region. *Environment and Planning B: Planning and Design*, 30, 865–884.

Luo, W. & Whippo, T., (2012). Variable catchment sizes for the two-step floating catchment area (2SFCA) method. *Health Place,* 18, 789–795.

Luz, H. & Portugal, L. (2022). Understanding transport-related social exclusion through the lens of capabilities approach. *Transport Reviews*, 42(4), 503-525.

Ma, K. & Banister, D. (2006). Excess commuting: a critical review. *Transport reviews: a Transnational Transdisciplinary Journal,* 26 (6), 749-767.

Mackie, P., Jara-Díaz, S. & Fowkes, A. (2001). The value of travel time savings in evaluation. *Transportation Research Part E: Logistics and Transportation Review,* 37(2-3), 91-106.

Madariaga, I. & Zucchini, E. (2020). Movilidad del cuidado en Madrid: nuevos criterios para las políticas de transporte. *Ciudad y territorio: Estudios territoriales*, LII(203), 89-102.

Madariaga, I. (2013). The mobility of care: Introducing new concepts in urban transportation. In. *Fair shared cities, the impact of gender planning in Europe*. Ashgate, Aldershot.

Maloutas, T. (2008). Residential Segregation in Context. In. *Residential Segregation in Comparative Perspective*. Ashgate.

Manaugh, K., Badami, M. & El-Geneidy, A. (2015). Integrating social equity into urban transportation planning: A critical evaluation of equity objectives and measures in transportation plans in North America. *Transport Policy*, 37, 167-176.

MapBiomas (2019). *Map Biomas Project - Collection 4.0 of Brazil's Annual Coverage and Land Use Map Series*.

Marcuse, P. (2009). Spatial Justice: Derivative but Causal of Social Injustice. *Justice Spatiale*, 1 Septembre, 1-6.

Maricato, E. (1996). *Metrópole na periferia do capitalismo: ilegalidade, desigualdade e violência*. Hucitec.

Maricato, E. (2017). The Future of Global Peripheral Cities. *Latin American Perspectives*, 44(2), 18-37.

Marini, R. (2000). *Dialetica da dependência*. Vozes.

Marini, R. M. (1973). Dialética da dependência. Revista Latinoamericana de Ciências Sociales, 5.

Markevych, I., Schoierer, J., Hartig, T., Chudnovsky, A., Hystad, P., Dzhambov, A.M., de Vries, S., Triguero-Mas, M., Brauer, M., Nieuwenhuijsen, M.J., Lupp, G., Richardson, E.A., Astell-Burt, T., Dimitrova, D., Feng, X., Sadeh, M., Standl, M., Heinrich, J. & Fuertes, E., (2017). Exploring pathways linking greenspace to health: Theoretical and methodological guidance. *Environ. Res*., 158, 301–317.

Marques, E. (2000). *Estado e redes sociais: permeabilidade e coesão nas políticas urbanas no Rio de Janeiro*. Revan/Fapesp.

Marques, E. & Bichir, R. (2001). Investimentos públicos, infra-estrutura urbana e produção da periferia em São Paulo. *Espaço & Debates*, São Paulo, 20(42).

Marques, E. & Faria, C. (2013). *A política pública como campo multidisciplinar*. Editora Unesp/Editora FioCruz.

Marques, E. (1997). Notas críticas à literatura sobre Estado, políticas estatais e atores políticos. *Revista Brasileira de Informação Bibliográfica em Ciências Sociais*, v. 43, n. 1, p. 67–102.

Marques, E. (2016). De volta aos capitais para melhor entender as políticas urbanas. *Novos Estudos CEBRAP*, 35(2), 14-33.

Marques, E. (2016). *São Paulo in the Twenty-First Century: Spaces, Heterogeneities, Inequalities.* Routledge.

Marques, E. (2017). *Opportunities and Deprivation in the Urban South: Poverty, Segregation and Social Networks in São Paulo*. Routledge.

Marques, E. (2019). Housing and urban conditions in Brazil. In. *Paths of Inequality in Brazil: A Half-Century of Changes*. Springer International Publishing, 163–182.

Marquetti, D., Oliveira, R. & Figueira, A. (2019). Are global north smart city models capable to assess Latin American cities? A model and indicators for a new context. *Cities*, 92, 197-207.

Marsden, G. & Rye, T. (2010). The governance of transport and climate change. *Journal of Transport Geography*, 18, 669-678.

Martens, K. (2006). Basing transport planning on principles of social justice. *Berkeley Planning Journal*, 13(1), 1-17.

Martens, K. (2012). Justice in transport as justice in accessibility: Applying Walzer's 'Spheres of Justice' to the transport sector. *Transportation*, 39(6), 1035-1053.

Martens, K. (2017). *Transport justice: designing fair transportation systems*. Routledge.

Martinez, C., Hodgson, F., Mullen, C & Timms, P. (2018). Creating inequality in accessibility: The relationships between public transport and social housing policy in deprived areas of Santiago de Chile. *Journal of Transport Geography*, 67, 102-109.

Maryanti, M., Khadijah, H., Uzair, M. & Ghazali, M. (2016). The urban green space provision using the standards approach: issues and challenges of its implementation in Malaysia. *WIT Transactions on Ecology and The Environment*, 210.

Massey, D. & Denton, N. (1993). *American apartheid: segregation and the making of the underclass*. Harvard University Press.

Massey, D. S., & Tannen, J. (2017). Suburbanization and segregation in the United States: 1970–2010. *Ethnic and Racial Studies*, 41(9), 1594-1611.

Matas, A. (2007). Demand and Revenue Implications of an Integrated Public Transport Policy: the case of Madrid. *Transport Reviews*, 24(2), 195-217.

Matas, A., Raymond, J. & Roig, J. (2010). Job Accessibility and Female Employment Probability: The Cases of Barcelona and Madrid. *Urban Studies,* 47(4), 769–787.

Mayntz, R. (2003). New challenges to governance theory. In. *Governance as Social and Political Communication*. Manchester University Press.

McCracken, D., Allen, D. & Gow, A. (2016). Associations between urban greenspace and health-related quality of life in children. *Preventive Medicine Reports,* 3, 211-221.

Mennis, J. (2003). Generating surface models of population using dasymetric mapping. *The Professional Geographer*, 55(1):31-42

METRO-SP (2017). *Pesquisa Origem e Destino*. Companhia do Metropolitano de São Paulo.

METRO-SP (2019). *Relatório Integrado da Administração*. Companhia do Metropolitano de São Paulo.

Moovit (2019) *Global Public Transport Report*. Moovit Inc.

Moreno-Monroy, A., Lovelace, R. & Ramos, F. (2018). Public transport and school location impacts on educational inequalities: Insights from São Paulo. *Journal of Transport Geography*, 67, 110-118.

Motiram, S. & Nugent, J. (2007). Economic and political inequality and the quality of public goods. *International Journal of Development Issues*, 6(2).

MTA (2019). *MTA Operating Budget Report*. Metropolitan Transit Authority.

Murray, A. T., & Davis, R. (2001). Equity in regional service provision. *Journal of Regional Science*, 41, 577–600.

Nassir, N., Hickman, M., Malekzadeh, A. & Irannezhad, E. (2016). A utility-based travel impedance measure for public transit network accessibility. *Transp. Res. Part A Policy Pract.,* 88, 26–39.

Neutens, T., Schwanen, T., Witlox, F. & Maeyer, P. (2010). Equity of urban service delivery: A comparison of different accessibility measures. *Environ. Plan. A*, 42, 1613–1635.

Nieuwenhuis, J., Tammaru, T., Van Ham, M., Hedman, L. & Manley, D. (2019). Does segregation reduce socio-spatial mobility? Evidence from four European countries with different inequality and segregation contexts. *Urban Studies,* 57(1), 176-197.

NYMTC (2008). *Regional Household Travel Survey*. New York Metropolitan Transportation Council.

OECD (2021) *Education at a Glance 2021: OECD Indicators*.

Ong, P. & Houston, D. (2002). Transit, Employment and Women on Welfare. *Urban Geography,* 23(4), 344–364.

ONS (2011). *Census*. Office for National Statistics.

ONS (2018). *Living Cost and Food Survey*. Office for National Statistics.

ONS (2020). *Standard Occupational Classification (SOC).* Office for National Statistics.

Ortuzar, J. & Willumsen, L. (2011). Modelling transport. John Wiley & Sons.

Paez, A., Higgins, C. & Vivona, S. (2019). Demand and Level of Service Inflation in Floating Catchment Area (FCA) *Methods. Plos One,* 14 (6). e0218773.

Paez, A., Scott, D. & Morency, C. (2012). Measuring accessibility: positive and normative implementations of various accessibility indicators. *Journal of Transport Geography*, 25, 141-153.

Pajares, E., Buttner, B., Jehle, U., Nichols, A. & Wulfhorst, G. (2021). Accessibility by proximity: Addressing the lack of interactive accessibility instruments for active mobility. *Journal of Transport Geography*, 93, 103080.

Palmateer, C. & Levinson, D. (2017). *Justice, Exclusion, and Equity: An Analysis of 48 U.S. Metropolitan Areas*. University of Sydney.

Paulley, N., Balcombe, R., Mackett, R., Titheridge, H., Preston, J, Wardman, M., Shires, J. & White, P. (2006). The demand for public transport: The effects of fares, quality of service, income and car ownership. *Transport Policy*, 13, 295-306.

Peach, C. (1999). London and New York: contrasts in British and American models of segregation with a comment by Nathan Glazer. *International Journal of Population Geography,* 5(5), 319-347.

Peng, Z., Bai, G., Wu, H., Liu, L. & Yu, Y. (2021). Travel mode recognition of urban residents using mobile phone data and MapAPI. *Environment and Planning B: Urban Analytics and City Science*, 48(9).

Pereira, R. (2018). Transport legacy of mega-events and the redistribution of accessibility to urban destinations. *Cities*, 81, 45-60.

Pereira, R. (2019). Future accessibility impacts of transport policy scenarios: Equity and sensitivity to travel time thresholds for Bus Rapid Transit expansion in Rio de Janeiro. *Journal of Transport Geography,* 74, 321–332.

Pereira, R. H., Schwanen, T., & Banister, D. (2016). Distributive justice and equity in transportation. *Transport Reviews*, 37(2), 170-191.

Pereira, R. H., Schwanen, T., Banister, D. & Wessel, N. (2019). Distributional effects of transport policies on inequalities in access to opportunities in Rio de Janeiro. *The Journal of Transport and Land Use*, 12(1), 741-764.

Pereira, R., Banister, D. & Schwanen, T. (2018). Distributional Effects of Transport Policies on Inequalities in Access to Opportunities in Rio De Janeiro. *SSRN*, 1–39.

Pereira, R., Braga, C., Serra, B. & Nadalin, V. (2019). Desigualdades socioespaciais de acesso a oportunidades nas cidades brasileiras. *Ipea*, 2535.

Pereira, R., Braga, K., Servo, L., Serra, B., Amaral, P., Gouveia, N. & Paez, A. (2021). Geographic access to COVID-19 healthcare in Brazil using a balanced float catchment area approach. *Social Science and Medicine*, 273, 113773.

Pereira, R., Saraiva, M., Herszenhut, D., Braga, C. & Conway, M. (2021). r5r: Rapid Realistic Routing on Multimodal Transport Networks with R5 in R. *Findings*, March.

Perez, G. (2019). *Políticas de movilidad y consideraciones de género en América Latina*. CEPAL.

Perrotta, A. (2016). Transit Fare Affordability: Findings From a Qualitative Study. *Public Works Management & Policy*, 22(3), 226-252.

Petruccelli, J. & Saboia, A. (2013). *Características Étnico-Raciais Da População: Classificações e Identidades*. IBGE.

Pinçon, M. & Pinçon-Charlot, M. (1989). *Dans les beaux quartiers*. Seuil.

Pizzol, B., Giannotti, M. & Tomasiello, D. (2021). Qualifying accessibility to education to investigate spatial equity. *Journal of Transport Geography*, 96, 103199.

Pollitt, C. & Bouckaert, G. (2011). *Public Management Reform: A Comparative Analysis*. Oxford University Press.

Pons, I., Monteiro, J. & Speicys, R. (2015). Big Data para análise de métricas de qualidade de transporte: metodologia e aplicação. *Cadernos Técnicos ANTP*, 20, 1-94.

Poulantzas, N. (1980). *O Estado, o poder, o socialismo.* Graal.

Préteceille, E. & Cardoso, A. (2008). Río de Janeiro y São Paulo: cidades duales? Comparación con París. *Ciudad y Territorio - Estudios Territoriales,* 158(XLI), 3–26.

Préteceille, E. (2000). Segregation, class and politics in large cities. In. *Cities in Contemporary Europe*. Cambridge University Press.

Pritchard, J. P., Tomasiello, D., Giannotti, M., & Geurs, K. (2019). An International Comparison of Equity in Accessibility to Jobs: London, São Paulo, and the Randstad. *Findings*, February.

Ramos, É M., Bergstad, C. J., & Nässén, J. (2020). Understanding daily car use: Driving habits, motives, attitudes, and norms across trip purposes. *Transportation Research Part F: Traffic Psychology and Behaviour*, 68, 306-315.

Reardon, S. F., & O'Sullivan, D. (2004). Measures of spatial segregation. Sociological Methodology, 34(1), 121–162.

Ribeiro, L. & Santos, O. (2003). Democracia e segregação urbana: reflexões sobre a relação entre cidade e cidadania na sociedade brasileira. *Eure,* 29(88), 79–95.

Rodrigue, J. (2020). *The Geography of Transport Systems*. Routledge.

Rodrigues, F., Freiberg, G., Cruz, M., Martins, W., Vanzella, R. & Jacobsen, A. (2013). *Modelos de gestão para a integração metropolitana do Sistema de TPC.* Estudo de bases técnicas – Secretaria Nacional de Mobilidade Urbana, Ministério das Cidades.

Rolnik, R. (2019). *Urban Warfare: Housing under the Empire of Finance*. Verso Press USA.

Rolnik, R., (2017). *Territórios em conflito. São Paulo: espaço, história e política.* Três estrelas.

Rosenbloom, S. (2006). Understanding Women's and Men's Travel Patterns: The Research Challenge. *Conference on Research on Women's Issues in Transportation*.

Sader, E. (2013). *Quando novos personagens entraram em cena: experiências, falas e lutas dos trabalhadores da Grande São Paulo, 1970-80.* Paz e Terra.

Sanchez, F. (2003). *A reinvenção das cidades para um mercado mundial*. Argos.

Sanchez, T. & Brenman, M. (2017). *The right to transportation: moving to equity*. Routledge.

Sanchez, T. (2002). The impact of Public Transport on US Metropolitan Wage Inequality. *Urban Studies,* 39(3), 423–436.

Sanchez, T.W., (1999). The Connection Between Public Transit and Employment. *J. Am. Plan. Assoc*., 65, 284–296.

Santos, M. (1979). *The Shared space: the two circuits of the urban economy in underdeveloped countries*. Methuen Publishing.

Santos, M. (2008). *Espaço e método*. EDUSP.

Santos, T. (1970). The Structure of Dependence. *The American Economic Review*, 60(2), 231-236.

Sarkar, S. (2019). Urban scaling and the geographic concentration of inequalities by city size. *Environment and Planning B: Urban Analytics and City Science,* 46(9), 1627–1644.

Sassen, S. (2004). *Global networks, linked cities*. Routledge.

Scalon, M. (2013). Social stratification and its transformation in Brazil. In. *Handbook on social stratification in the BRIC countries: Change and perspective*. World scientific.

Schwanen, T., Lucas, K., Akyelken, N., Solsona, D., Carrasco, J. & Neutens, T. (2015). Rethinking the links between social exclusion and transport disadvantage through the lens of social capital. *Transportation Research Part A: Policy and Practice,* 74, 123–135.

Seth, S. & Santos, M. E. (2020). Multidimensional Inequality and Human Development. In. *The Cambridge Handbook of the Capability Approach*, 392 – 416.

Seyferth, G. (2002). Colonização, Imigração e a Questão Racial No Brasil. *Revista USP,* 53.

Shehu, H. (2018). Factors Influencing Primary School Non-attendance among Children in Northwest Nigeria. *Literacy Information and Computer Education Journal,* 9 (2), 2916-2922.

Sheller, M. (2018). *Mobility justice: the politics of movement in an age of anxiety*. Verso Books.

Shen, Q. (1998). Location characteristics of inner-city neighborhoods and employment accessibility of low-wage workers. *Environ. Plan. B Plan. Des.,* 25, 345–365.

Shoman, W., Alganci, U. & Demirel, H. (2018). A comparative analysis of gridding systems for point-based land cover/use analysis. *Geocarto International*, 34(8), 867-886.

Silva, C. & Anders, L. (2019). Is there such a thing as good enough accessibility?. *Transportation Research Procedia*, 41 (2019) 694–707.

Skocpol, T. (1985*). Bringing the State Back In: Strategies of Analysis in Current Research.* Cambridge University Press.

Slovic, A., Tomasiello, D., Giannotti, M., Andrade, M. & Nardocci, A. (2019). The long road to achieving equity: Job accessibility restrictions and overlapping inequalities in the city of São Paulo. *Journal of Transport Geography,* 78, 181-193.

Soukhov, A., Páez, A., Higgins, C. & Mohamed, M. (2023). Introducing spatial availability, a singly-constrained measure of competitive accessibility. *PLoS ONE*, 18(1), e0278468.

Southworth, F. (1978). A Highly Disaggregated Modal-Split Model—Some Tests. *Environ. Plan. A Econ. Sp.,* 10, 795–812.

SPTRANS (2019). *Relatório Integrado da Administração*. São Paulo Transporte S/A.

Susilo, Y. & Dijst, M. (2010). Behavioural decisions of travel-time ratios for work, maintenance and leisure activities in the Netherlands. *Transp. Plan. Technol*., 33, 19–34.

Tammaru, T., Strömgren, M., van Ham, M. & Danzer, A. (2016). Relations between residential and workplace segregation among newly arrived immigrant men and women. *Cities,* 59, 131–138.

Taylor, B., Miller, D., Iseki, H. & Fink, C. (2009). Nature and/or nurture? Analyzing the determinants of transit ridership across US urbanized areas. *Transportation Research Part A: Policy and Practice,* 43(1), 60-77.

Telles, E. (1992). Residential Segregation by Skin Color in Brazil. *American Sociological Review*, 57(2), 186-197.

