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Does better accessibility help to reduce social exclusion? Evidence from the city of São Paulo, Brazil

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A B S T R A C T

Most transport equity and transport-related social exclusion (TRSE) studies assume that increasing accessibility levels lead to increased activity participation and, therefore, a reduction in social exclusion. Although this assumption makes sense from a theoretical point of view, this causal relationship has not yet been validated in practice. Previous studies investigating the accessibility-participation relationship were inconclusive, indicating that increasing accessibility has a limited impact on activity participation levels, if any. Moreover, the existing empirical evidence in the literature in the Global South context is scarce, is merely correlational and fails to infer causality between both variables. The contributions of the paper are threefold. First, (a) to provide a conceptual model of the causal relationship between accessibility, activity participation and risk of transport-related social exclusion (TRSE); second, (b) to summarise the available empirical evidence about the accessibility-activity participation relationship through a systematic literature review; and third, (c) to provide evidence of the causal relationship between accessibility and activity participation levels in a Global South context. Three Poisson regression models associated with an instrumental variable identification strategy were used to assess the causal effect between accessibility and participation in total, mandatory and discretionary activities in the city of São Paulo, Brazil. The three models showed a highly significant, strong correlation between an individual's accessibility level and their actual participation in total, mandatory and discretionary activities. Models that ignore the possible endogeneity present in the relationship between accessibility and activity participation may underestimate the effect of accessibility. Based on our results, we argue that low accessibility levels may severely restrict individuals' life chances and add evidence that accessibility has to be an important instrument to support transport policies' decision-making.

1. Introduction

The lack of access to critical opportunities in society is associated with substantial economic and social costs (United Nations, 2016). Studies on the relationship between accessibility and social issues date back 1970s (e.g. Wachs and Kumagai, 1973; Black and Conroy, 1977). However, the interest in assessing transport investments and other policies from the perspective of accessibility has emerged only in the last two decades (Martens, 2016b). Currently, accessibility measures have been used to assess the distributional effects of transport policies and identify groups at risk of social exclusion (Páez et al., 2010; Curl et al., 2011; Boisjoly and El-Geneidy, 2017a; Allen and Farber, 2020). Accessibility is treated by transport-related social exclusion (TRSE) research as a key indicator for the

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number of opportunities available to individuals, where it is assumed that greater levels of accessibility lead to higher levels of participation and thus less social exclusion.

Despite the theoretical consistency of this statement, most of the accessibility measures used in practice to assess TRSE risk account only for some of the components (Kamruzzaman et al., 2016; Pyrialakou et al. (2016)) that shape an individual's possibilities of participation and do not capture the complex social interactions, perceptions, and behaviours that influence activity participation (Bantis and Haworth, 2020; Luz and Portugal, 2021; Curl et al., 2011; Martens, 2016a). The empirical research that has tested the accessibility-activity participation relationship did not indicate a consensus regarding its validity. Some articles found that accessibility levels are associated with higher activity participation levels (Allen and Farber, 2020; Calvo et al., 2019; Merlin, 2015; Ding et al., 2016), while others found that this relationship is weak or not statistically significant (Kitamura et al., 1997; Ewing et al., 1996; Wang and Cao, 2017). Some papers found that this relationship may be valid for a specific type of activity, transport mode, or accessibility measure (Cordera et al., 2017; Thill and Kim, 2005; Masoumi, 2021; Zhang et al., 2019), and others, in contrast, attest that higher accessibility leads to lower activity participation (Williams, 1989; Wu et al., 2012; Lavieri et al., 2018). This lack of consensus may suggest that it is not sure that TRSE evaluations using accessibility measures produce reliable results.

To assess transport-related social exclusion, the distribution of accessibility among the population should be sufficient since we want to assess what people can potentially access and not necessarily the activities they accessed and participated in. People would not be considered socially excluded if they could participate in desired activities but did not do so, since they have the freedom of choice. In this sense, we could restrict our analysis to accessibility distribution if we were sure that the chosen accessibility measure represents an individual's participation possibilities.

However, as previously mentioned, the currently existing accessibility measures cannot capture all the factors influencing an individual's ability to participate in activities. Because of this, it is also necessary to assess the number of activities that individuals have participated in to ensure that the chosen accessibility measure is appropriate to guide transportation policies aimed at reducing social exclusion (Luz and Portugal, 2021). When we assess the accessibility-activity participation relationship of a single individual, we can expect that some people may have a high level of accessibility but a poor level of activity participation. These individuals (a) do not prefer to participate frequently in activities, (b) there are other barriers to activity participation not included in the accessibility analysis (e.g., disabled people, mental barriers, social isolation) or (c) the accessibility analysis does not fit preference/needs of people well enough (e.g., maybe there is a school available but not of the right type). However, if we aggregate the individuals' data and test this relationship for a whole population at once, in that case, it is expected that higher levels of accessibility are associated with greater participation in activities, on average, and, consequently, a lower level of social exclusion (Luz and Portugal, 2021). In this sense, a helpful accessibility metric for assessing TRSE must be associated, at least in part, with the activity participation level. Otherwise, it is possible that the chosen accessibility measure does not represent the possibilities for individuals to participate in activities.

To the best of the authors' knowledge, only three previous studies that tested the relationship between accessibility and participation in activities were from the perspective of social inclusion or equity (Allen and Farber, 2020; Fransen et al., 2018; Cheng et al., 2019). Most studies investigated accessibility and participation in activities relationship from a trip generation perspective and, consequently, adopted an aggregated approach, failing to control people's interpersonal heterogeneity adequately. Moreover, most studies focus on Global North contexts, and empirical evidence for Global South contexts is scarce. Finally, and perhaps most importantly, none of the reviewed studies on the accessibility-activity participation relationship controlled for endogeneity (when one of the independent variables correlates with the regression error term) adequately. In the presence of endogenous variables, the consistency of the estimators is compromised, which may bias the results and hinder the identification of a cause-effect relationship between the explanatory and dependent variables. Past studies only attested to the association between variables but failed to identify the cause-effect relationship.