Telles, E. (2004). Residential segregation. In. *Race in Another America: The Significance of Skin Color in Brazil*. Princeton University Press, 194–214.

TFL (2019). *How we are funded.* Transport for London.

TFL (2019). *Travel in London.* Report 12. Transport for London.

Theil, H. (1972). Statistical Decomposition Analysis: with applications in the social and administrative. North-Holland, Amsterdam.

Tilly, C. (1998). Durable inequalities. UCLA Press.

Tomasiello, D. & Giannotti, M. (2022). Unfolding time, race and class inequalities to access leisure. *Environment and Planning B: Urban Analytics and City Science*, 0(0).

Tomasiello, D., Bazzo, J., Parga, J., Servo, L. & Pereira, R. (2023). Desigualdades raciais e de renda no acesso à saúde nas cidades brasileiras. *Texto para discussão - Instituto de Pesquisa Econômica Aplicada*, 2832.

Torres, H. D., & Bichir, R. M. (2009). Residential Segregation in Sao Paulo: Consequences for Urban Policies. *Urban Segregation and Governance in the Americas*, 145-165.

UNESCO (2019). *Qualidade da infraestrutura das escolas públicas do ensino fundamental no Brasil*. Organização das Nações Unidas para a Educação, a Ciência e a Cultura no Brasil - Universidade Federal de Minas Gerais (UFMG) e Ministério da Educação.

USBLS (2018). *Consumer Expenditure Survey*. United States Bureau of Labor Statistics.

USCB (2018). *Integrated Public Use Microdata Series from the United States Census Bureau.* University of Minnesota.

Vale, D. (2020). Effective accessibility: Using effective speed to measure accessibility by cost. *Transportation Research Part D: Transport and Environment*, 80, 102263.

Van Eck, J. & Jong, T. (1999). Accessibility analysis and spatial competition effects in the context of GIS-supported service location planning. *Computers, Environment and Urban Systems,* 23, 75-89.

Van Wee, B., Hagoort, M. & Annema, J. (2001). Accessibility measures with competition. *Journal of Transport Geography*, 9, 199-208.

Vance, C. & Rich, I. (2007). Gender and the Automobile: Analysis of Nonwork Service Trips. *Journal of the Transportation Research Board*, 2013, 54–61.

Vasconcellos, E. (2000). *Transporte urbano nos países em desenvolvimento: reflexões e propostas*. Annablume.

Veeneman, W. & Mulley, C. (2018). Multi-level governance in public transport: Governmental layering and its influence on public transport service solutions. *Research in Transportation Economics*, 69, 430-437.

Vetter, D. & Massena, R. (1981). Quem se apropria dos benefícios líquidos dos investimentos do Estado em infra-estrutura? Uma teoria de causação circular. In. *Solo Urbano*. Zahar, 49-77.

Villaça, F. (1998). *O Espaço Intra-Urbano No Brasil*. Studio Nobel.

Vuchic, V. (1984). The auto versus transit controversy: toward a rational synthesis for urban transportation policy. *Transportation and Research Part A*, 18 (2), 125-133.

Wachs, M. & Kumagai, G. (1973). Physical accessibility as a social indicator. *Socio-economic planning sciences,* 7 (5), 437-456.

Walker, J. (2011). *Human Transit How Clearer Thinking About Public Transit Can Enrich Our Communities and Our Lives.* Island Press.

Wang, F. & Tang, Q. (2013). Planning Toward Equal Accessibility to Services: A Quadratic Programming Approach. E*nvironment and Planning B: Planning and Design*, 40 (2), 195–212.

Wardman, M. (2001). A review of British evidence on time and service quality valuations. *Transportation Research Part E: Logistics and Transportation Review*, 37(2-3), 107-128.

Welch, T. & Mishra, S., (2013). A measure of equity for public transit connectivity. *J. Transp. Geogr.,* 33, 29–41.

White, M. (1988). Urban commuting journeys are not wasteful. *Journal of Political Economy*, 96 (5), 1097-1110.

Whitzman, C. (2007). Stuck at the front door: gender, fear of crime and the challenge of creating safer space. *Environment and Planning A*, 39, 2715-2732.

WHO (2023). *The global health observatory*. Available at https://www.who.int/data/gho/data/indicators

WID - World Inequality Database (2022). Retrieved from https://wid.world/

Wixey, S., Jones, P., Lucas, K. & Aldridge, M. (2005). User needs literature review. Measuring accessibility as experienced by different socially disadvantaged groups. *Transport Studies Group*, University of Westminster - UK.

Wu, H. & Levinson, D. (2019). *Access Across Australia*. The University of Sydney.

Wu, H., & Levinson, D. (2020). Unifying access. *Transportation Research Part D: Transport and Environment*, 83, 102355.

Yang, F., Yao, Z., Ding, F., Tan, H & Ran, B. (2019). Understanding Urban Mobility Pattern with Cellular Phone Data: A Case Study of Residents and Travelers in Nanjing. *Sustainability*, 11(19), 5502.

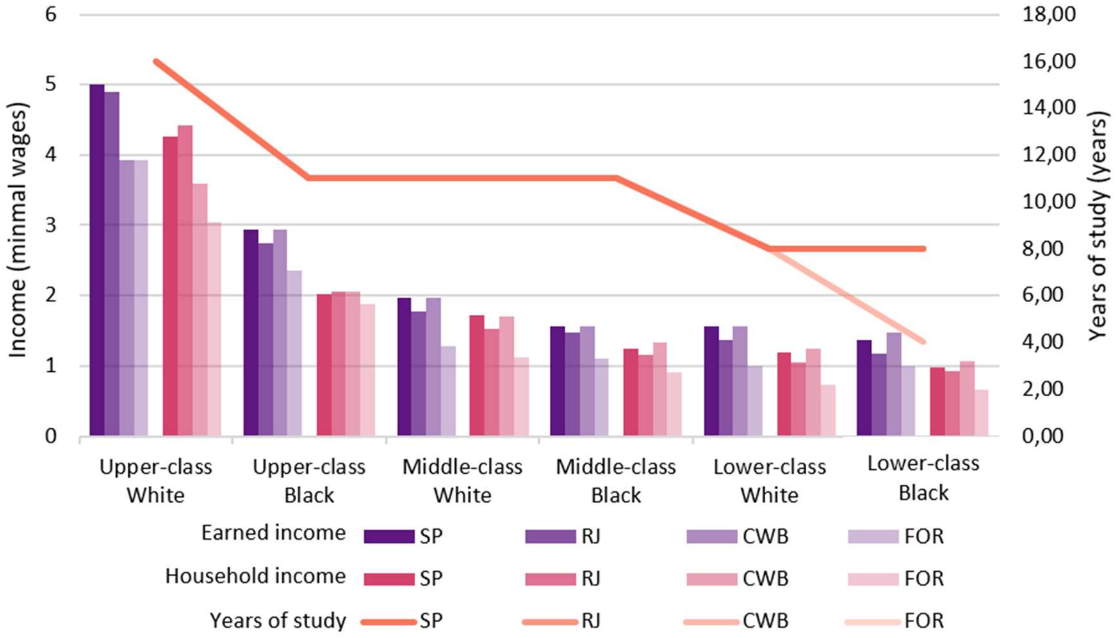
Young, I. (2001). Equality of Whom? Social Groups and Judgments of Injustice. *The Journal of Political Philosophy,* 9(1), 1–18.

Young, I. (2017). Equality of Whom? Social Groups and Judgments of Injustice. *Theories of Justice*, 185-202.

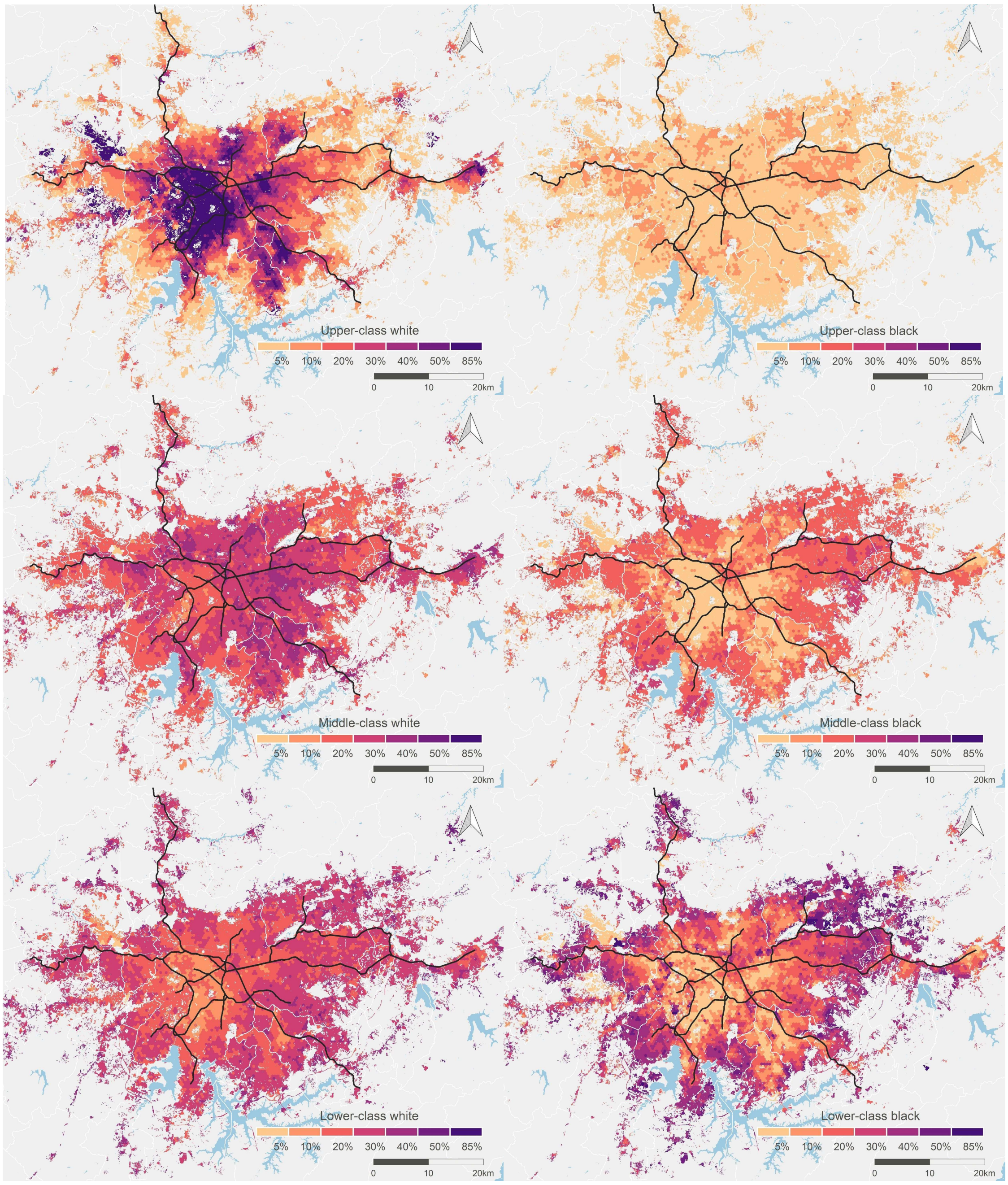
Zhang, X., Lu, H. & Holt, J. (2011). Modeling spatial accessibility to parks: A national study. *Int. J. Health Geogr.*, 10, 1–14.

A Appendix – Supplementary material of chapter 1: Cumulative (and self-reinforcing) spatial inequalities: interactions between accessibility and segregation in four Brazilian metropolises

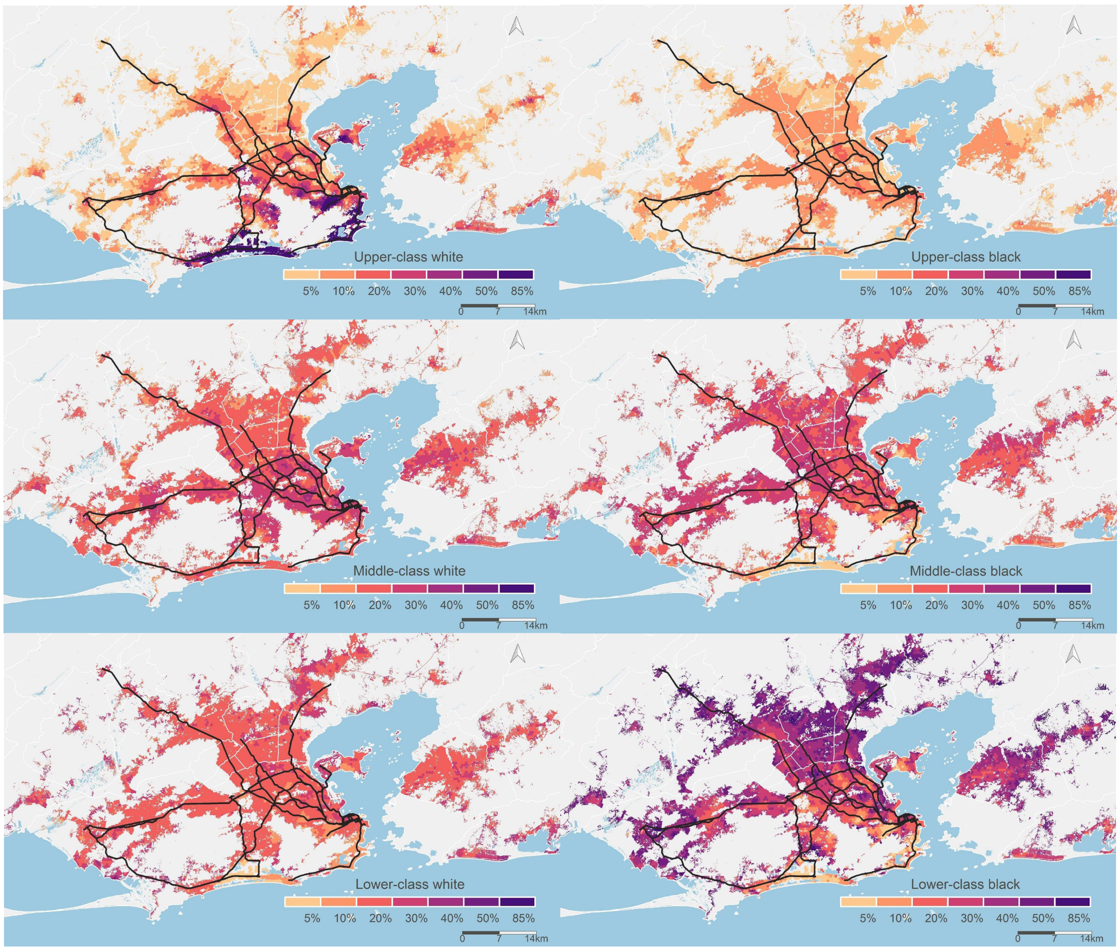
Appendix A-1: Median values of earned income, average household income per capita (in minimal wages of R$510 or $120) and approximate years of study in São Paulo, Rio de Janeiro, Curitiba and Fortaleza, by class and race.



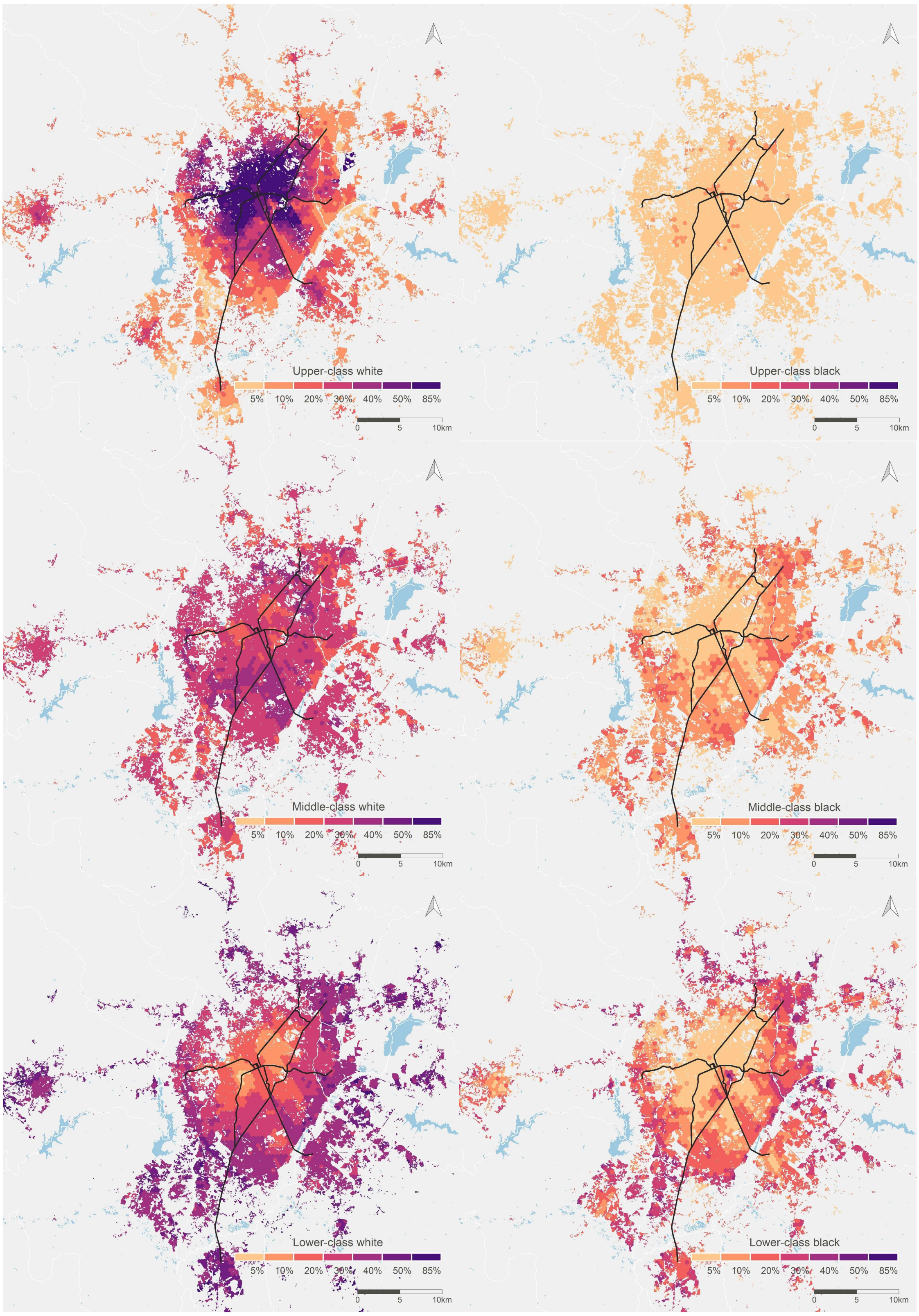
Appendix A-2: Spatial distribution of workers by class and race in São Paulo.