The causal theory is vital for the practice of policy research. It is used to diagnose problems, predict future impacts of policy interventions, and assess the effectiveness of past interventions (Steinberg, 2007). However, policy design often fails to focus on causality, which is the true driving force of policy effect and therefore misconstrues the potential effectiveness of policy design (Capano and Howlett, 2021). Causality is the basis of explanation (why this happened?) and prediction (what might happen in the future?). The better we understand the causality of a system, the better our strategy for manipulating that system will be.

Given the imperative of accessibility planning for inclusive transport policies, this article has three objectives: (a) to provide a conceptual model of the causal relationship between accessibility, activity participation and risk of transport-related social exclusion (TRSE), (b) to summarise the available empirical evidence about the accessibility-activity participation relationship through a systematic literature review, and (c) to provide evidence of the causal relationship between accessibility and activity participation in a context of the Global South to support transport policies. We assess the cause-effect relationship of accessibility-activity according to the type of activities accessed, mandatory activities (work and education), discretionary activities (leisure, shopping or having a meal), and total activities (without purpose distinction) in the city of São Paulo, Brazil. We developed three Poisson regression models associated with an instrumental variable identification strategy to control endogeneity in the relationship under study.

Unlike more recent studies on the topic that tend to use more sophisticated measures of accessibility, we decided to use the cumulative measure of accessibility opportunities (CUM) due to its simplicity, low data requirements, ease of interpretation and popularity among policymakers. Aspects such as ease of operationalisation and interpretation are crucial for the accessibility measure to be used by planners, especially in a Global South context, where transport agencies face data limitations and have poorly qualified technical staff (Barboza et al., 2021). Disaggregation is another feature that distinguishes our research from previous studies that employed place-based accessibility measures. We assessed the accessibility-activity participation relationship while considering the individual's accessibility level and his/her sociodemographic characteristics.

Sections 2.1 and 2.2. address the objectives (a) and (b), respectively. Section 3 describes the study area and regional context of the empirical part. Section 4 introduces the methodology and describes the instrumental variable identification strategy adopted to infer causality between accessibility and participation. Section 5 is dedicated to the descriptive statistics of our data. Section 6 presents the results and section 7 conclusions.

2. Background

2.1. *Transport-Related social exclusion (TRSE) and accessibility*

An individual is socially excluded if "he or she is geographically resident in a society, but for reasons beyond his or her control, he or she cannot participate in the normal activities of citizens in that society, and he or she would like to so participate" (Burchardt et al., 1999, p. 229). According to Preston and Rajé (2007), a helpful way of thinking about social exclusion is to reshape Amartya Sen's theory of entitlement. Sen suggests that famines are not caused by a lack of food but by a lack of access to food (Sen, 1983). Similarly, social exclusion is not due to a lack of social opportunities but a lack of access to those opportunities (Preston and Rajé, 2007) In this sense, the transport system is critical in providing people access to activities, services, and opportunities dispersed in space (Farrington, 2007).

Given that the primary purpose of transport systems is to provide access to opportunities that people have reason to value (van Wee and Geurs, 2011; Martens, 2016a; Allen and Farber, 2020; Martens, 2016b), individuals can be deprived of participation in society and be at risk of transport-related social exclusion (TRSE) if these systems fail to achieve their purpose. Formally, transport-related social exclusion is defined as the process by which people are prevented from participating in the economic, political, and social life of the community because of reduced accessibility to opportunities, services, and social networks, due to in whole or in part, to poor potential mobility (Kenyon et al., 2002). It means that the partial or complete people's inability to traverse space limits individuals from reaching different opportunities, indicating accessibility poverty (Jeekel and Martens, 2017) which, in turn, can manifest itself in social exclusion (Luz and Portugal, 2021). Simply put, people at risk of TRSE are those in accessibility poverty. In this sense, transport policies aimed to promote social inclusion should increase the accessibility levels of those in accessibility poverty conditions (Luz and Portugal, 2021).

The accessibility notion was first introduced by Hansen (1959) in the late 50 s and defined as the "potential of opportunities for interaction." However, its link with social exclusion emerged with UK policymakers in the early 2000 s with the publication of the iconic report "Making the Connections: Transport and Social Exclusion", launched by the Social Exclusion Unit (2003). The Social Exclusion Unit (2003) document brought a new narrative to the accessibility notion: the ability of people to reach and take part in opportunities and activities normal for that society (Farrington and Farrington, 2005; Farrington, 2007; Social Exclusion Unit, 2003).

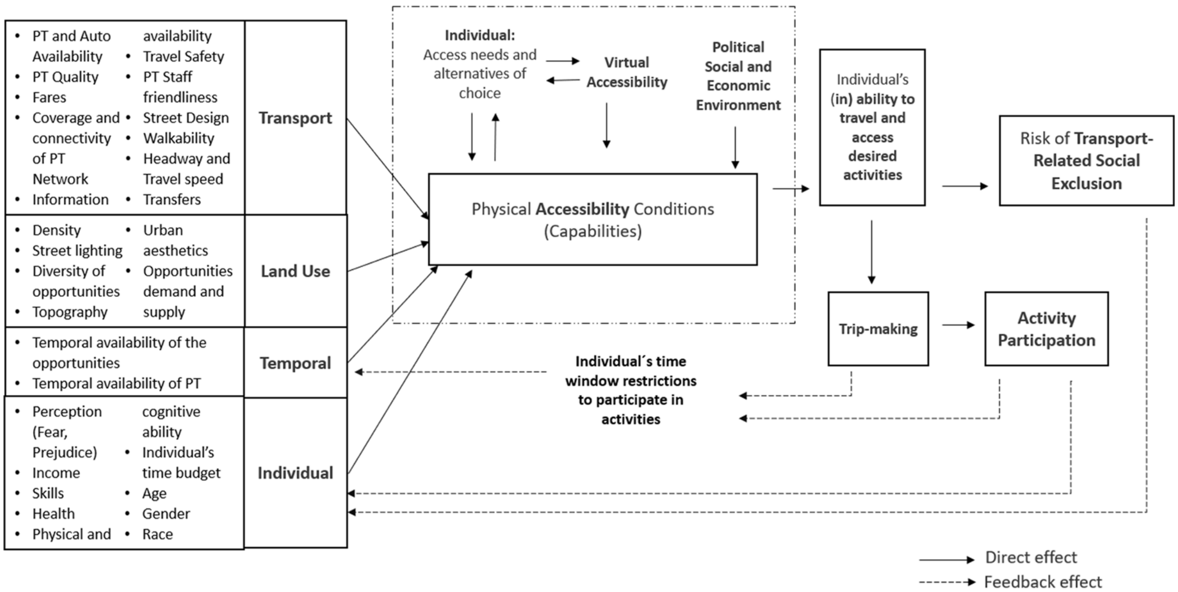

Fig. 1. Conceptual model of the causal relationship between accessibility, activity participation, and the risk of transport-related social exclusion Source. Authors' elaboration.

From this point of view, accessibility is understood as an attribute of individuals in their interaction with the environment, considering how personal characteristics interact with the transport system, land-use, and political, economic, and social environment to shape the individuals' accessible opportunities set (Pereira et al., 2017; Lucas., 2006, 2012; Luz and Portugal, 2021).

Recently, many transport equity and TRSE studies advocate for the application of the Capabilities Approach to express concepts such as the accessibility narrative brought by TRSE literature (Bantis and Haworth, 2020; Hananel and Berechman, 2016; Martens, 2016a; Pereira et al., 2017; Luz and Portugal, 2021). According to those studies, the notion of accessibility as a human capability allows expressing the broad diversity of individuals and how they interact with transport and land use resources and the environment to determine people's participation opportunities (Vecchio and Martens, 2021; Luz and Portugal, 2021; Pereira et al., 2017). Although beneficial to articulate the TRSE accessibility narrative theoretically, the idea of accessibility as a human capability faces a practical challenge (Pereira et al., 2017). Accessibility as a human capability requires one to address accessibility as a result of a combination of personal abilities and perceptions, transport and land-use resources, and the political, social and economic environment, which is a much more complex and multidimensional concept than those used in conventional transport and accessibility studies (Pereira et al., 2017; Vecchio and Martens, 2021; Luz and Portugal, 2021).

Despite the wide range of accessibility measures developed over time (Geurs and van Wee, 2004; Handy and Niemeier, 1997; Kwan, 1998; Neutens et al., 2010), none of them alone can capture all the accessibility as human capability nuances (Luz and Portugal, 2021). Depending on the accessibility measure selected, some accessibility factors will be privileged while others will be neglected (Geurs and van Wee, 2004; Handy, 1996; Kamruzzaman et al., 2016; Kwan, 1998; Martens, 2016a; Neutens et al., 2010; Pyrialakou et al. (2016)). Different accessibility measures account for different facets of how individuals interact with the spatial structure and distribution of opportunities (Fransen et al., 2018). In this sense, different accessibility measures might provide different insights into the equitable distribution of opportunities (Neutens et al., 2010) and, therefore, indicate different policy alternatives.

Fig. 1 provides a conceptual model of the causal relationship between accessibility, activity participation, and transport-related social exclusion risk. Accessibility comprises four components: transport, land use, temporal and individual (Geurs and van Wee, 2004; Luz and Portugal, 2021; Lucas, 2012). The individual's accessibility, i.e. her capabilities, is defined by the transport and land use resources and their respective temporal constraints, plus the individual's perceptions and abilities to convert these resources into access options (Luz and Portugal, 2021; Pereira et al., 2017; Vecchio and Martens, 2021. The individual's ability to travel and access activities will be an outcome of the interaction between her capabilities, her political, economic, and social environment context and their needs and activity alternatives. The travel and activity participation needs will also be influenced by the individual's virtual accessibility (Hong and Thakuriah, 2016; Lavieri et al., 2018). There are four potential effects of virtual accessibility on trip making - substitution (save trips), complementarity (generate trips), modification (change planned activities or trips) and neutrality (negligible effect) (Mokhtarian and Salomon, 1997; Hong and Thakuriah, 2016).

The interaction of all these elements will influence trip making. Since trip making is rarely an end in itself, but usually a means to another end (activity participation), the higher the number of trips, the higher the number of activities an individual participates in. When accessibility conditions are insufficient to enable individuals to make the trip and access the desired activity, they become at risk of transport-related social exclusion.

Participation in activities and non-participation will impact the individual and temporal component of accessibility, creating a feedback loop (Luz and Portugal, 2021). Firstly, the temporal component accessibility will be affected by the restriction in an individual's time window to participate in activities. For example, given that the time budget a person has available to participate in activities is limited (24 h minus the time she is sleeping and personal care, such as eating), the more (and longer) activities they engage in, the less time they have available to participate in other activities. For instance, longer mandatory activities, like work and education, combined with long trips to access it will leave less (or almost none) time budget for other activities. In other words, as they participate in more activities, their accessibility level reduces. Secondly, participation in activities may improve the individual's abilities and skills, expanding the range of activities (accessibility) in which she can participate in. In contrast, an individual who cannot access some types of activities may not be able to develop her skills and thus, will face limited accessibility to jobs. For example, people who participate in education-type activities can build skills and qualify for better jobs that were previously not accessible due to their previous qualifications. Or an older person who can practice physical exercise near their home can improve their physical mobility conditions, allowing them to get on the bus that was previously not accessible due to vehicle design or sudden stops. In sum, participation in activities may improve individuals' skills or physical condition, which, in turn, will expand the range of activities in which they can participate, even though there are limits in this process, as pointed by Fig. 1.

Some sources of endogeneity in the presented framework may compromise the identification of a causal relationship between accessibility and activity participation. Wooldridge (2015) lists three traditional sources of endogeneity in applied econometrics: omitted variables, measurement errors and simultaneity. All three sources are present in the framework. First, the accessibility measures used in practice account only for some of the components that shape an individual's possibilities of participation. It means that they are subject to omitted variables since they do not capture all the accessibility factors and complex social interactions, perceptions, and behaviours that influence activity participation (Bantis and Haworth, 2020; Luz and Portugal, 2021; Curl et al., 2011). Even when many control variables are used to mitigate this source of endogeneity, some aspects such as perception, health, and physical and cognitive ability are challenging to measure. Second, measurement errors in accessibility variables and other independent variables are frequent in studies about the relationship between accessibility and activity participation. For example, when location-based accessibility measures are used, measurement errors regarding the actual position of the individual exist. Also, studies that calculate the accessibility based on GTFS data are subject to measurement errors since most GTFS data are based on a planned public transport timetable, which does not necessarily correspond to what happens in the real world. Other sources of measurement errors are related to the temporal availability of opportunities. Third, simultaneity is present in the feedback loops of the framework. Accessibility can affect the number of trips carried out and the number of activities the individual participates in. At the same time, trips made and activities in which she engaged affect her level of accessibility, as discussed previously.