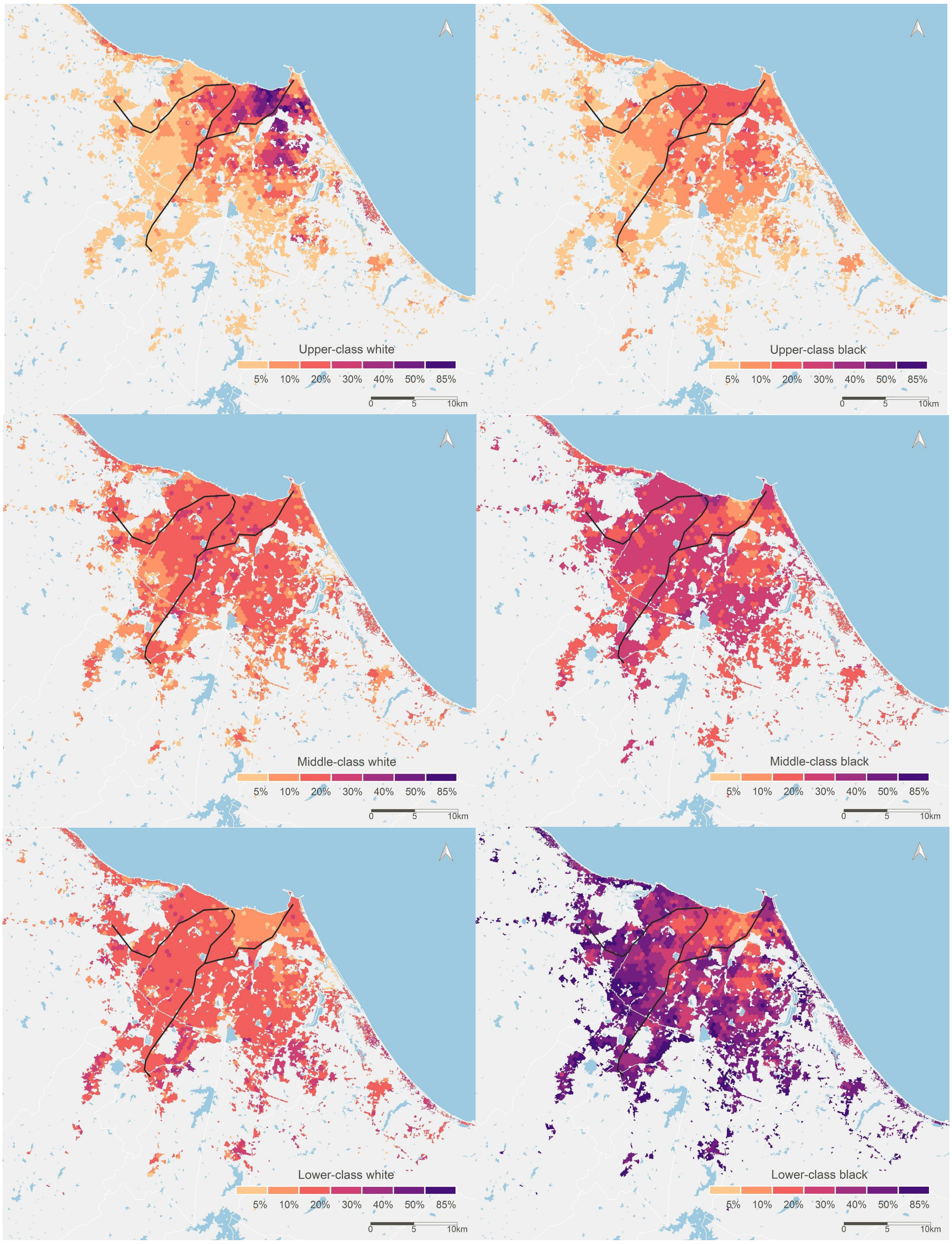
Appendix A-3: Spatial distribution of workers by class and race in Rio de Janeiro.



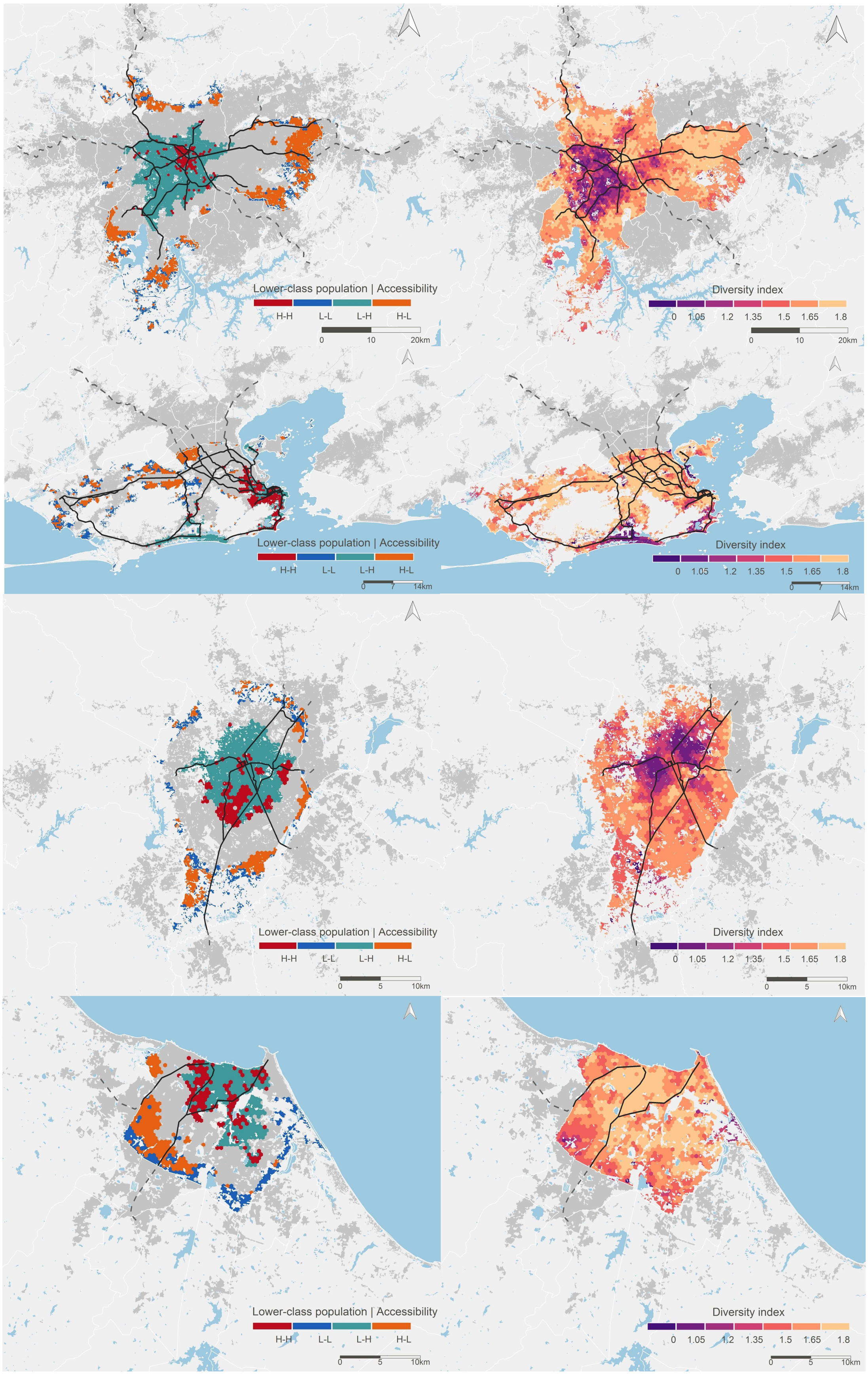
Appendix A-4: Spatial distribution of workers by class and race in Curitiba.



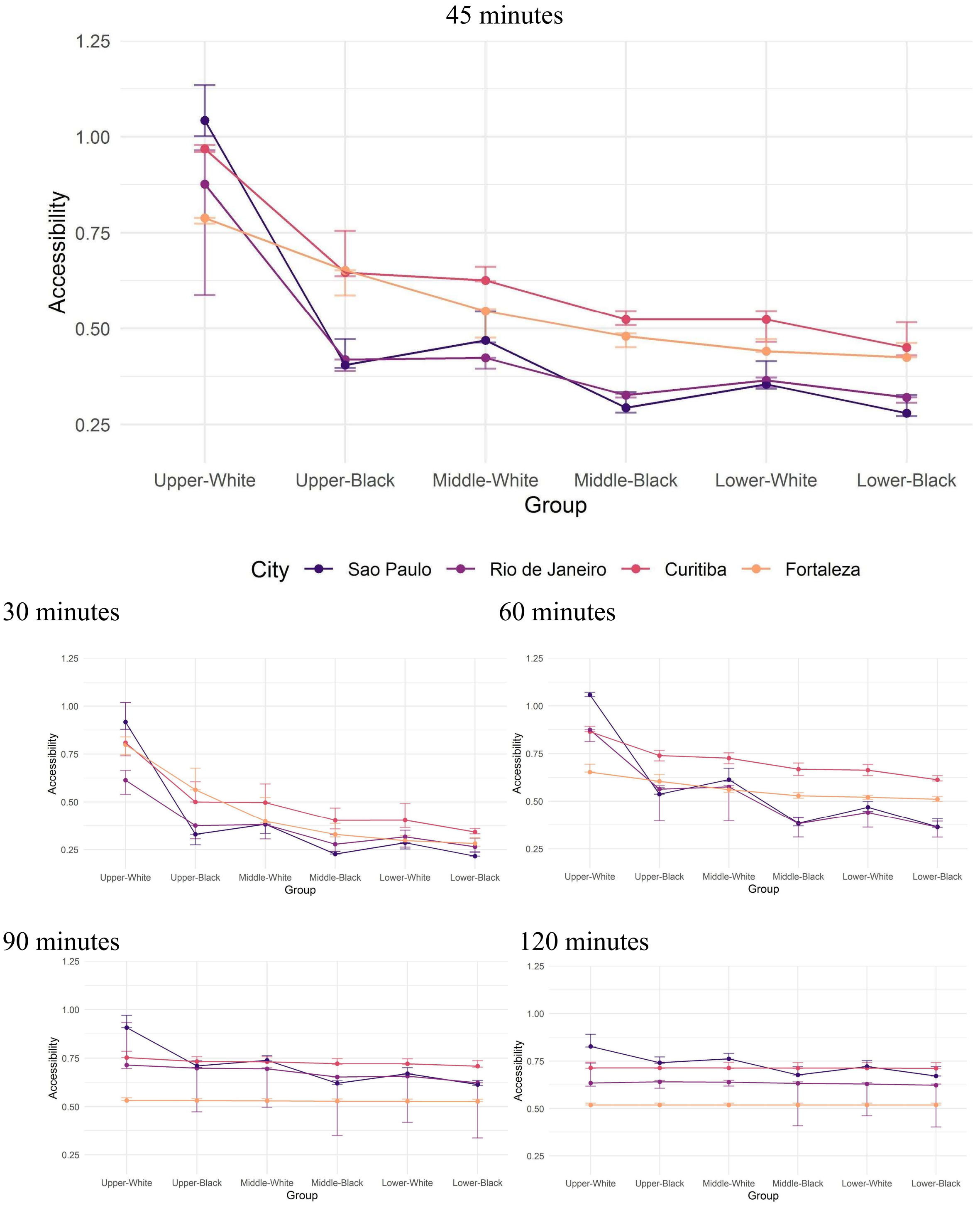
Appendix A-5: Spatial distribution of workers by class and race in Fortaleza.



Appendix A-6:Bivariate map of job accessibility and low-class population and spatial diversity of social groups in São Paulo, Rio de Janeiro, Curitiba and Fortaleza.



Appendix A-7:Median accessibility by social and racial group in São Paulo, Rio de Janeiro, Curitiba and Fortaleza.

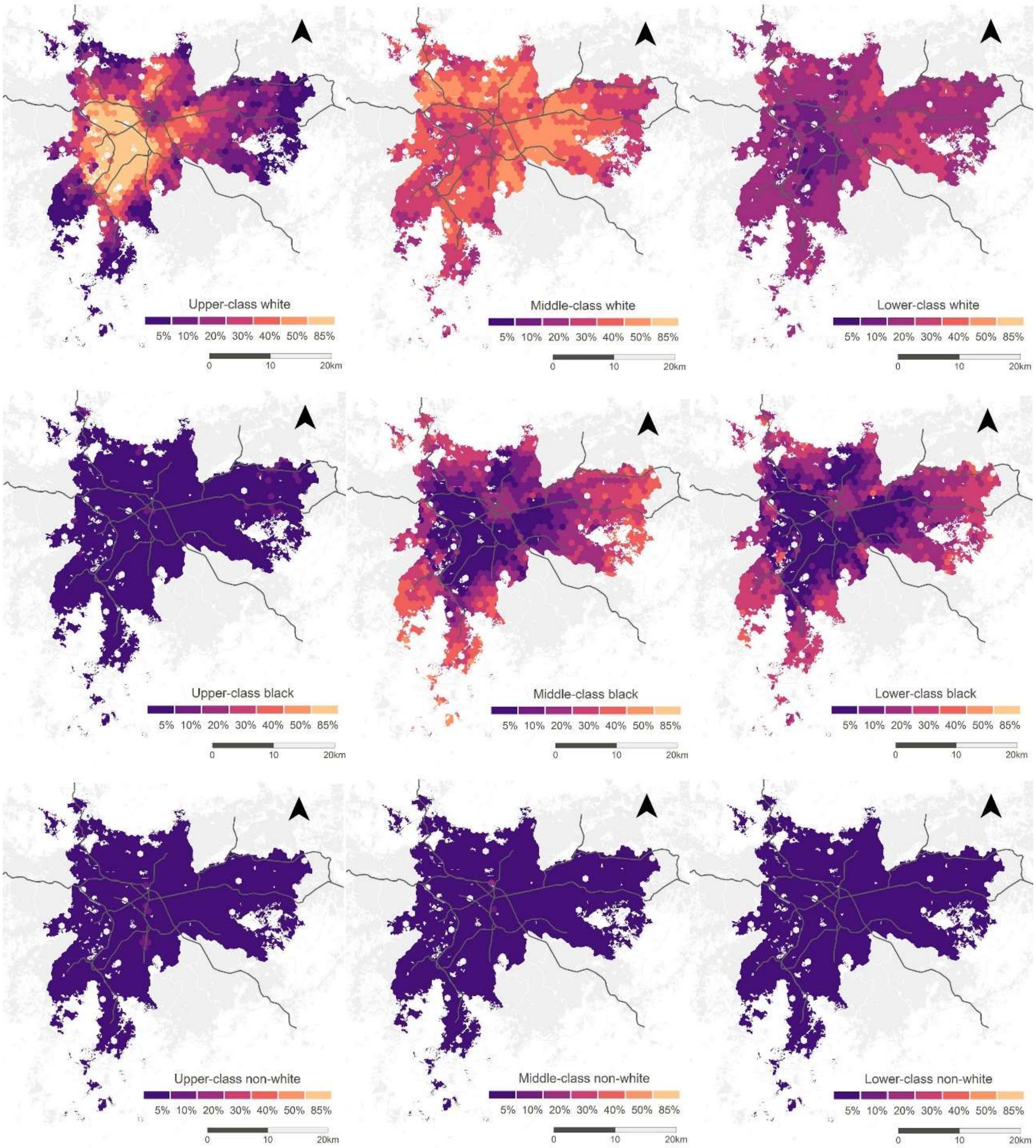


B Appendix – Supplementary material of chapter 2: The unequal impacts of time, cost and transfer accessibility on cities, classes and races

Appendix B-1: Social composition of Sao Paulo, New York City and London

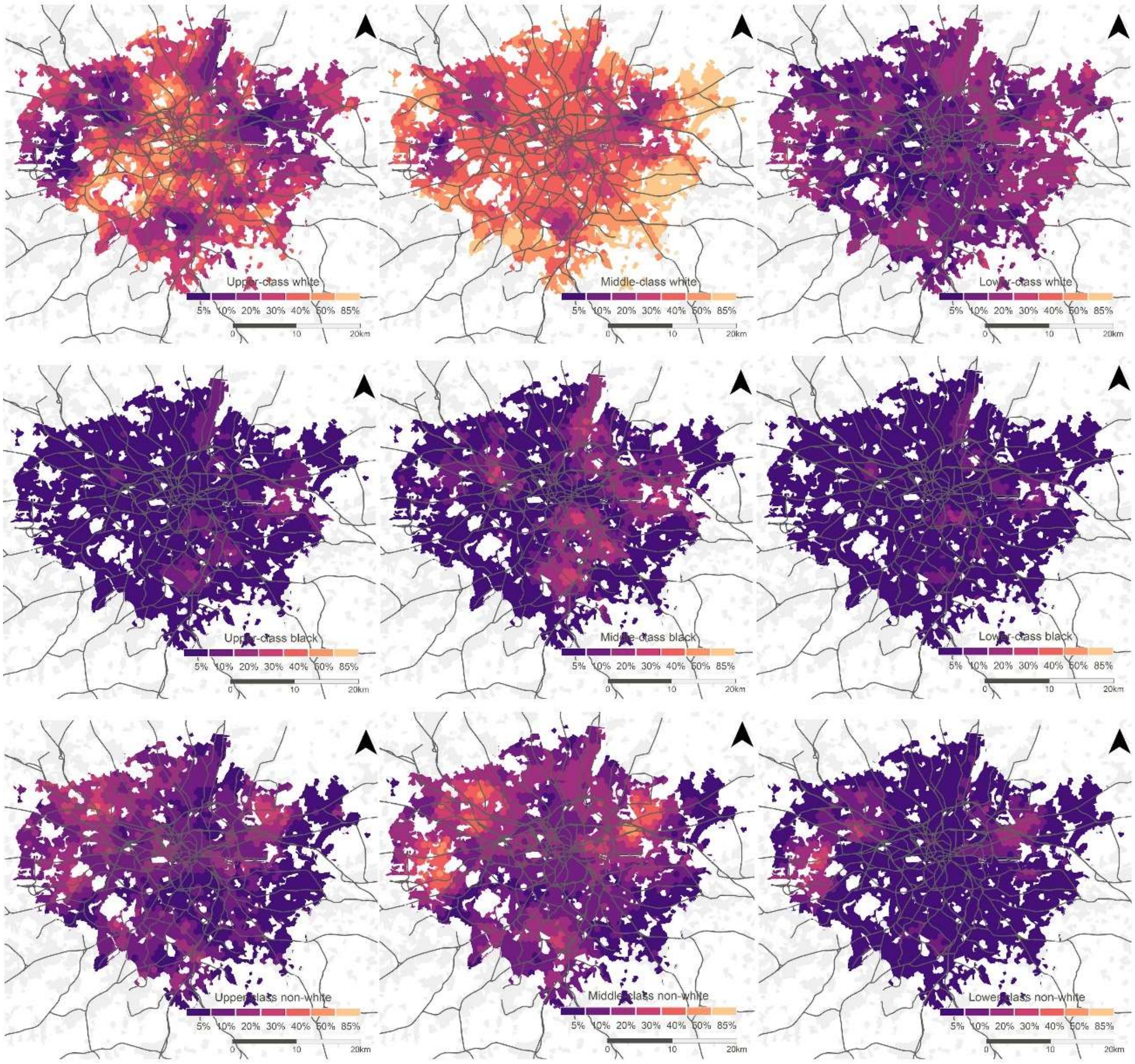
	São Paulo	New York City	London
Population	12.2 million	8.4 million	9 million
Area (km)	1,521 km²	784 km²	1,569 km²
White upper-class	19.4%	14.8%	23.5%
Black upper-class	2.5%	3.5%	2.8%
Non-white/Non-black upper-class	0.3%	4.2%	7.8%
White middle-class	30.9%	28.7%	33.9%
Black middle-class	17.4%	14.3%	6.0%
Non-white/Non-black middle class	0.2%	12.9%	11.7%
White lower-class	15.7%	8.2%	8.5%
Black lower-class	13.6%	6.4%	2.1%
Non-white/Non-black lower class	0.0%	7.0%	3.7%

Appendix B-2: Spatial distribution of urban workers in Sao Paulo, by class and race.