Most transport equity and TRSE studies assume that increasing accessibility levels lead to increased activity participation and, therefore, a reduction of social exclusion. Although this assumption makes sense from a theoretical point of view, this causal relationship has not yet been validated in practice. In this regard, a more in-depth understanding of the relationship between the most conventional accessibility measures and activity participation is necessary to define sufficient levels of accessibility and design effective policies to mitigate TRSE (Martens, 2016b; Allen and Farber, 2020). However, there has been little empirical research about whether popular accessibility measures positively relate to activity participation and lower risk of social exclusion.

2.2. Accessibility and activity participation

Measuring accessibility in all its dimensions is highly complex; therefore, no accessibility measure adequately captures all possibilities for participation in activities (Martens, 2016a). Empirical evidence on whether accessibility levels correlate with activity participation; and whether a given accessibility measure reflects the individuals' participation possibilities are scarce in the literature. More evidence is found outside the TRSE literature on the relationship between accessibility and trip making. It is plausible that the number of trips made by an individual is directly related to the number of activities in which she/he participated (Allen and Farber, 2020; Merlin, 2015; Luz and Portugal, 2021). Hence, the evidence provided by this group of studies is also helpful in understanding if higher accessibility levels are related to more activity participation (Merlin, 2015) and thus reduced risk of TRSE.

We conducted a systematic literature review to collect empirical evidence about the relationship between accessibility and activity participation/trip-making. The materials reviewed in this section are primarily from articles published in journals. On 11 January 2022, a search was performed in the scientific base Scopus with the following combination of words: ((“accessibility”) AND (“activity participation” OR “participation in activit*” OR “activity rates” OR “trip generation” OR “trip making” OR “trip rates”) in the Title, Abstract or Keyword of the papers. The search returned 289 documents. After applying the filter for documents of the type “article”, published in Journals and written in English, 211 papers remained in the sample. After reading the titles and abstracts of the 211 articles, 171 documents that did not investigate the relationship between accessibility and activity participation or trip-making were discarded, remaining only 40 documents. After carefully examining the 40 articles' full text, 23 out of 40 articles were included in the final literature selection. Finally, we used a forward and backward snowball technique to complement the literature review. The final literature reviewed thoroughly for this section consists of 38 articles. An overview and the key findings of the 38 articles review are presented in appendix A.

Evidence of the relationship under study is scarce for the Global South context, particularly in Latin American countries. Of the 38 articles reviewed, only five are in Global South countries (Ding et al., 2016; Cheng et al., 2019; Krasić and Novačko, 2015; Wang and Cao, 2017; Masoumi, 2021). Moreover, most studies (24) are related to travel forecasting and focus on understanding the relationship between accessibility and the number of trips made. Few studies (9) focus on assessing the relationship between accessibility and activity participation. Five articles have examined the relationship between accessibility, trip generation and activity participation. None of the reviewed studies that have focused on social exclusion and equity aspects related to accessibility provision (Fransen et al., 2018; Allen and Farber, 2020; Cheng et al., 2019) included causal inference methods as the present work does. Studies focusing on trip generation tend to adopt an aggregate approach, using zones as the unit of analysis. At the same time, most papers on activity participation utilise the individual or household as observation.

Most of the reviewed articles used place-based measures of accessibility. The most widely adopted accessibility measure was the gravity type (15 studies) and minimum or weighted distance or time to activities, transport stop or CBD (15 studies), followed by cumulative-opportunities measure (6 studies). Some authors adopted simpler place-based measures (container-type accessibility) that account for only the land use component of accessibility (households density, population density, jobs density, area characteristics) (5 studies) or only aspects of transport infrastructure (3 studies). Other accessibility measures found in the literature are utility-based measures and spatio-temporal measures, such as the volume and the number of activities within the space–time prism (Kitamura et al., 2001), available time for activity participation (Landau et al., 1981; Fransen et al., 2018) and Burns-Miller measure (Ding et al., 2016). Lavieri et al. (2018) further tested the influence of virtual accessibility on the level of participation in face-to-face activities.

Although we might expect higher accessibility levels to be associated with a greater number of trips and more activity participation from a theoretical point of view, the empirical results do not indicate a consensus regarding the validity of this statement. Thirteen articles found that accessibility levels are associated with higher trip making and activity participation (Allen and Farber, 2020; Calvo et al., 2019; Ding et al., 2016; Golob, 2000; Handy, 1996; Koenig, 1980; Krasić and Novačko, 2015; Leake and Huzayyin, 1980; Lee and Goulias, 1997; Merlin, 2015; Purvis et al., 1996; Robinson and Vickerman, 1976; Tian and Ewing, 2017), while seven studies found that this relationship is weak (Hanson and Schwab, 1987; Kitamura et al., 1997) or not statistically significant (Downes and Morrell, 1981; Ewing et al., 1996; Handy, 1993; Wang and Cao, 2017; Wermuth, 1982).

All the studies that adopted space–time accessibility measures identified a positive relationship with at least one type of activity participation. The studies that found no significant or weak effect were published before 1996 (except for Wang and Cao (2017)). Those papers used methods and data less sophisticated than the more recent papers. They all adopted place-based accessibility measures, and only one looked at the relationship between accessibility and activity participation (Wermuth, 1982). However, Wermuth (1982) applied a less robust accessibility measure, location characteristics, as a control variable in the ANOVA. The other five works were focused on trip-making.

Fourteen articles found mixed effects regarding the relationship between accessibility and activity participation/trip making. For example, Cordera et al. (2017) found that the validity of the relationship varies according to the mode of transport. While greater accessibility is associated with a decrease in the number of trips to work by private vehicles, they also found that it is related to an increase in public transport trips. Cheng et al. (2019) found that population density, considered by them to be a type of accessibility measure, significantly affects trip generation, but employment density does not. On the other hand, population and employment density variables show insignificant impacts on activity participation. Kröger et al. (2018) found that accessibility to the nearest business district positively impacts home-based shopping trips but not home-based work trips. Schwanen et al. (2007) suggest that men may take care of more household tasks in a neighbourhood with good accessibility to shops due to fewer space–time constraints. However, they also found that as the travel time to the nearest shopping centre for clothing or footwear rises, individuals participate more frequently in shopping for convenience goods independent of their spouse.

Kitamura et al. (2001) notice that the size of the space–time prism is the critical determinant of activity participation but not the number of opportunities within the prism. Fransen et al. (2018) findings indicate a moderate positive correlation between the available time for activity participation and partaking in discretionary activities. Despite the positive findings for the space–time measure, Fransen et al. (2018)'s findings indicate that the gravity-type measure shows a negative and highly significant relationship to activity participation. Seo et al. (2013) found that maintenance trips are negatively associated with accessibility levels, while other purpose trips are positively associated. Thill and Kim (2005) tested 72 variations of accessibility measures. They found that half of the statistically significant accessibility variables revealed a positive relationship with trip making, while the other half indicated a negative relationship. According to Zhang et al. (2019)'s findings, people who live in denser neighbourhoods (considered by the authors an accessibility measure) are more likely to make more home-based work and shopping trips; however, household density negatively impacts participation in entertainment and social activities. Landau et al. (1981) found that time constraints were significant in the leisure trip models and not in the maintenance trip models. The number of employees in commerce and services in residential areas positively influences the number of maintenance trips but negatively influences leisure trip making. Finally, three studies found a strictly negative relationship between accessibility and activity participation or trip making (Lavieri et al., 2018; Williams, 1989; Wu et al., 2012). Williams (1989) found that activity participation reduces as accessibility increases and that there is no association between the number of trips made and the accessibility conditions. Although Wu et al. (2012) and Lavieri et al. (2018) found a negative relationship, their findings are reasonable according to the theoretical literature. Wu et al. (2012) findings indicate that higher walking and public transport accessibility levels are associated with fewer trips by car. Lavieri et al. (2018) findings indicate that virtual accessibility negatively impacts the number of physical maintenance activities. However, Lavieri et al. (2018) also found that physical accessibility negatively impacts the number of maintenance activities and that individuals who perceive ease of access to opportunities tend to concentrate their maintenance activities in fewer and longer episodes.

Some conclusions can be drawn from the empirical evidence within this literature review on the relationship between accessibility and activity participation or trip making. First, there is no consensus on whether greater levels of accessibility lead to greater activity participation or trip making. Secondly, very few studies have investigated this relationship from TRSE and transport equity perspectives, and most looked at this relationship from a trip generation perspective. Thirdly, due to their focus, those studies applied accessibility measures aggregated by zones and failed to adequately control people's interpersonal heterogeneity. However, the TRSE literature points out that individual characteristics play an essential role in an individual's chances of participation in society (Luz and Portugal, 2021). Fourth, most studies focus on Global North contexts, and empirical evidence is scarce for Global South contexts. Fifth, given the variability of the findings, one of the hypotheses to be raised is that this relationship is sensitive to the quality of the data and the sophistication of the methods used. Also, likely, this relationship is context-specific.

All studies reviewed in this section investigated only the correlational relationship between accessibility measures and activity participation. Although studies that dońt operationalize accessibility measures are out of the scope of the present literature review, it's worth mentioning two studies[1] (Miller et al., 2015; Zhang et al., 2021) that assess the causal relationship through before/after studies, and account for variables related to accessibility in a broader aspect. Those studies used a before/after quasi-experimental design. Using GPS systems and accelerometers, Miller et al. (2015) assessed changes in the physical activity pattern of study participants before and after the Light Rail Transit construction and evaluated differences in these patterns while controlling for sociodemographic variables in Salt Lake City, Utah, United States. Miller et al. (2015) point out that public transit in the neighbourhood contributes to individuals undertaking new physical activities. Although the study does not directly apply an accessibility measure, the construction of the LRT has increased accessibility in the region. Zhang et al. (2021) investigated how the launch of on-demand transit services changed patterns of nightlife activity participation of socially disadvantaged individuals in Belleville, Ontario, Canada. Zhang et al. (2021) found that users' satisfaction with reliability and service quality is positively associated with activity participation. Despite

[1] The two papers (Miller et al., 2015; Zhang et al., 2021) were added based on a suggestion of a reviewer.

Zhang et al. (2021) not using a conventional accessibility measure, the reliability and service quality improvement may be seen as an increase in accessibility.

Unlike the present work, none of the reviewed studies used identification strategies to infer a causal relationship between accessibility measures and activity participation or trip making. One may argue that structural equation modelling (SEM) can account for the causal relationships between the variables included in the model. However, Bollen and Pearl (2013, p. 308) argue that “developers and users of SEMs are under the mistaken impression that SEMs can convert associations and partial associations among observed and/or latent variables into causal relations.” For a more in-depth discussion, see Bollen and Pearl (2013).

Much of the TRSE research treat accessibility as a critical indicator of the number of opportunities available to individuals. From a theoretical perspective, such a statement makes complete sense. However, previous studies investigating the accessibility-participation relationship were inconclusive, indicating that increasing accessibility has a limited impact on activity participation levels, if any (Fransen et al., 2018; Martens, 2016a). It may suggest that the link between accessibility and activity participation is less direct than expected. In this sense, evaluating policy interventions using accessibility measures may lead to misleading results regarding the possible impacts on activity participation (Martens, 2016) and, therefore, on social exclusion.

3. Study Area and regional context

The study focuses on the City of São Paulo, Brazil, Latin America’s largest city and home to 12 million people. São Paulo’s development illustrated Brazil’s fast urbanisation process throughout the last century when the city had average annual growth rates of 4.5 per cent until 1950 (Moreno-Monroy and Ramos, 2020). Following the 1950 s, the city had its most significant development driven by the placement of industrial parks, leading to an ongoing spatial reconfiguration closely linked to a traditional monocentric pattern (Moreno-Monroy and Ramos, 2020). In the following decades, the unmanaged centrifugal expansion developed a wide suburban outer belt filled by the poor and less educated population (Moreno-Monroy and Ramos, 2020). Consequently, the locations with lower levels of job accessibility are also those with poorer socioeconomic status, shorter life expectancies and disproportionally precarious infrastructure (Slovic et al., 2019).