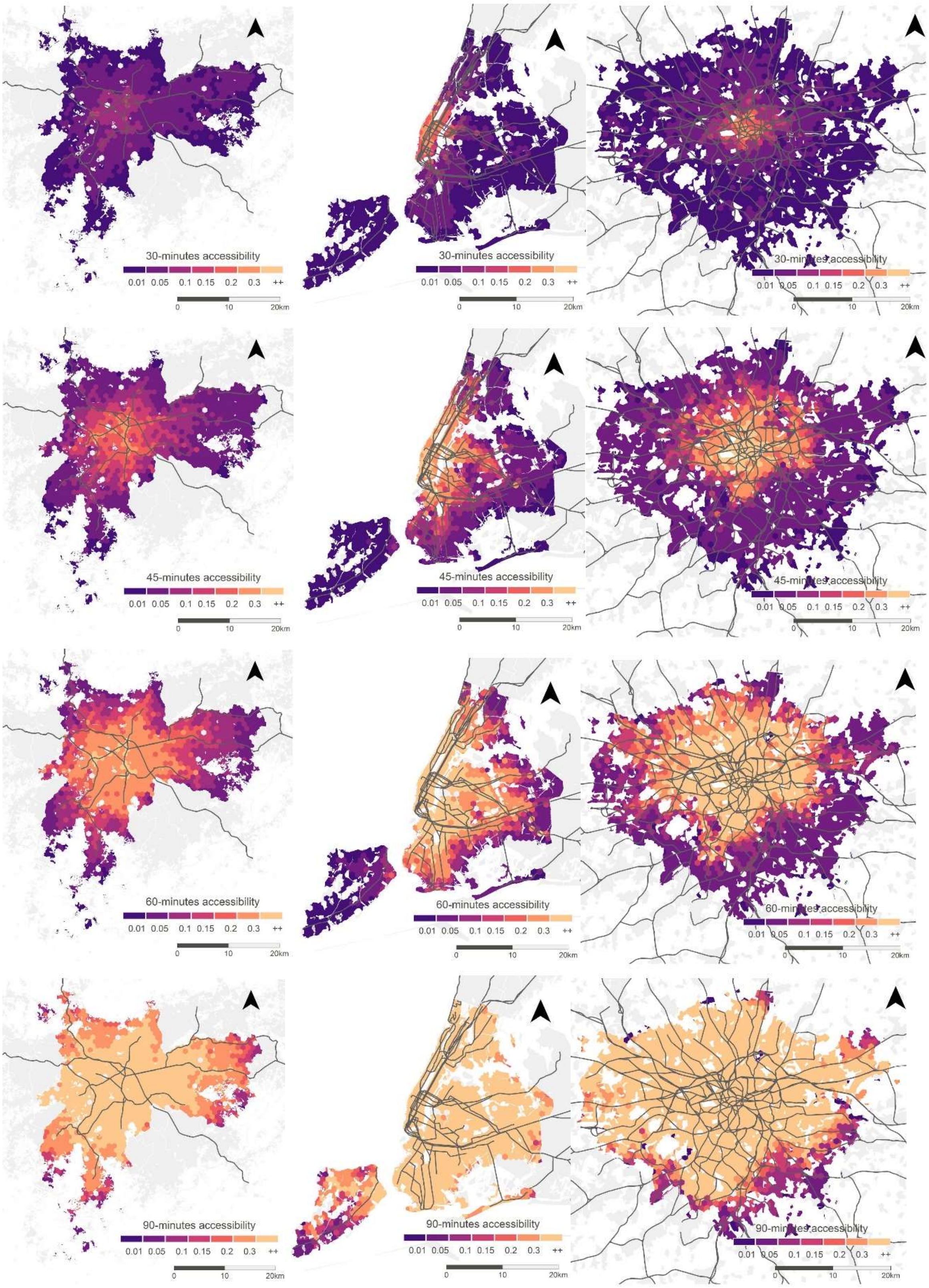


*Appendix B-3:*Spatial distribution of urban workers in New York City, by class and race.

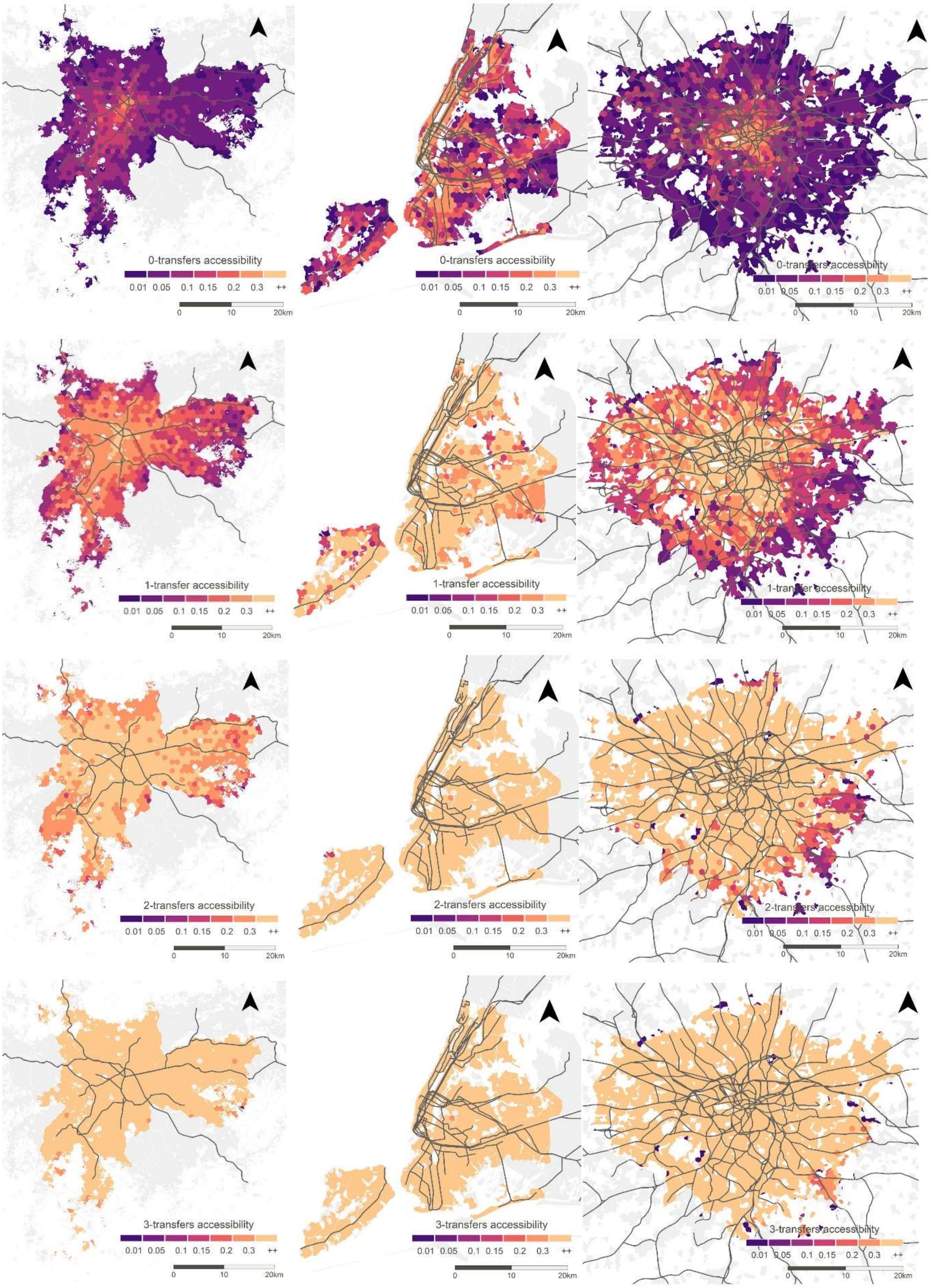
*Appendix B-4:*Spatial distribution of urban workers in London, by class and race.



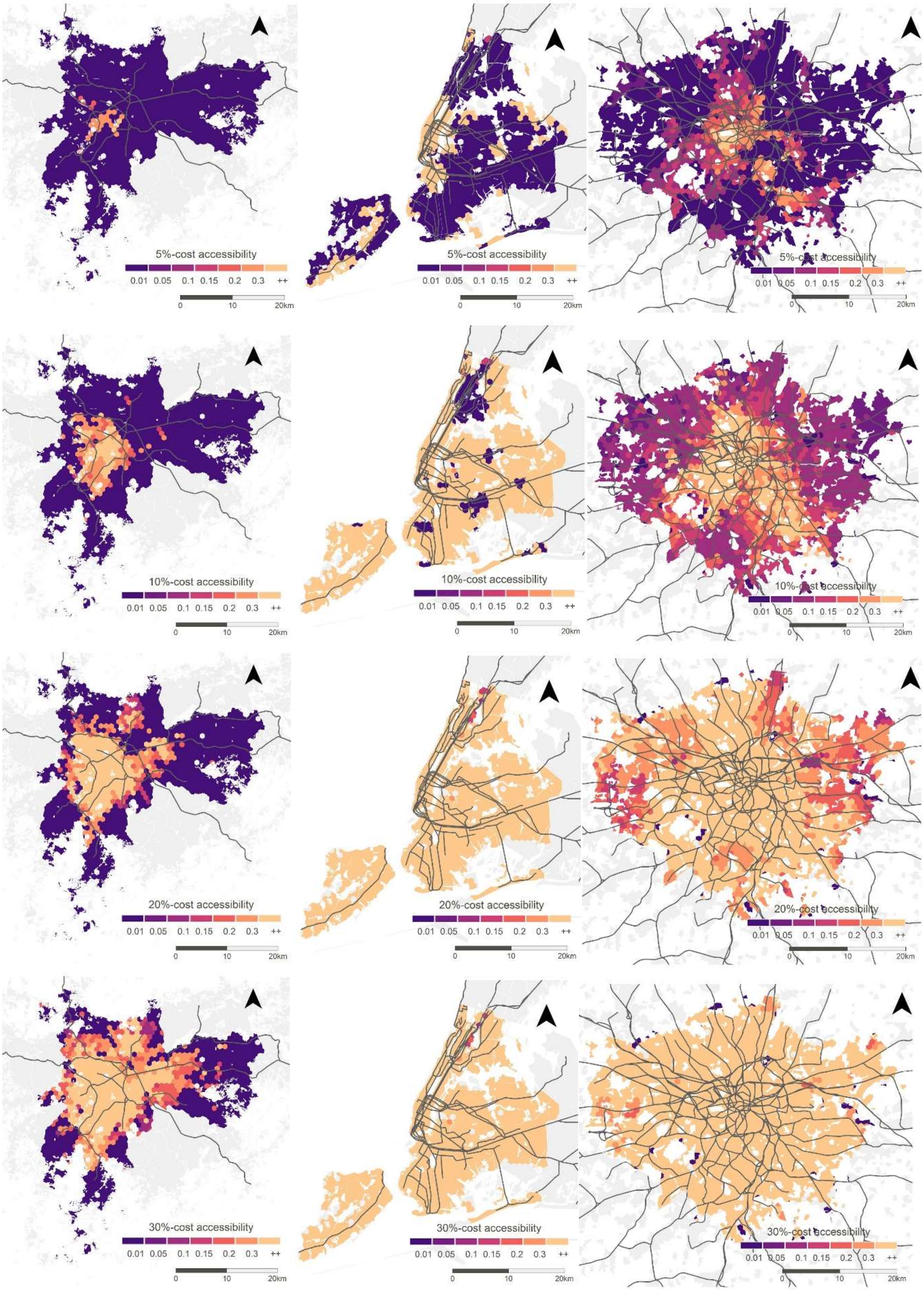
Appendix B-5: Time accessibility in São Paulo, New York City and London



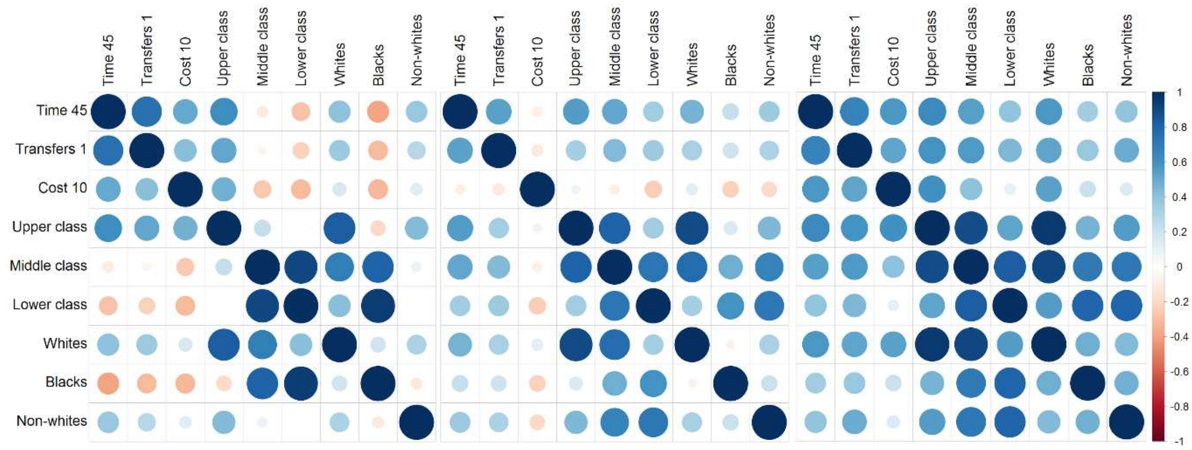
*Appendix B-6:*Transfer accessibility in São Paulo, New York City and London



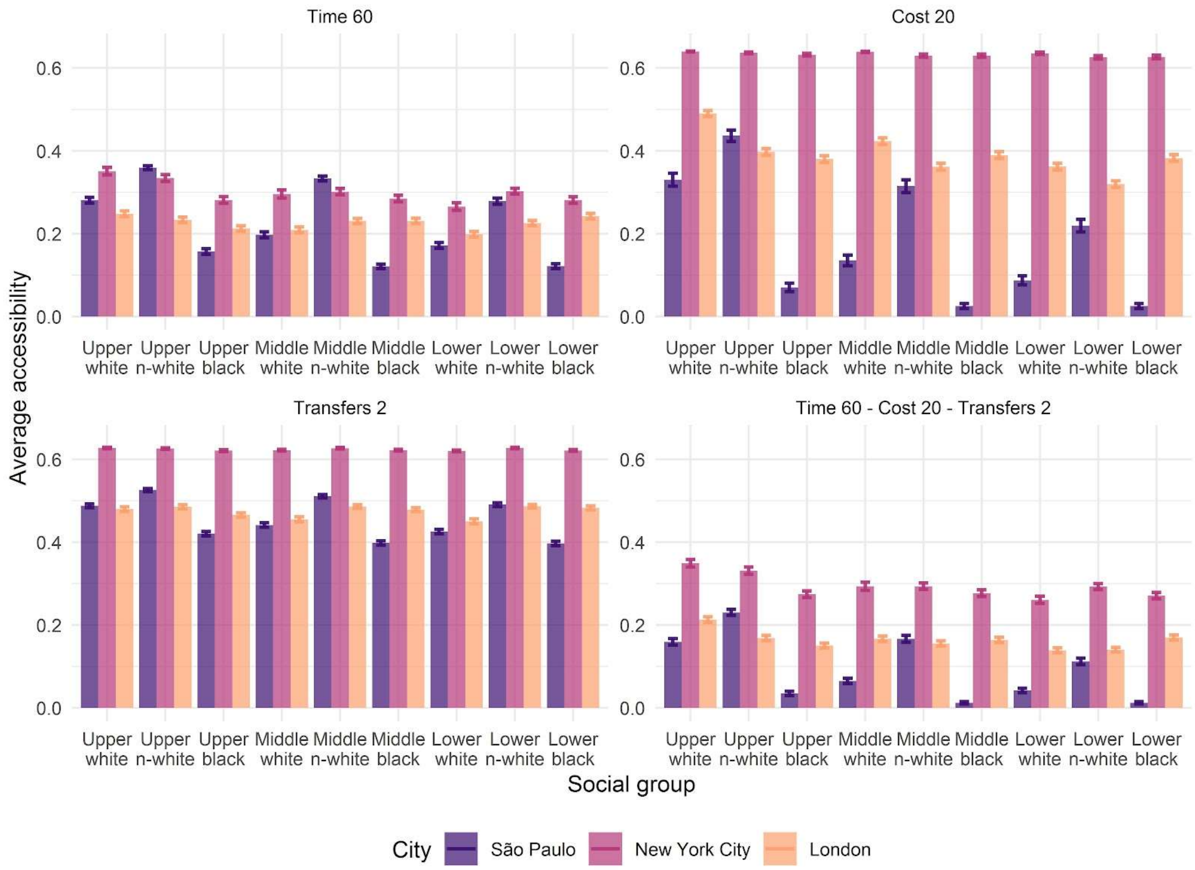
*Appendix B-7:*Cost accessibility in São Paulo, New York City and London