Due to uncontrolled urban expansion, the historical prioritisation of private over collective modes of transport, and a suboptimal and uneven provision of urban public transport, a considerable share of the more disadvantaged population faces low accessibility levels and, therefore, longer commuting times and distances (Slovic et al., 2019; Boisjoly et al., 2020; Biderman, 2008). The weaker transport connectivity in regions farther from the wealthier central areas and the concentration of jobs in the CBD prevent carless workers from accessing potential employers far from the focal points of public transport accessibility (Haddad and Barufi, 2017; Boisjoly et al., 2017). As a result, access to opportunities is constrained for this population group, making São Paulo much more unequal than Global North cities (Giannotti et al., 2021).

The 2017 São Paulo Origin-Destination (OD) Survey estimates that 42 million trips are made daily in the Metropolitan Region of São Paulo, 67 % in motorised vehicles and 33 % in non-motorised modes (Companhia do Metropolitano de São Paulo, 2019). Among the motorised trips, approximately 54 % occur in collective modes, while 46 % are in private vehicles. There is a high public transport dependency among low-income households. When evaluated by income bracket, 72 % of families’ trips with monthly incomes up to U$ 580[2] occur by public transport, while in the highest income group U$ 3484, only 20 % are made by public transport (Companhia do Metropolitano de São Paulo, 2019).

4. Methodology

This paper focuses explicitly on inferring a causal relationship between accessibility levels and activity participation in a Global South context, the city of São Paulo. The study focuses on the social consequences of activity participation rather than the implications of particular travel demand. In this sense, we do not differentiate the activities individuals access by transport mode. We assessed the accessibility-activity participation relationship according to the type of activities accessed, mandatory activities (work and education), discretionary activities (leisure, shopping or having a meal), and total activities (without distinguishing between purposes).

The methodology section is organised into four parts. The next subsection describes the database used in the study. Subsection 4.2 presents the accessibility indicator adopted in the analysis. Subsection 4.3 describes the econometric models and the rationale for their choice. Finally, subsection 4.4 discusses the identification strategy adopted to control the models’ endogeneity and allow inference of causality between accessibility and activity participation.

4.1. Data

The data used in this research come from different databases, such as the 2017 Origin and Destination (OD) Survey of the São Paulo Metropolitan Region (Compahia do Metropolitano de São Paulo – Metrô, 2019); Access to Opportunities Project (AOP) (Pereira et al., 2019); 2010 Demographic Census of the Brazilian Institute of Statistical Geography (Instituto Brasileiro de Geografia e Estatística - IBGE, 2011); and the 2010 Paulista Social Vulnerability Index (Fundação Sistema Estadual de Análise de Dados, 2013).

Data on individuals’ activities were taken from the 2017 RMSP Origin and Destination (OD) Survey. The OD survey collects

[2] 1 US Dollar (U$) = 3,29 Brazilian Real (R$). April 2018 values.

information regarding daily trips within the Metropolitan Region of São Paulo and sociodemographic data from households, families, and individuals. The OD Survey data is collected from households chosen through sampling. All individuals answer a questionnaire about their sociodemographic information and trips made on the weekday before the OD Survey taker's visit. The data of the 2017 OD Survey were collected between June 2017 and October 2018, except for the school holiday periods, which were considered atypical for conducting the survey.

Data at the individual level were extracted from the OD 2017 Survey database exclusively for the São Paulo municipality. The choice to conduct the research only within the city of São Paulo is justified by the unavailability of accessibility data for the entire metropolitan region. The selected variables include age, gender, study status, level of education, employment status, number of family members, individual monthly income, and family status. Individuals aged 13 or younger were removed from the data set because they depend on other family members to travel and participate in activities. New variables were generated from the original database by dividing the number of private vehicles (cars and motorcycles) and family monthly income by the number of people in the family.

Variables regarding the number of activities the individual participated in were created from the travel diary. Trips to destinations other than home were considered an activity in the "total activities" category, trips for work or study purposes to destinations other than home were considered a mandatory activity, and trips for discretionary purposes (leisure, shopping or having a meal) to destinations other than home were counted as a discretionary activity. It is important to note that the sum of discretionary activities and mandatory activities does not equal the number of total activities. Some categories, such as travel for health purposes, were only included in the total activities category.

Since the OD Survey does not account for individuals' race, we tried to incorporate this aspect by calculating the proportion of declared black people living in the hexagon where the individual lives. Although this data was taken from the AOP, it originally came from the 2010 IBGE Demographic Census.

The third database used was the 2010 Paulista Index of Social Vulnerability (IPVS), produced by the State of São Paulo Legislative Assembly. The IPVS is calculated based on information from the 2010 IBGE Demographic Census and considers information on income, health, participation in the labour market, access to public services and opportunities for social mobility. The IPVS is divided into six levels that vary according to the combination of these variables; however, for this study, we grouped these six levels into two categories: living in a region of high social vulnerability and not living in a region of high social vulnerability. The use of all categories would imply too few observations in some categories, and the differentiation between the levels is quite subtle and not relevant to the scope of this study.

Most of the sociodemographic and built environment variables selected were adopted in previous studies that assessed the accessibility-activity participation relationship from an equity perspective, such as age, gender, per capita income and vehicle ownership, study status, family status, level of education and population density (Fransen et al., 2018; Allen and Farber, 2020; Cheng et al., 2019).

After merging the different databases to the OD Survey data and generating the new variables based on this data, we excluded observations that were not complete, resulting in a sample of 47,167 individuals. Those individuals where the value of their accessibility was not available in the Access to Opportunities Project (AOP) database were excluded from the sample. Approximately 1.83 % of the sample was removed (877 observations).

4.2. Accessibility measure

The accessibility data used in this study was extracted from the Access to Opportunities Project (AOP) of the Institute for Applied Economic Research (IPEA) (Pereira et al., 2019). AOP aims to understand transport conditions and inequalities of access to opportunities in Brazilian cities. The AOP estimates the population's access to job opportunities by public transport in the largest urban regions in Brazil annually. Such estimates are made using GTFS (General Transit Feed Specification) data on public transport provided by the municipalities, data on the road network for September 2019 from the Open Street Map website, data from the 2010 Demographic Census of the Brazilian Institute of Statistical Geography (IBGE) and data on formal employment from the 2017 Annual Social Information Report (RAIS) of the Ministry of Labour.

Job accessibility variables by public transport were selected from the AOP database. Accessibility levels were measured using the cumulative opportunity measure (CUM) and depict the proportion of formal jobs in the municipality accessed by public transport within a given travel time threshold. Computed travel times were calculated during peak hours and included walking to and from stops, waiting for a transit vehicle, time spent travelling in a transit vehicle, and any time spent transferring between vehicles. The accessibility values calculated by the AOP have a high spatial resolution, with values aggregated in H3 hexagons at resolution 9, developed by technology company Uber. More specifically, the values are aggregated in hexagons of 174.38 m side. The level of accessibility of the OD Survey respondent was determined by the latitude and longitude of her household. That is, the individual's accessibility level was assigned according to the hexagon in which her home was located.

The CUM measure is defined as follows:

$$CUM = \frac{\sum_j a_j h_\delta(c_{ij})}{N} \quad (1)$$

Where a_j is the number of jobs in j, δ is the time threshold, c_ij the travel time between an individual's location (i) and location j, and $h_\delta(c_ij)$ assumes the value one if $c_ij \leq \delta$ and 0 if $c_ij > \delta$, and N is the total number of formal jobs in the São Paulo municipality. Four different travel times by public transport thresholds were tested: 30, 60, 90 and 120 min. Despite the limitation of our accessibility data that is restricted to employment opportunities, Allen and Farber (2020) and Cordera et al. (2017) pointed out that employment distributions are theorised to be a proxy for many other types of potential destinations (e.g., services, stores, informal jobs, etc.). Thus, the accessibility values used are reasonable estimates of the level of accessibility to general activities in the city.

The CUM measure was selected due to the unanimity among researchers concerning its ease of operationalisation, communication, and interpretation (Koenig, 1980;Geurs and van Wee, 2004; Neutens et al., 2010; Curl et al., 2011; Neutens, 2015). It is one of the most used accessibility measures in practice (Boisjoly and El-Geneidy, 2017b). CUM requires only information regarding opportunities' quantity and spatial distribution, and travel time from the reference location to these opportunities. It does not require data regarding the attractiveness of the activities and does not require the adoption of a transport deterrence function with a calibrated parameter. In addition, the computational power demanded to calculate CUM is considerably lower than other more realistic measures, allowing the application at the macro scale, such as entire cities and metropolitan regions. Due to the less powerful equipment requirements, CUM is much easier to implement by technicians in transportation planning agencies and interpreted by policymakers and the population, which is crucial in the Global South context, where most transport agencies face data limitations and have low-skilled technical staff (Barboza et al., 2021).

From the perspective of accessibility as a human capability, one should ideally adopt a person-based accessibility measure that accounts for as many as possible personal characteristics that shape an individual's accessibility. However, many policy evaluations and interventions use cumulative opportunities measure as a metric to assess equity and risk of transport-related social exclusion. In this sense, we want to test whether one of the most straightforward and commonly used measures in practice still has a causal effect on activity participation. In other words, we want to check whether even a measure that captures only some characteristics of the transport and land-use components of accessibility is still a valuable tool to inform more inclusive transport policies.

4.3. *Activity participation models*

The proposed models estimate whether accessibility influences the total, mandatory and discretionary activities carried out by individuals. More specifically, we intend to assess if higher accessibility levels cause more activity participation and, therefore, reduce the risk of TRSE. Our dependent variables are counts and follow a similar distribution to Poisson. The total activities variable has the mean precisely equal to the variance, while the variables of mandatory activities (work and study) and discretionary activities (leisure, shopping and having a meal) have variance values very close to the mean. In addition, we conducted tests for overdispersion (when the residual deviance is higher than the degrees of freedom of the model) proposed by Cameron and Trivedi (1990). According to the test, the total and mandatory activities variables did not present overdispersion. On the other hand, the discretionary activities variable presented statistical significance for dispersion. However, the dispersion value (η) identified was tiny (0.02). Griffith (2013) suggests that if $0 \leq \eta \leq \frac{0.5}{\lambda}$ Overdispersion will not pose a problem, and there will be little gain in replacing the Poisson regression model with a Negative Binomial model. For the discretionary activities model, we have $((\eta = 0.02) \leq \frac{0.5}{0.18} = 2.78$, which indicates that overdispersion will not cause problems to the Poisson regression model. Furthermore, as Cameron and Trivedi (2009) pointed out, robust standard errors in the model can control for smooth violations in the equidispersion property. Table 1 presents the descriptive statistics of the dependent variables.

We tested four job accessibility variables, with 30, 60, 90 and 120 min of public transport travel time threshold. The 90 min threshold accessibility variable presented a higher residual deviation after its introduction in each model. It indicated that the best accessibility variable would be the one with 90 min threshold, as a higher residual deviation best explains dependent variables (Roback and Legler, 2021). Quadratic and cubic specifications for accessibility variables were tested to assess the best fit for the mathematical relationship between accessibility-activity participation. However, the best specification for all three models was linear.

We also tested a logistic transformation (Equation (2)) of the accessibility measures used by Allen and Farber (2020) to obtain a sigmoid relationship between accessibility and activity participation. In this transformation, A is the accessibility value, k is the curve's steepness, and A_m is the value at the midpoint of the curve (i.e. the value of accessibility where the slope is at maximum). We use Akaike's information criterion (AIC) (Akaike, 1973) to compare the models. The improvement in the explanatory power of the model obtained with the sigmoidal transformation of the accessibility was negligible. Moreover, the value of the parameters associated with the best AIC were $k = 2.8$ and $A_m = 1.0$. However, with such specifications, the shape of the curve of the relationship between accessibility and participation in activities is practically identical to the shape obtained with the Poisson model without the accessibility logistic transformation (discussed in section 6.2). In this sense, to maintain the interpretability of the accessibility coefficients, we opted to maintain the Poisson model without the sigmoidal transformation of accessibility.

$$f(\mathrm{A}) = \frac{1}{1 + e^{(-k(\mathrm{A}-\mathrm{A_m}))}} \tag{2}$$

Control variables related to the sociodemographic information of individuals and characteristics of the region where the individual lives were also added to the models. Such variables were selected based on the transport-related social exclusion literature and the previous works on the relationship between accessibility and activity participation/trip making revised in section 2.2 and include family monthly income per capita, age, private vehicles ownership, gender, number of people in the family, the proportion of black people in the region, study status, family status, employment status, social vulnerability region, level of education, individual income, populational density, family status and presence of dependent children and elderly in the household. We consider all people under 18 or above 65 years old living with others in the same residence as a proxy for a dependent.