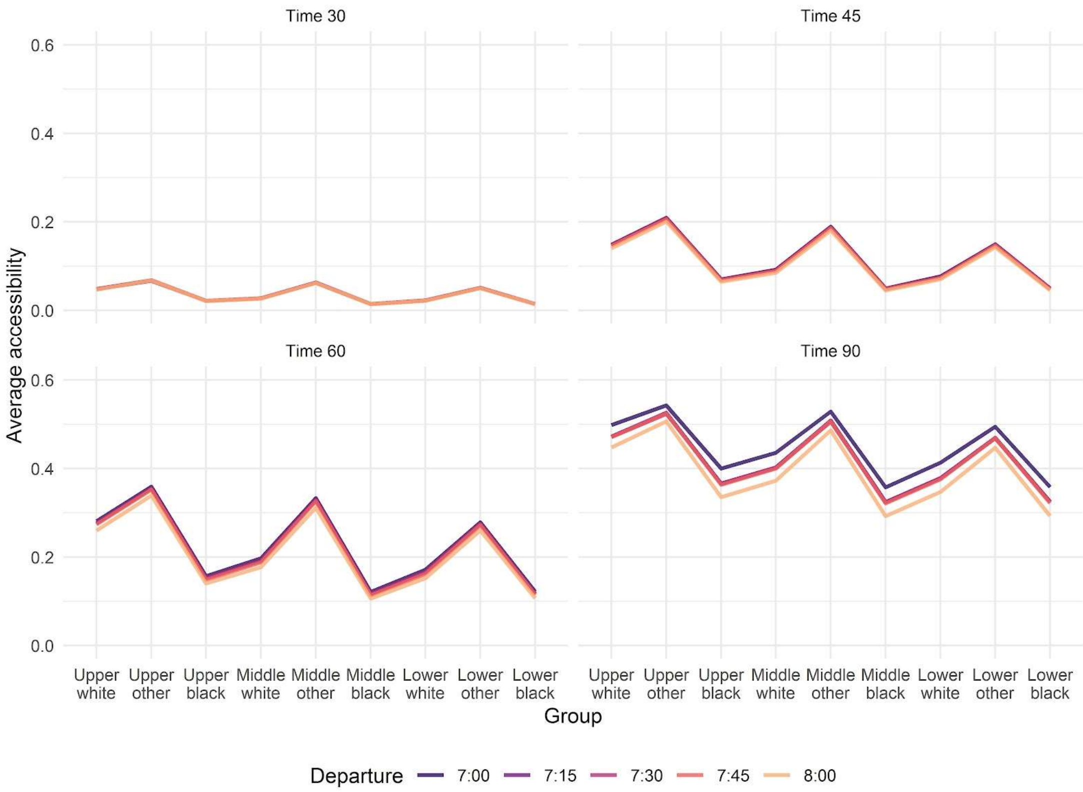
*Appendix B-8:*Correlation between time, transfer and cost accessibility and class and race in Sao Paulo (left), New York City (center) and London (right)



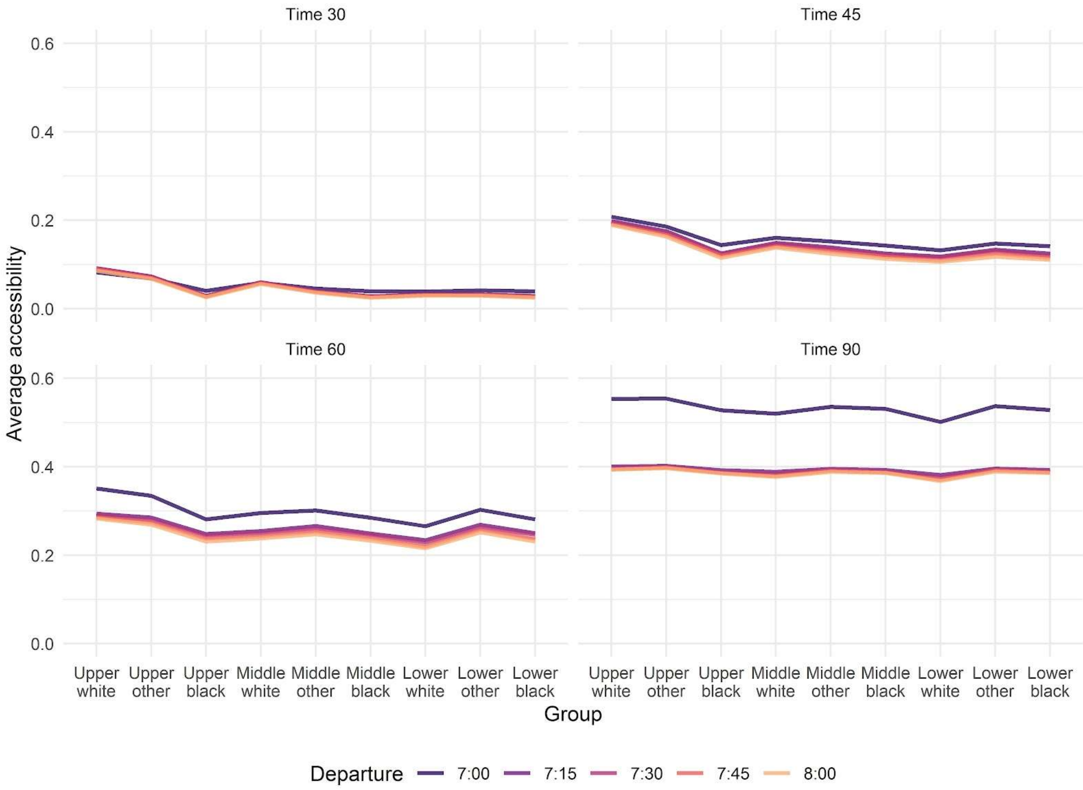
*Appendix B-9:*Average accessibility by class and race (whites, non-whites/non-blacks and blacks), considering dimensions of time, transfer and relative cost in São Paulo, New York City and London.



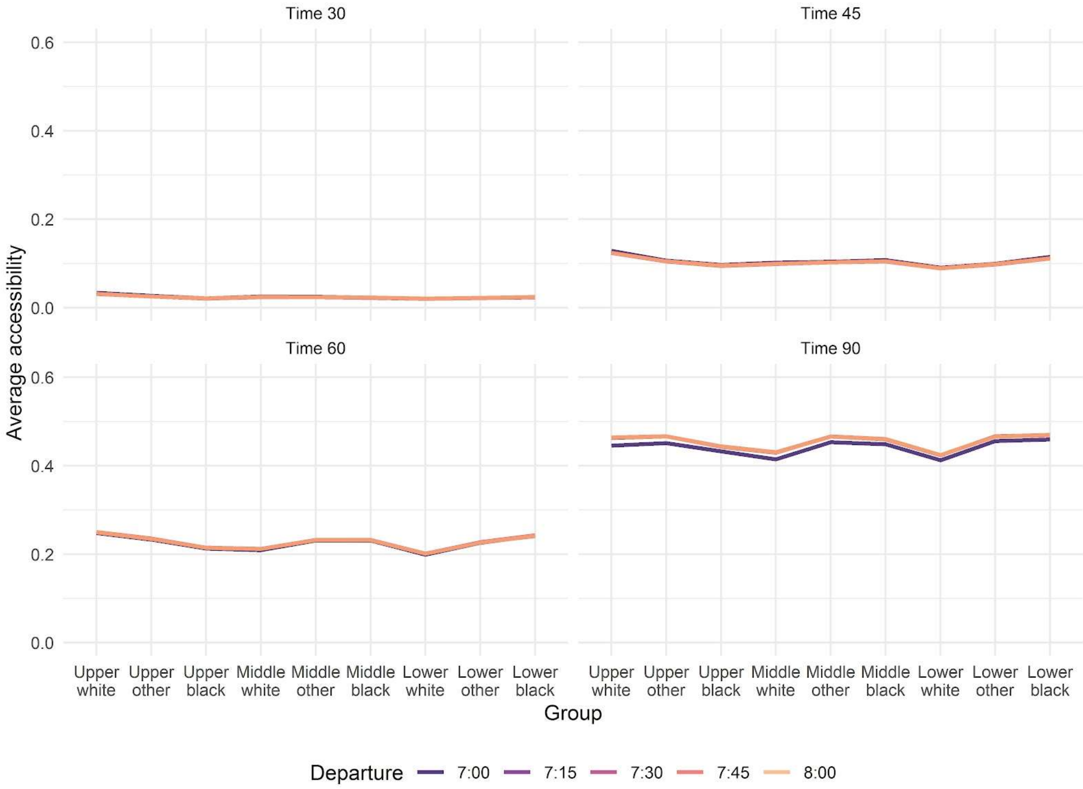
*Appendix B-10:*Robustness check of the average travel time accessibility by class and race, considering multiple departure times from 7am to 8am in São Paulo.



*Appendix B-11:*Robustness check of the average travel time accessibility by class and race, considering multiple departure times from 7am to 8am in New York City.



*Appendix B-12:*Robustness check of the average travel time accessibility by class and race, considering multiple departure times from 7am to 8am in London.



*Appendix B-13:*Correlations of travel time accessibility considering multiple departure times from 7am to 8am in São Paulo.

Time 30	**7:00**	**7:15**	**7:30**	**7:45**	**8:00**
7:00	1	0.983	0.983	0.977	0.980
7:15		1	0.992	0.989	0.986
7:30			1	0.991	0.989
7:45				1	0.988
8:00					1

Time 45	**7:00**	**7:15**	**7:30**	**7:45**	**8:00**
7:00	1	0.988	0.985	0.983	0.981
7:15		1	0.992	0.990	0.986
7:30			1	0.990	0.989
7:45				1	0.991
8:00					1

Time 60	**7:00**	**7:15**	**7:30**	**7:45**	**8:00**
7:00	1	0.987	0.985	0.981	0.979
7:15		1	0.993	0.990	0.987
7:30			1	0.991	0.989
7:45				1	0.992
8:00					1

Time 90	**7:00**	**7:15**	**7:30**	**7:45**	**8:00**
7:00	1	0.966	0.967	0.966	0.957
7:15		1	0.992	0.992	0.987
7:30			1	0.992	0.988
7:45				1	0.988
8:00					1

*Appendix B-14:*Correlations of travel time accessibility considering multiple departure times from 7am to 8am in New York City.

Time 30	**7:00**	**7:15**	**7:30**	**7:45**	**8:00**
7:00	1	0.956	0.957	0.957	0.961
7:15		1	0.996	0.992	0.990
7:30			1	0.993	0.990
7:45				1	0.993
8:00					1

Time 45	**7:00**	**7:15**	**7:30**	**7:45**	**8:00**
7:00	1	0.971	0.969	0.969	0.975
7:15		1	0.991	0.988	0.984
7:30			1	0.990	0.985
7:45				1	0.989
8:00					1

Time 60	**7:00**	**7:15**	**7:30**	**7:45**	**8:00**
7:00	1	0.962	0.959	0.970	0.982
7:15		1	0.988	0.980	0.973
7:30			1	0.980	0.974
7:45				1	0.984
8:00					1

Time 90	**7:00**	**7:15**	**7:30**	**7:45**	**8:00**
7:00	1	0.907	0.893	0.946	0.962
7:15		1	0.963	0.951	0.949
7:30			1	0.950	0.947
7:45				1	0.984
8:00					1

*Appendix B-15:*Correlations of travel time accessibility considering multiple departure times from 7am to 8am in London.

Time 30	**7:00**	**7:15**	**7:30**	**7:45**	**8:00**
7:00	1	0.976	0.975	0.977	0.978
7:15		1	0.992	0.993	0.991
7:30			1	0.994	0.992
7:45				1	0.993
8:00					1

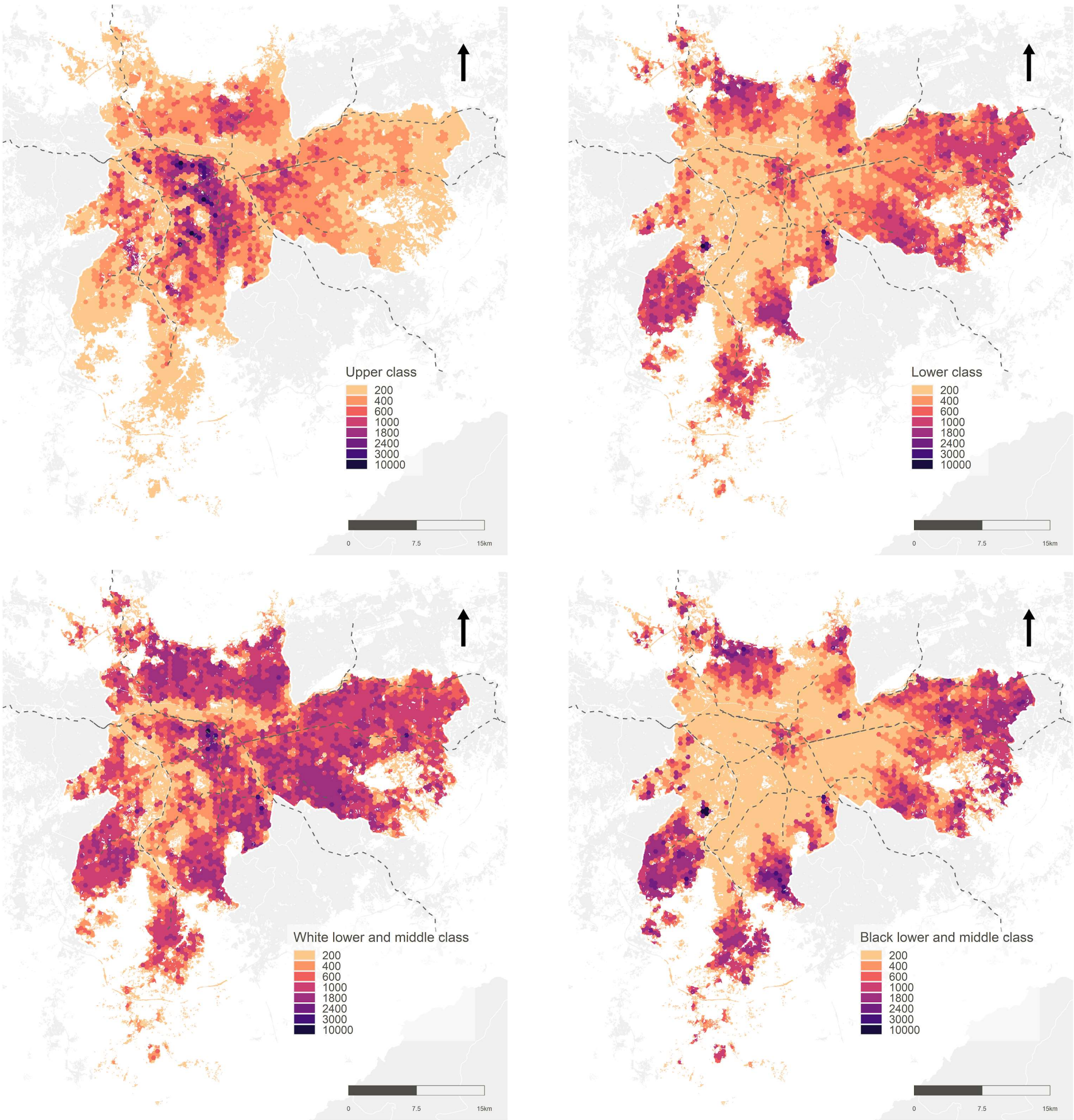
Time 45	**7:00**	**7:15**	**7:30**	**7:45**	**8:00**
7:00	1	0.977	0.976	0.977	0.978
7:15		1	0.993	0.994	0.994
7:30			1	0.995	0.994
7:45				1	0.995
8:00					1

Time 60	**7:00**	**7:15**	**7:30**	**7:45**	**8:00**
7:00	1	0.976	0.974	0.976	0.975
7:15		1	0.995	0.996	0.996
7:30			1	0.995	0.995
7:45				1	0.995
8:00					1

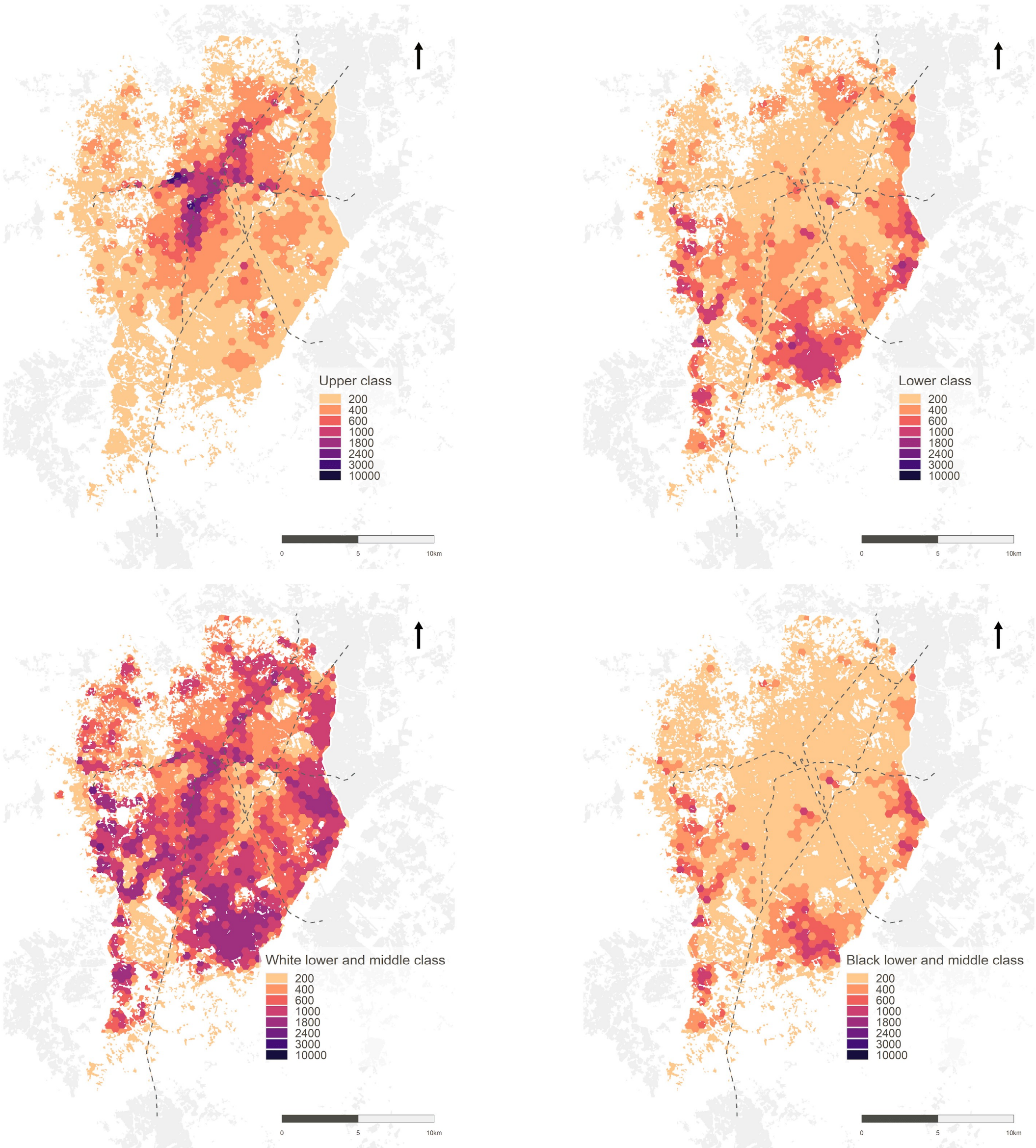
Time 90	**7:00**	**7:15**	**7:30**	**7:45**	**8:00**
7:00	1	0.939	0.941	0.938	0.938
7:15		1	0.995	0.996	0.994
7:30			1	0.995	0.994
7:45				1	0.995
8:00					1

C Appendix – Supplementary material of chapter 3: Evaluating the accessibility and availability of public services to reduce inequalities in everyday mobility

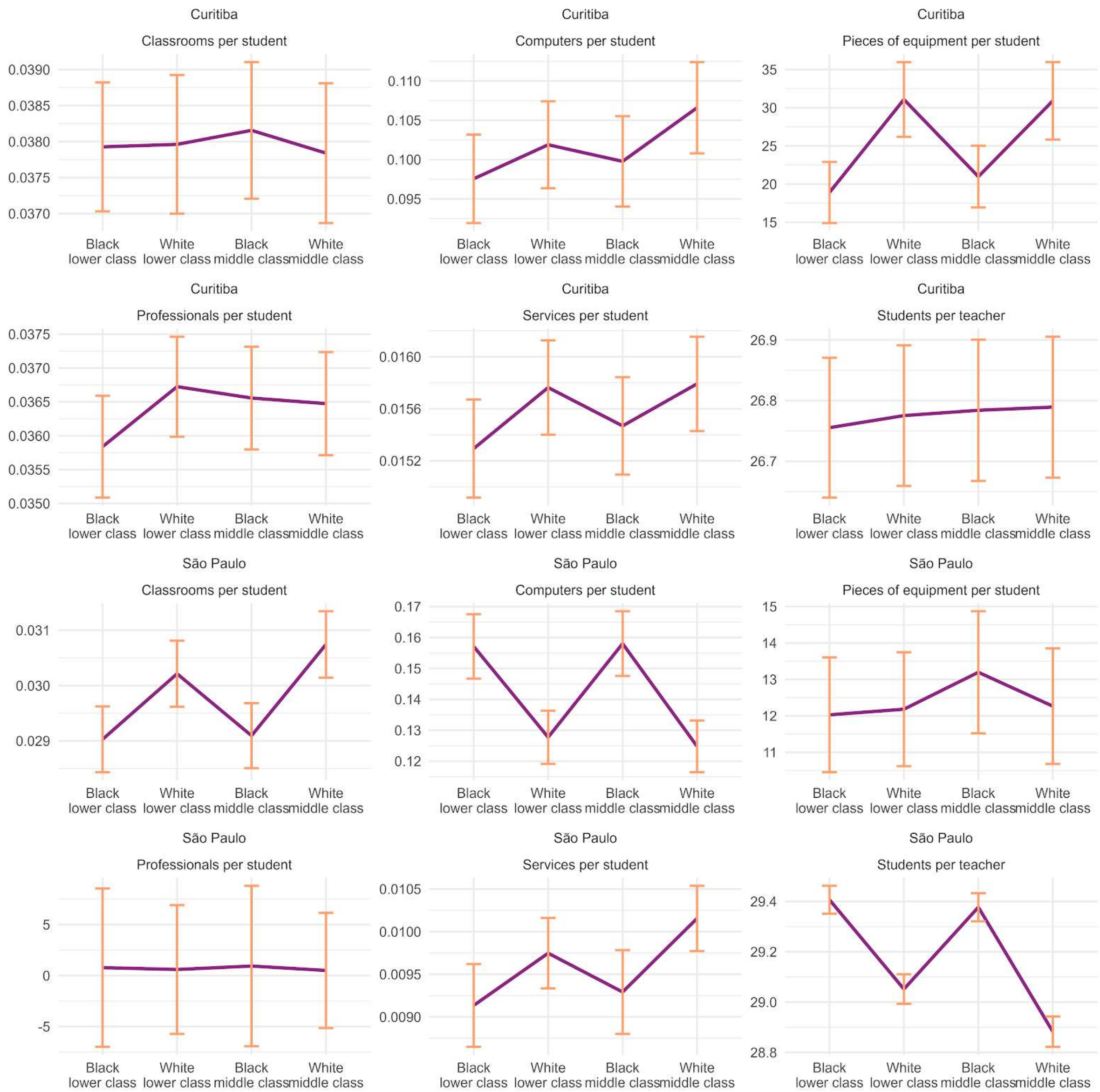
Appendix C-1: Spatial distributions of social groups in São Paulo



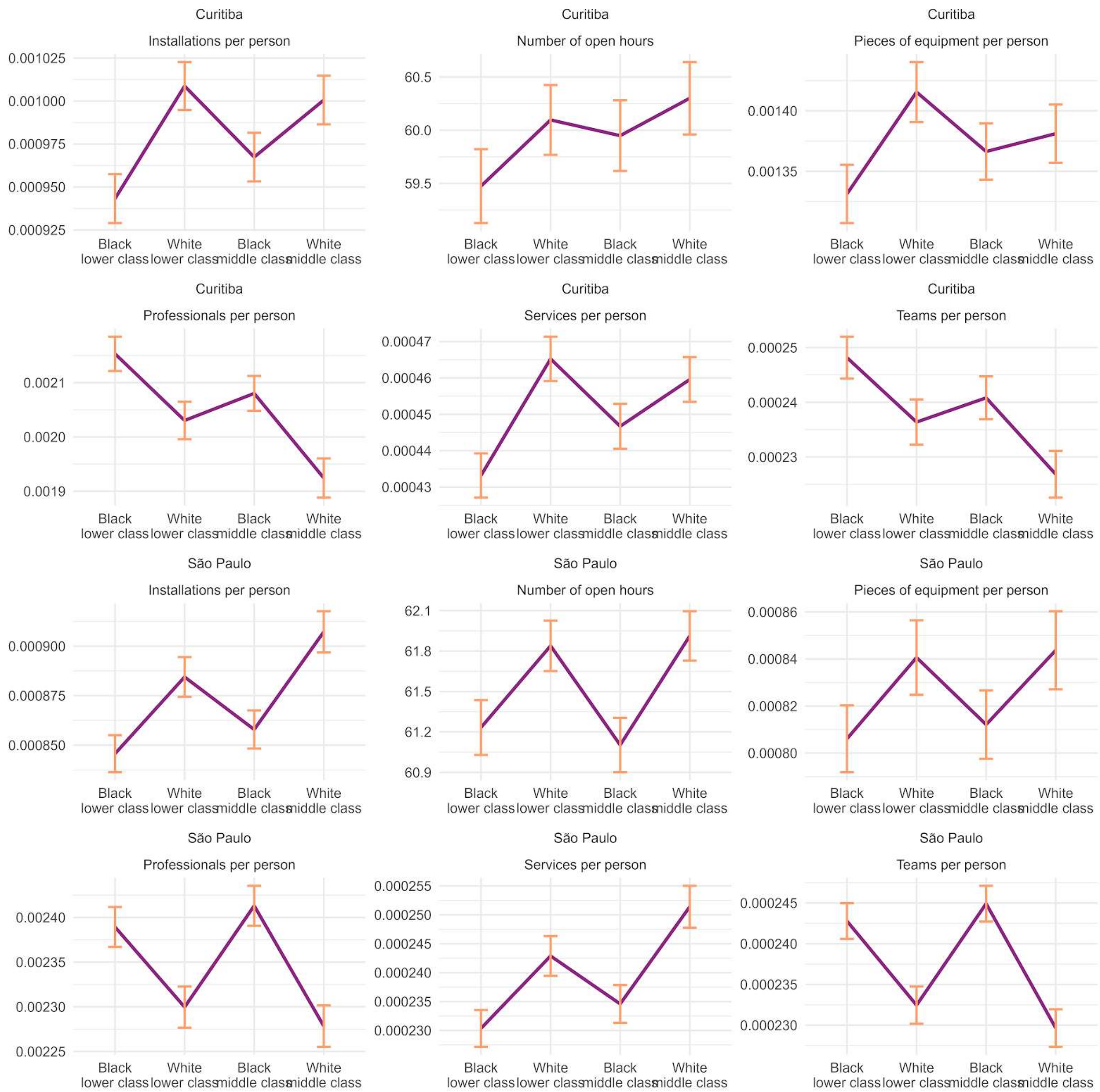
Appendix C-2: Spatial distributions of social groups in Curitiba



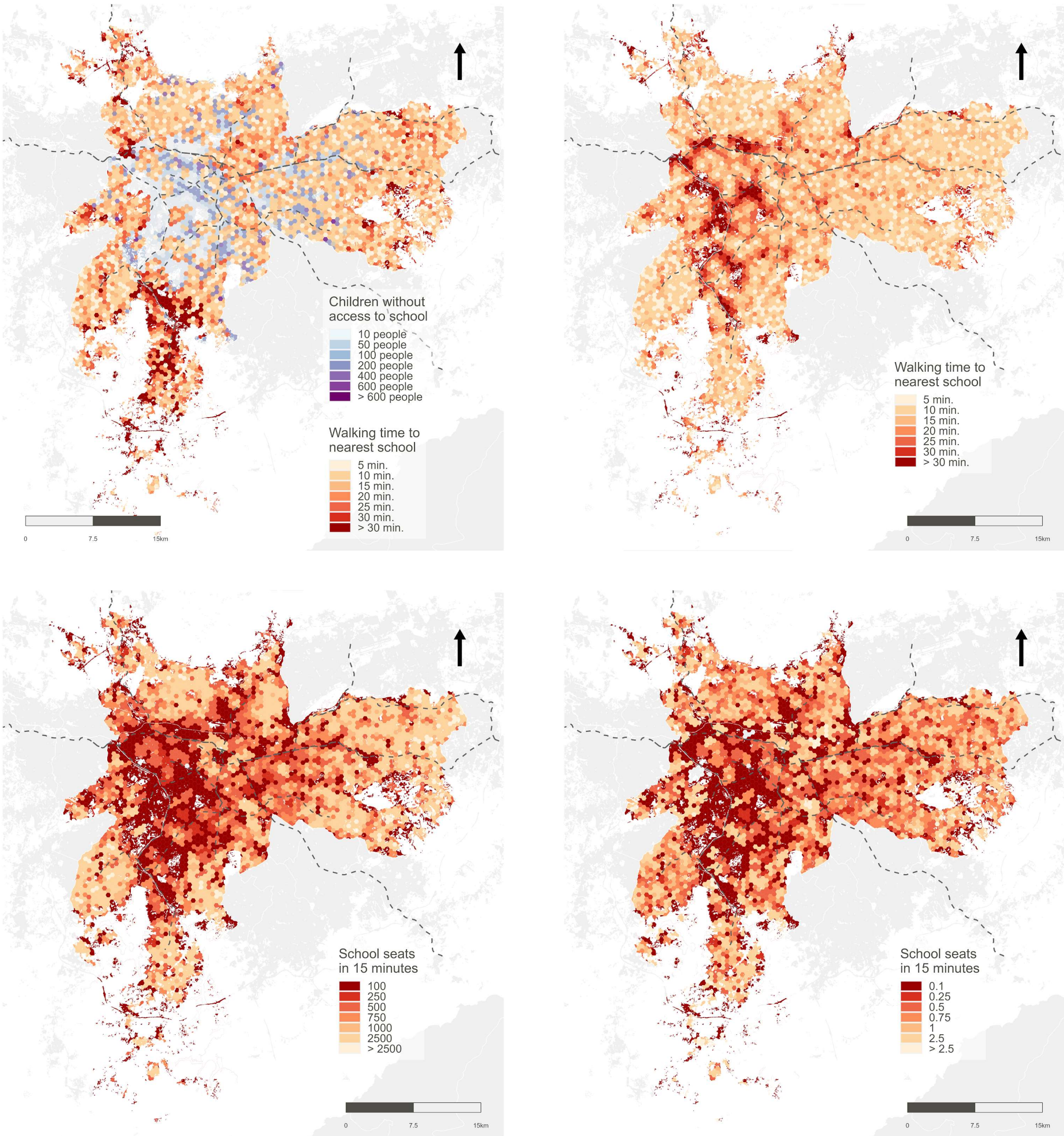
Appendix C-3: Average quality (and confidence intervals) of primary schools accessed by each social group



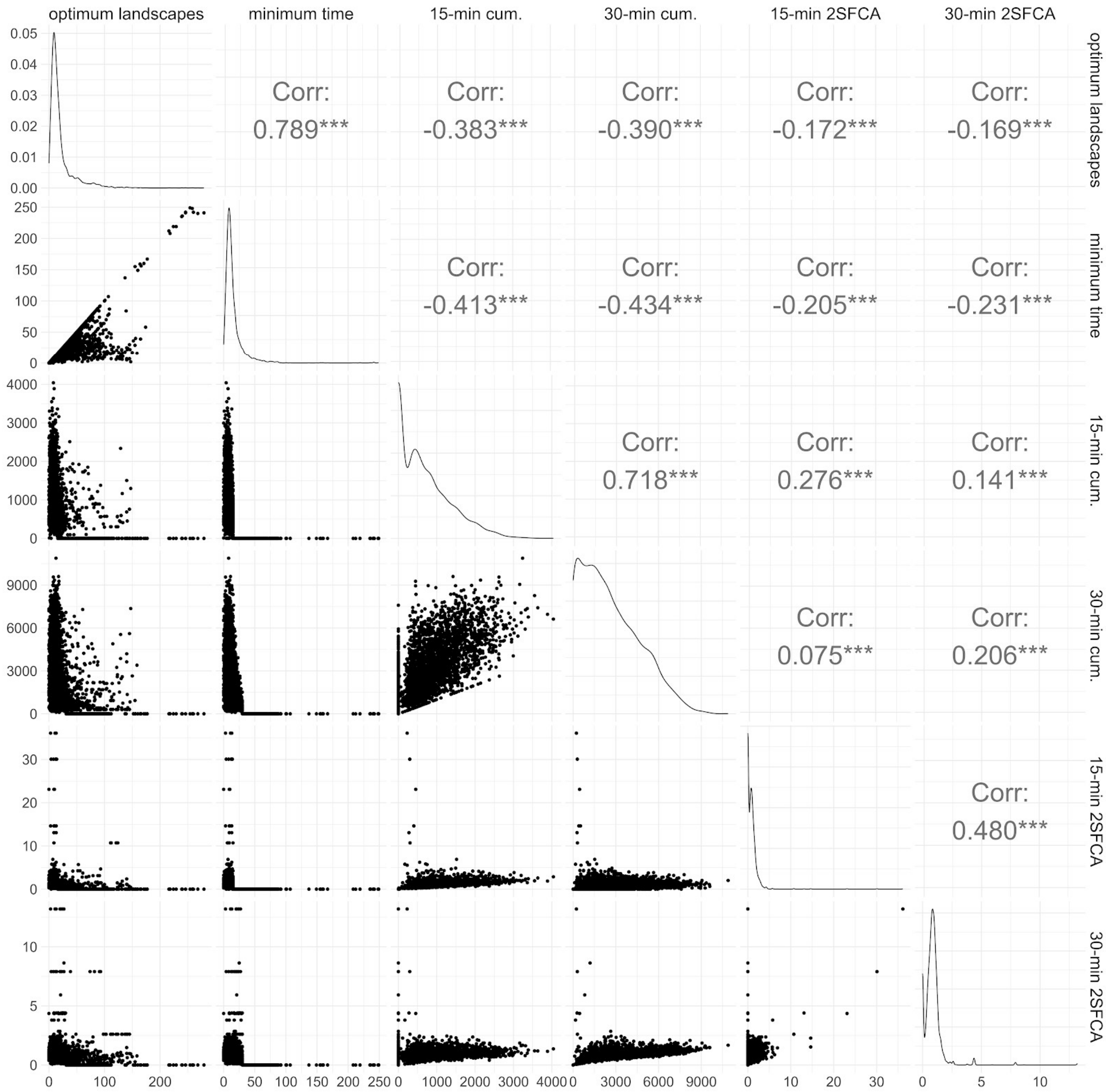
Appendix C-4: Average quality (and confidence intervals) of healthcare facilities accessed by social group



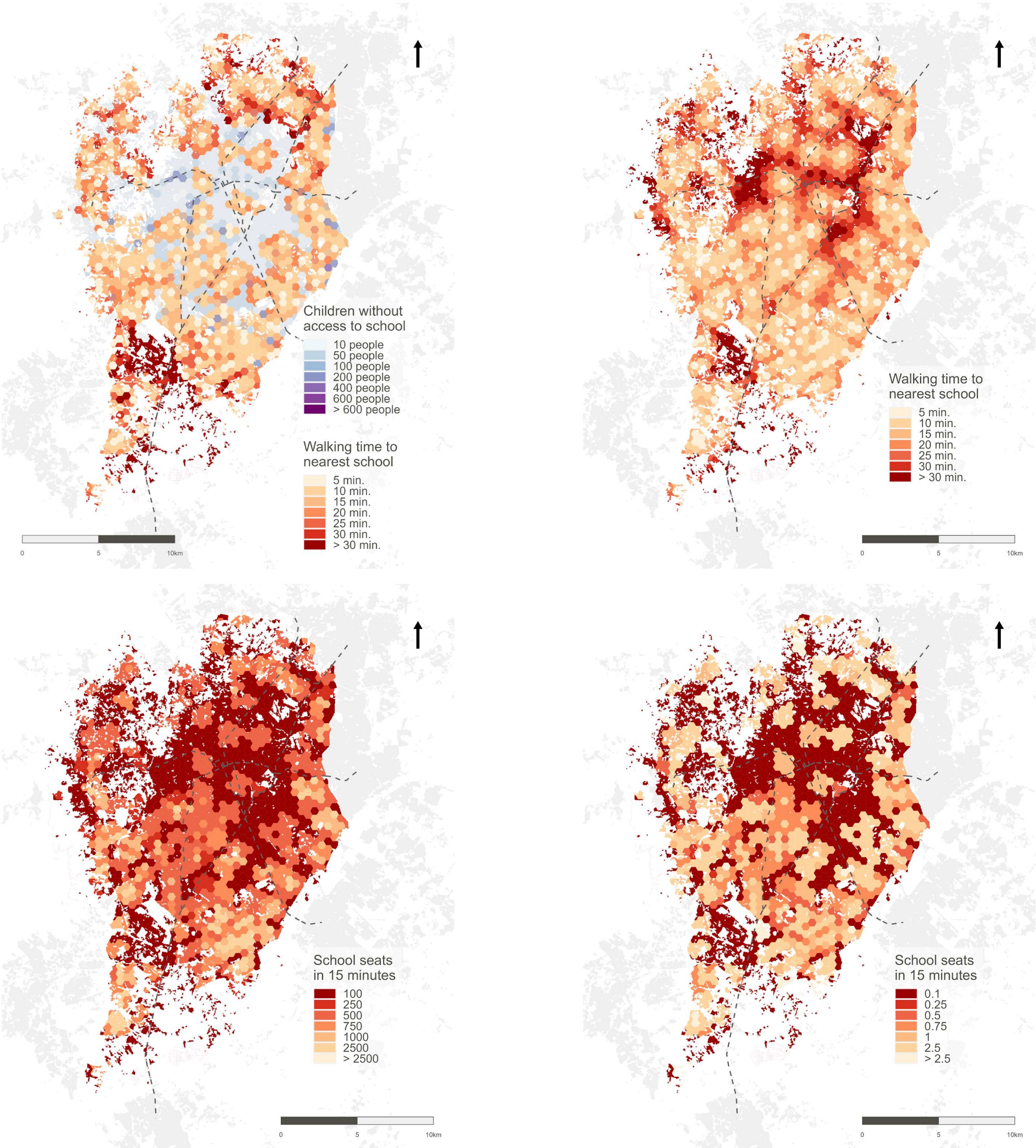
Appendix C-5: Accessibility to primary schools in São Paulo by multiple metrics: optimization-based (top left), minimum travel time (top right), 15-minute cumulative opportunities (bottom left) and 15-minute 2SFCA (bottom right).



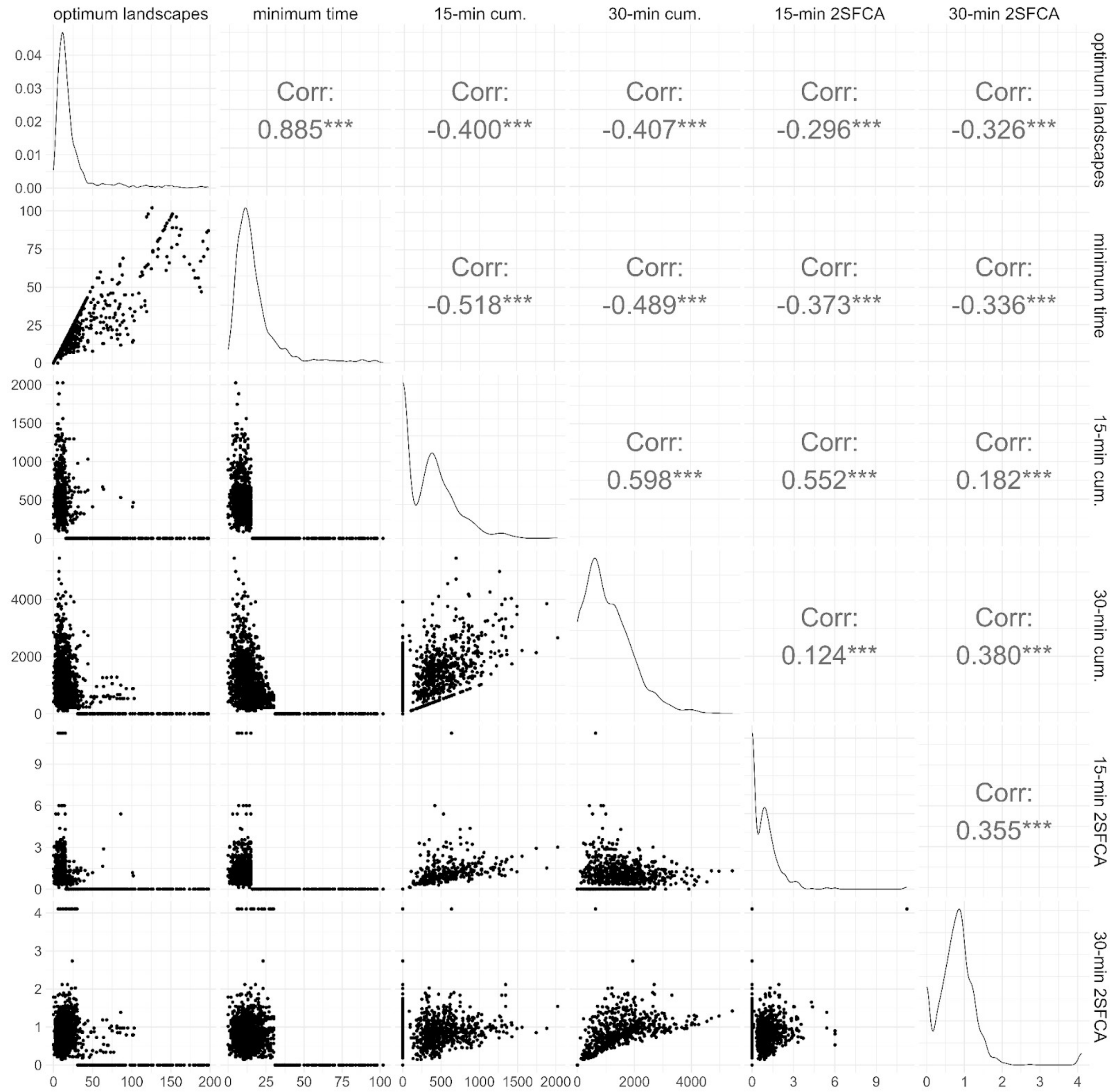
Appendix C-6: Correlation between accessibility to primary schools in São Paulo by multiple metrics: optimization-based, minimum travel time, 15-minute cumulative opportunities and 15-minute 2SFCA.



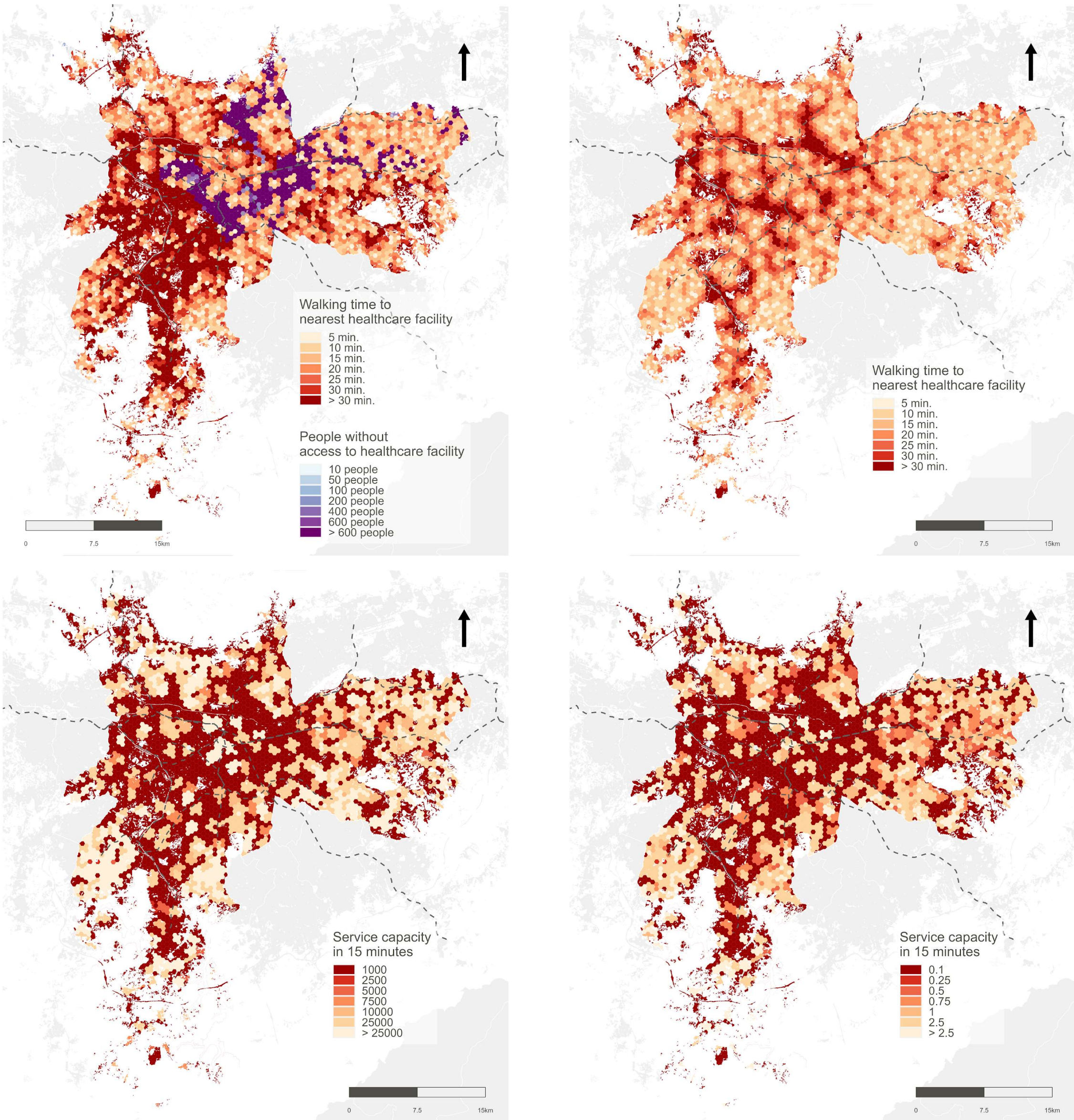
Appendix C-7: Accessibility to primary schools in Curitiba by multiple metrics: optimization-based (top left), minimum travel time (right left), 15-minute cumulative opportunities (center right) and 15-minute 2SFCA (bottom right).



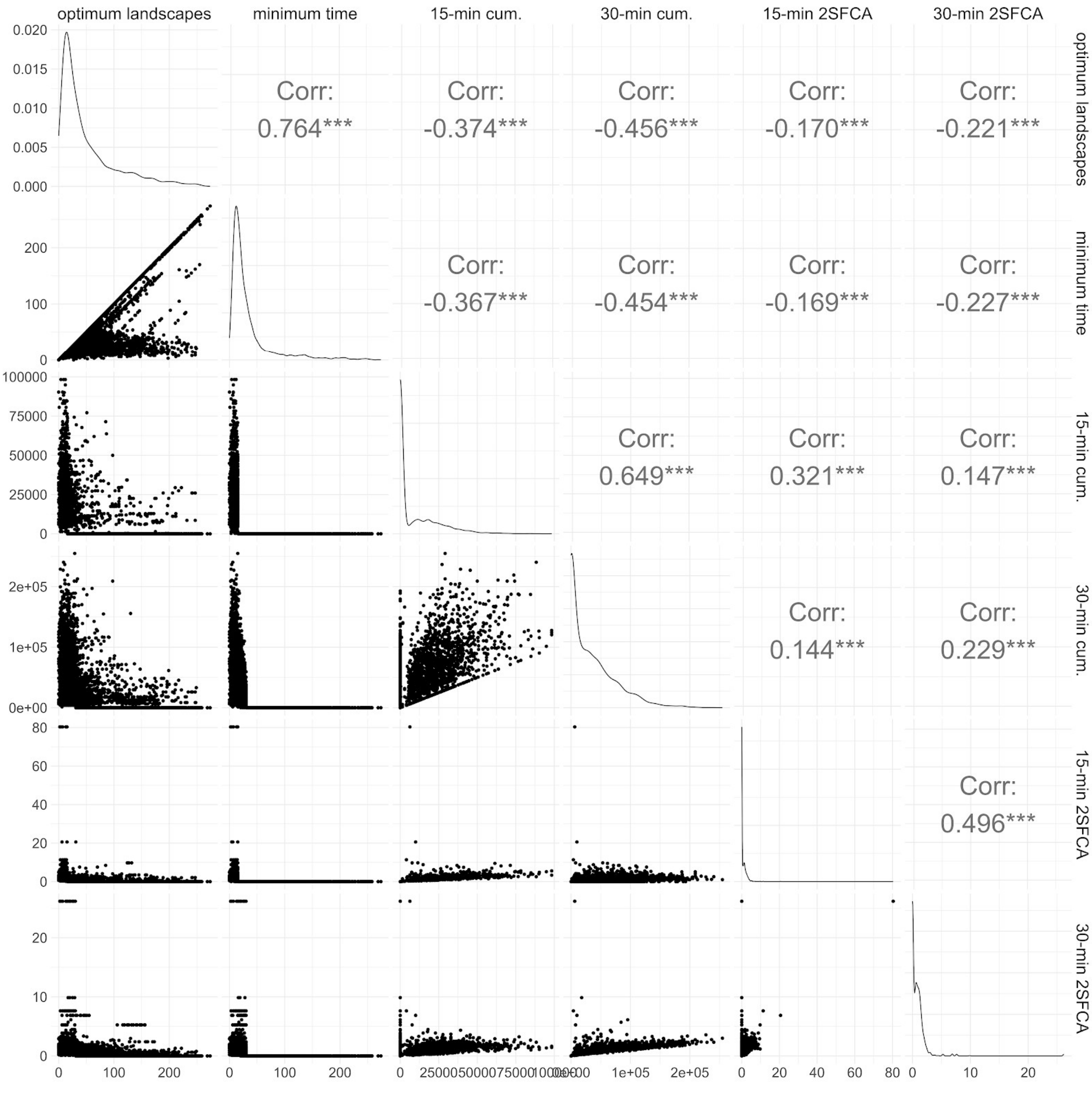
Appendix C-8: Correlation between accessibility to primary schools in Curitiba by multiple metrics: optimization-based, minimum travel time, 15-minute cumulative opportunities and 15-minute 2SFCA.



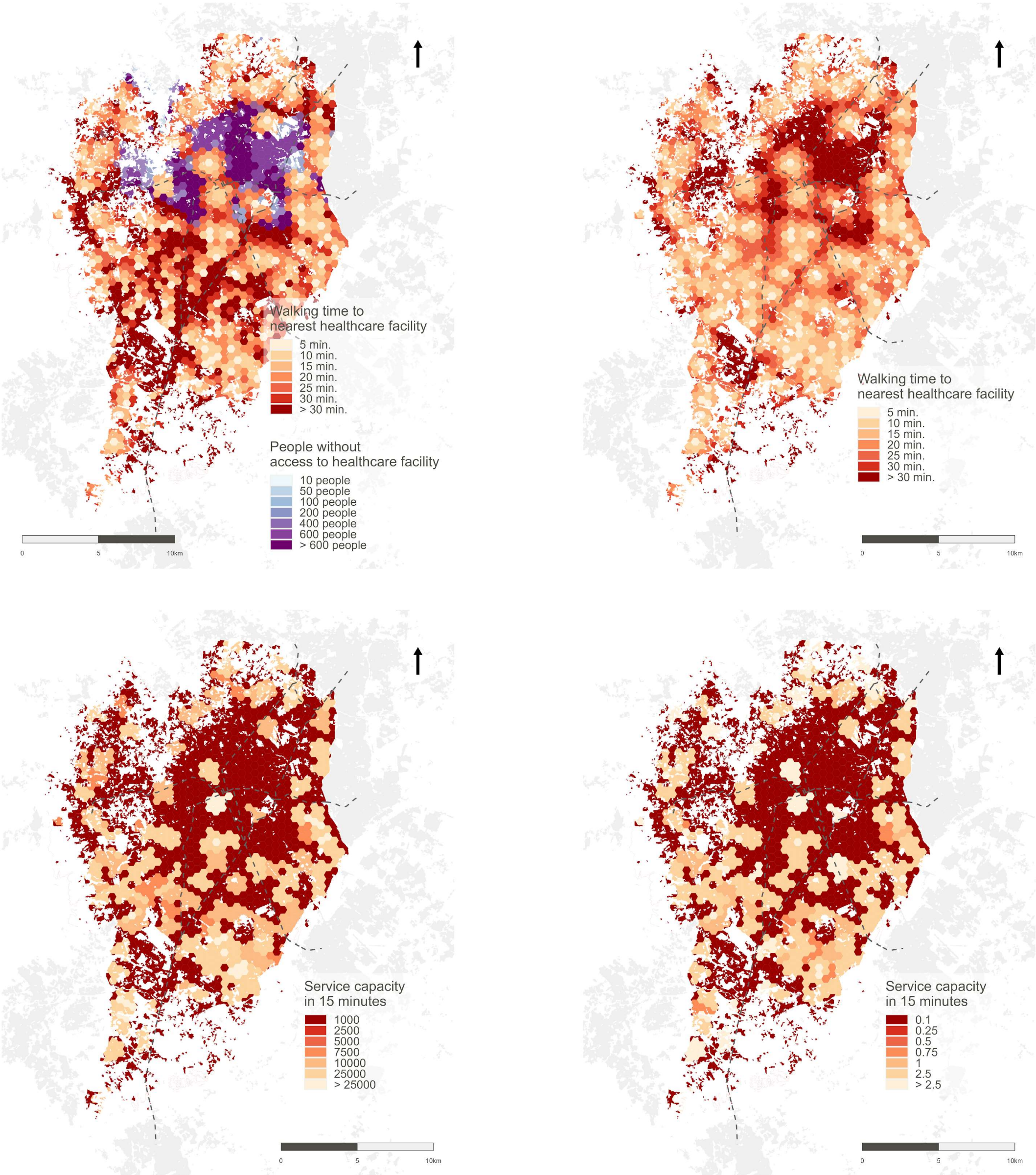
Appendix C-9: Accessibility to healthcare facilities in São Paulo by multiple metrics: optimization-based (top left), minimum travel time (top left), 15-minute cumulative opportunities (bottom left) and 15-minute 2SFCA (bottom right).



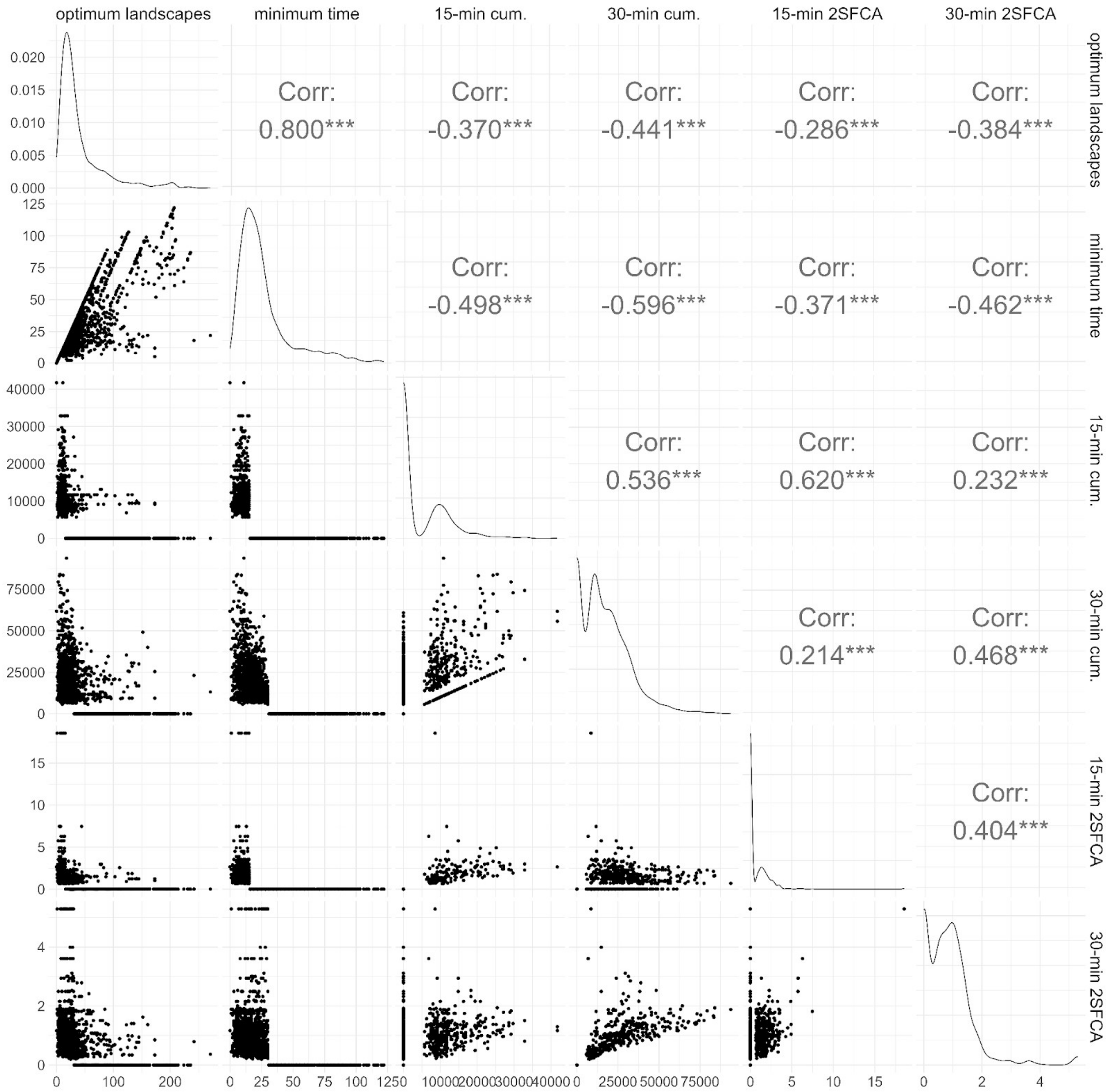
Appendix C-10: Correlation between accessibility to healthcare facilities in São Paulo by multiple metrics: optimization-based, minimum travel time, 15-minute cumulative opportunities and 15-minute 2SFCA.



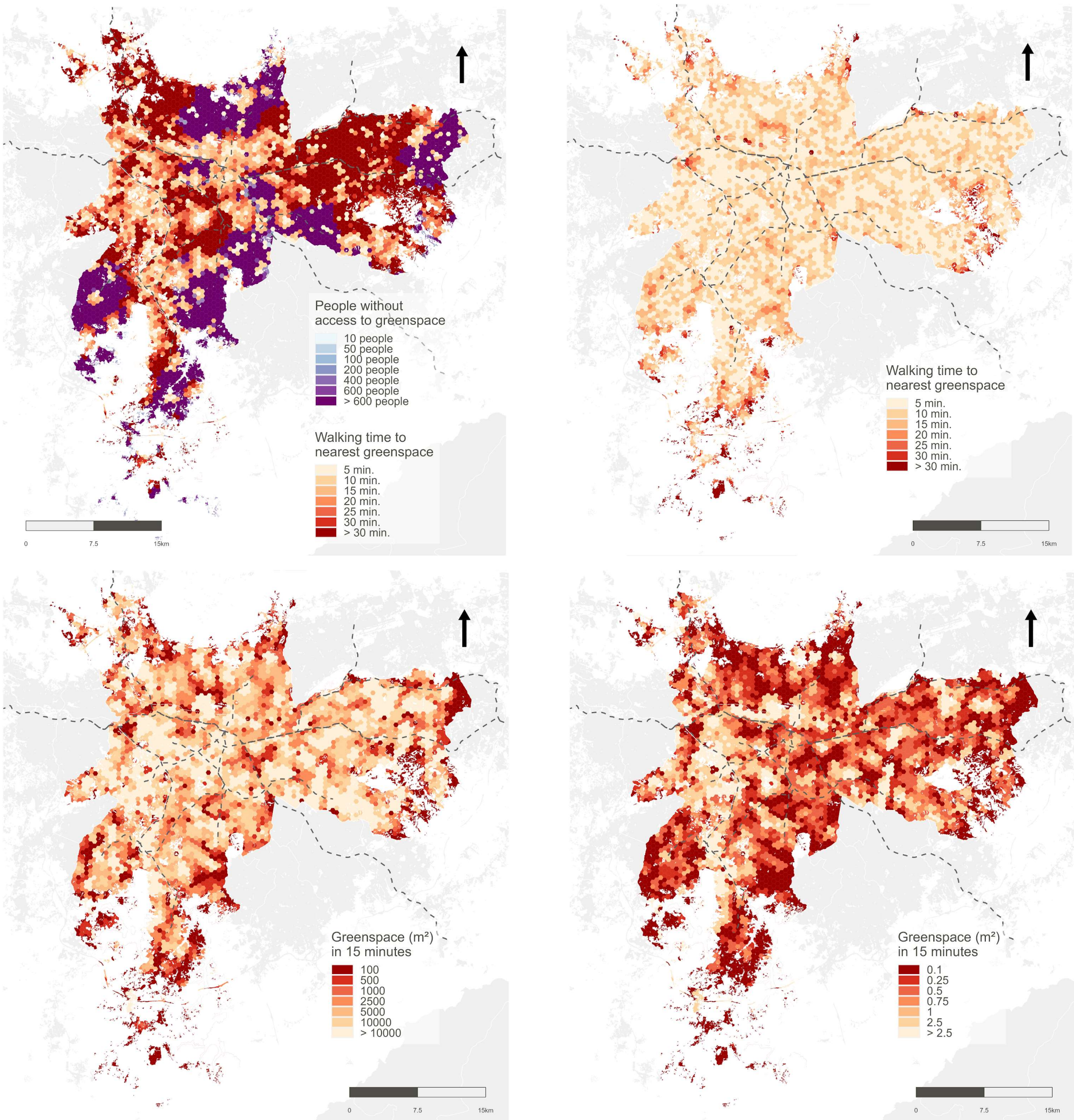
Appendix C-11: Accessibility to healthcare facilities in Curitiba by multiple metrics: optimization-based (top left), minimum travel time (top right), 15-minute cumulative opportunities (bottom left) and 15-minute 2SFCA (bottom right).



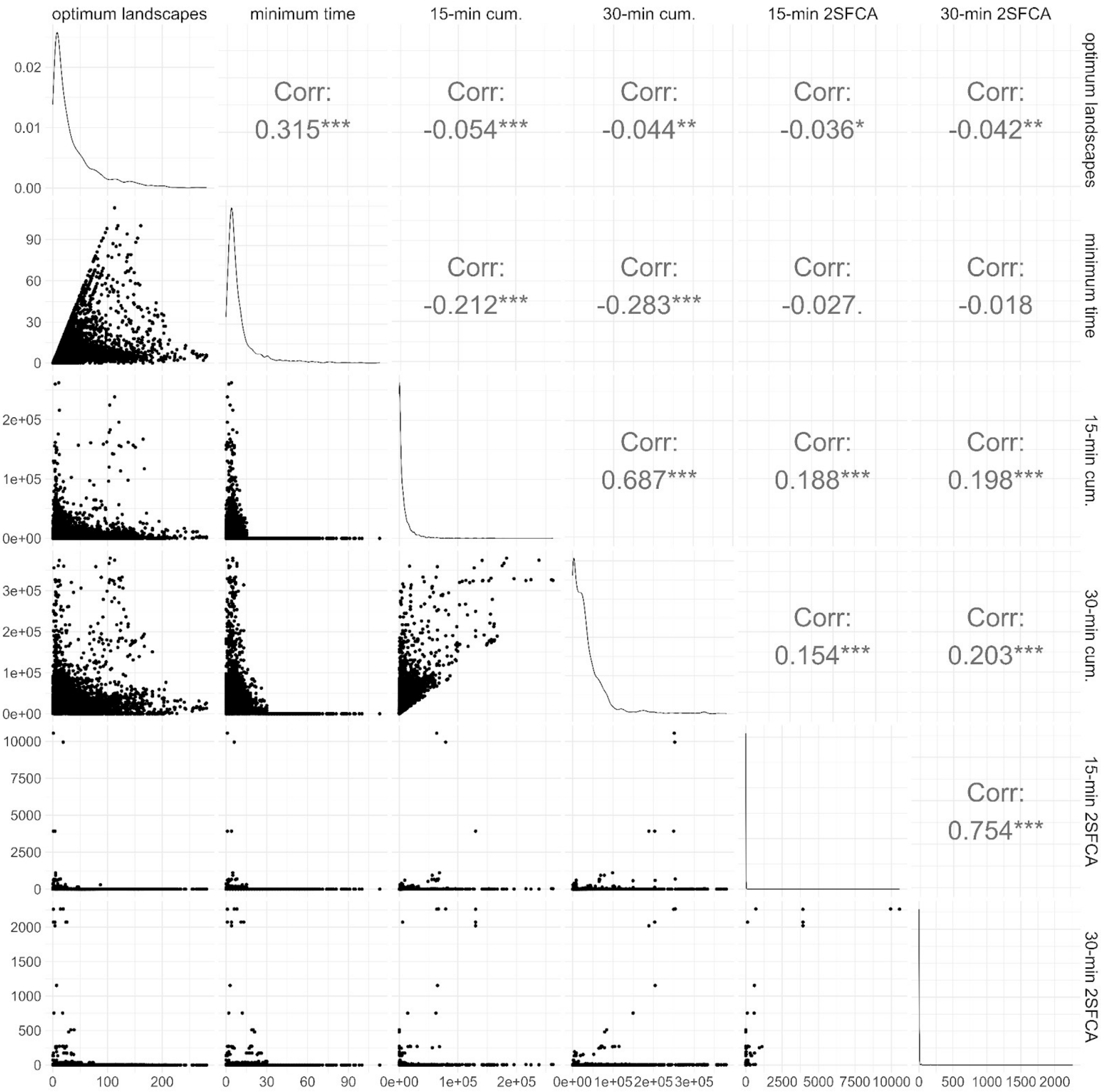
Appendix C-12: Correlation between accessibility to healthcare facilities in Curitiba by multiple metrics: optimization-based, minimum travel time, 15-minute cumulative opportunities and 15-minute 2SFCA.



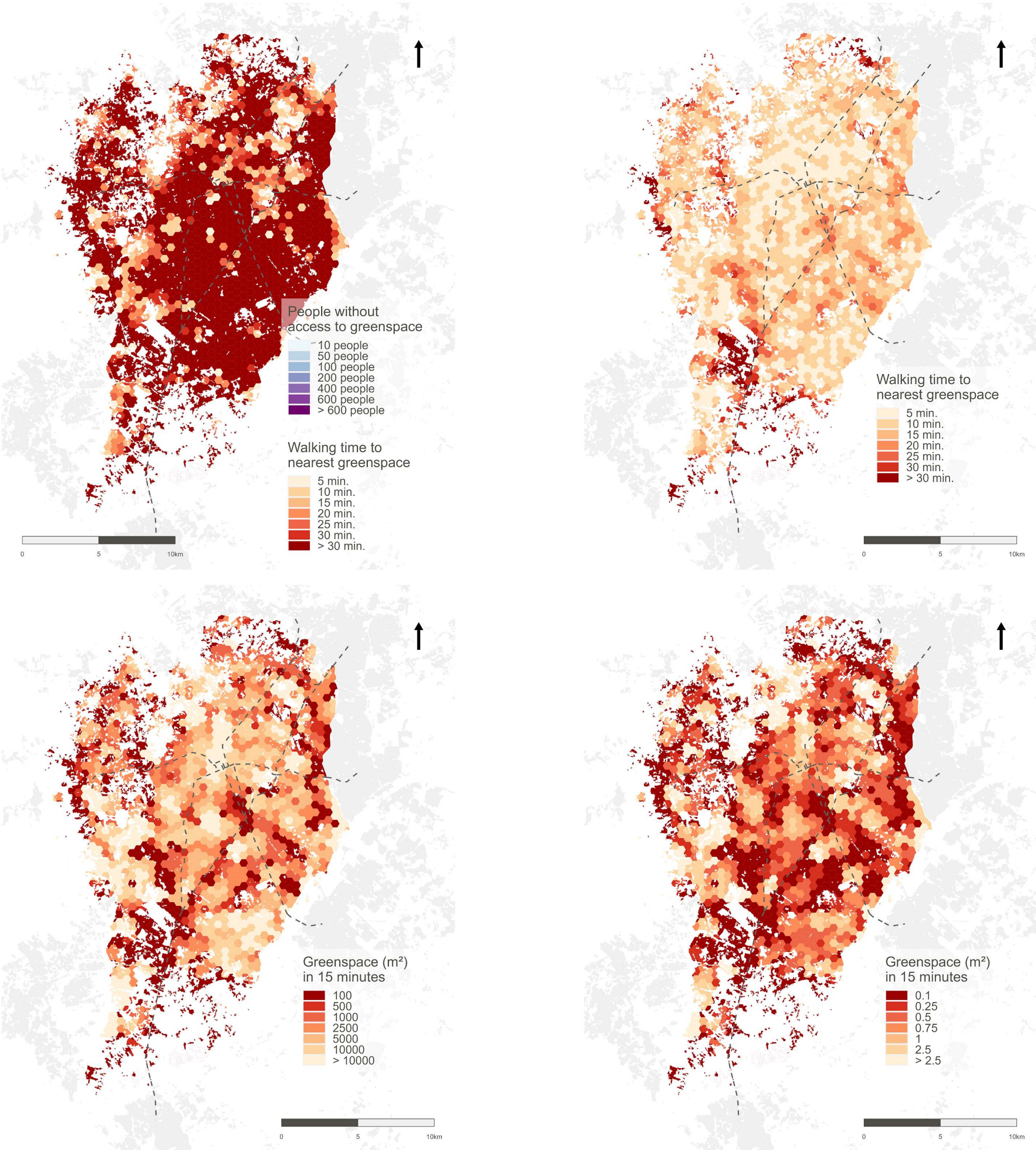
Appendix C-13: Accessibility to open greenspaces in São Paulo by multiple metrics: optimization-based (top left), minimum travel time (top right), 15-minute cumulative opportunities (bottom left) and 15-minute 2SFCA (bottom right).



Appendix C-14: Correlation between accessibility to open greenspaces in São Paulo by multiple metrics: optimization-based, minimum travel time, 15-minute cumulative opportunities and 15-minute 2SFCA.



Appendix C-15: Accessibility to open greenspaces in Curitiba by multiple metrics: optimization-based (top left), minimum travel time (top right), 15-minute cumulative opportunities (bottom left) and 15-minute 2SFCA (bottom right).



Appendix C-16: Correlation between accessibility to open greenspaces in Curitiba by multiple metrics: optimization-based, minimum travel time, 15-minute cumulative opportunities and 15-minute 2SFCA.