The existence of multicollinearity was assessed using the variance inflation factor (VIF). None of the variables presented a VIF value>5, indicating no multicollinearity problems among the independent variables included in the models. Moreover, LOESS-type non-linear models were used to assess the relationship between independent variables and the number of activities carried out. Some variables, such as family monthly income per capita, age and number of residents in the household, presented a quadratic relationship with the log of the number of activities. Only the variables that showed a drop in the residual deviance (increased the model's explanatory power) were added to the model. The best models were selected using Akaike's information criterion (AIC).

Given the large proportion of zeros in the sample, it seems plausible to think that a zero-inflated model would better fit the explanatory variables. However, the large proportion of zeros does not necessarily mean an excess of zeros. Evaluating Poisson distributions with incidence rates (λ) equal to the mean for the model's dependent variables (number of total activities, number of mandatory activities and number of discretionary activities), we found that the number of zeros in the sample is within the expected for such distributions. In this sense, there is no need to use a zero-inflated model.

Finally, the generic Poisson regression model for estimating the participation in total, mandatory and discretionary activities is defined as follows:

$$\lambda_i = \exp\left(\beta_{0_i} + \beta_{1_i}X_1 + \beta_{2_i}X_2 + \beta_{3_i}X_3\right)$$

where,

λ_i– Number of activities in which the individual participated..$(i = \mathrm{Total},\ \mathrm{mandatory},\ \mathrm{discretionary})$

β_{0_i}– Intercept.

X_1– Accessibility by public transport variable calculated from the CUM measure with a 90-minute threshold.

X_2– Vector of variables with individual sociodemographic information.

X_3– Vector of variables with information regarding the urban environment of the individual's residence.

β_{1_i}, β_{2_i}, β_{3_i}– Coefficients or coefficient vectors of the respective independent variables.

It is important to note that the variable of total activities individuals participated in is not equal to the sum of mandatory and discretionary activities variables. The total activities variable includes activities such as visiting a doctor, job search, and others, which are not included in the mandatory and discretionary categories.

Since we are not necessarily interested in making the results representative of the whole population in the region but in assessing the causal relationship between accessibility levels and participation in activities, we opted not to use the expansion factors of the OD Survey. It would bring additional uncertainty to the model without contributing to our primary goal.

We adopted an instrumental variable identification strategy to avoid endogeneity problems in the models and, consequently, to infer causality between the level of accessibility and the number of activities carried out. The following section describes the strategy and presents the reasoning for selecting the instrument. The models for the total, mandatory, and discretionary activities dependent variables before the application of the instrument are available in appendix B.

4.4. Endogeneity and instrumental variable

In a regression, the error or disturbance term represents factors other than × that affect y. When one of the independent variables correlates with the regression error term (u), this variable is endogenous (Wooldridge, 2015). In the presence of endogenous variables, the consistency of the estimators is compromised, preventing the identification of a cause-effect relationship between the explanatory and dependent variables. Hence, it is essential to use some identification strategy to control endogeneity and thus infer the causal effect of accessibility on activity participation. The best way to control endogeneity is to use natural experiments or policy-induced "quasi-random" changes in accessibility (Bastiaanssen et al., 2021). Since neither of these approaches is possible due to the cross-section

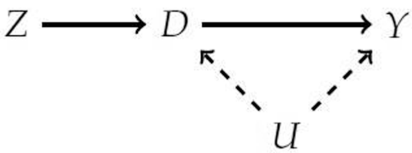

Fig. 2. DAG (directed acyclic graph) Source: Cunningham (2021).

nature of the database, we decided to apply an identification strategy based on an instrumental variable (IV).

Cunningham (2021) suggests drawing on a DAG (directed acyclic graph) that shows a chain of causal effects to understand the IV technique Fig. 2. In our model, variable Z denotes the instrumental variable, D the accessibility variable, Y the number of activities an individual has participated in, and u are all the unobservable factors affecting accessibility and activity participation. A better understanding of the factors affecting accessibility and participation in activities and the direction of these effects can be obtained from Fig. 1. To control the endogeneity of D (accessibility) and be able to determine its causal effect on Y (activity participation), one must choose an instrument that meets three criteria (Cunningham, 2021):Fig. 2.

(i) Z must be highly correlated and have a causal effect on D or share a common cause;

(ii) Z must affect Y only through D. There is no direct effect of Z on Y (Exclusionary constraint).

(iii) Z is not correlated with or is independent of u and, therefore, does not share a common cause with outcome Y. The instrument Z must not be correlated with the regression residuals of D on Y.

The instrumental variable method allows estimating the average effect of D on Y through the instrument Z, irrespective of having measured the other (omitted) variables necessary to control for the effects (u) that may cause confusion in the estimation of Y. The instrumental variable estimator bypasses the need to adjust for confounding variables by estimating the average effect of D on Y from two effects of Z: the average effect of Z on D (first stage) and the average effect of Z on Y (second stage). These two estimated effects are consistent since Z is randomly determined and does not correlate with the errors. As a result, it is possible to identify the causal effect of D (accessibility measured by CUM) on the number of activities individuals participate in (Y).

A good instrument for our model, therefore, must be highly correlated and have a causal effect or share a common cause with the accessibility variable (endogenous variable), must affect the number of activities in which individuals participate in only through accessibility, not share common causes with the activity participation and be randomly determined. Simply put, the instrument must be correlated with the number of activities in which individuals participate only through accessibility.

The selection of the instrumental variable was based on previous studies (Duranton and Turner, 2011; Jin and Paulsen, 2018; Haddad and Barufi, 2017), which suggest that geography is a strong determinant of transport infrastructure in a city. More specifically, the strategy adopted is the same that Haddad and Barufi (2017) used to assess the impact of accessibility on wages in the São Paulo

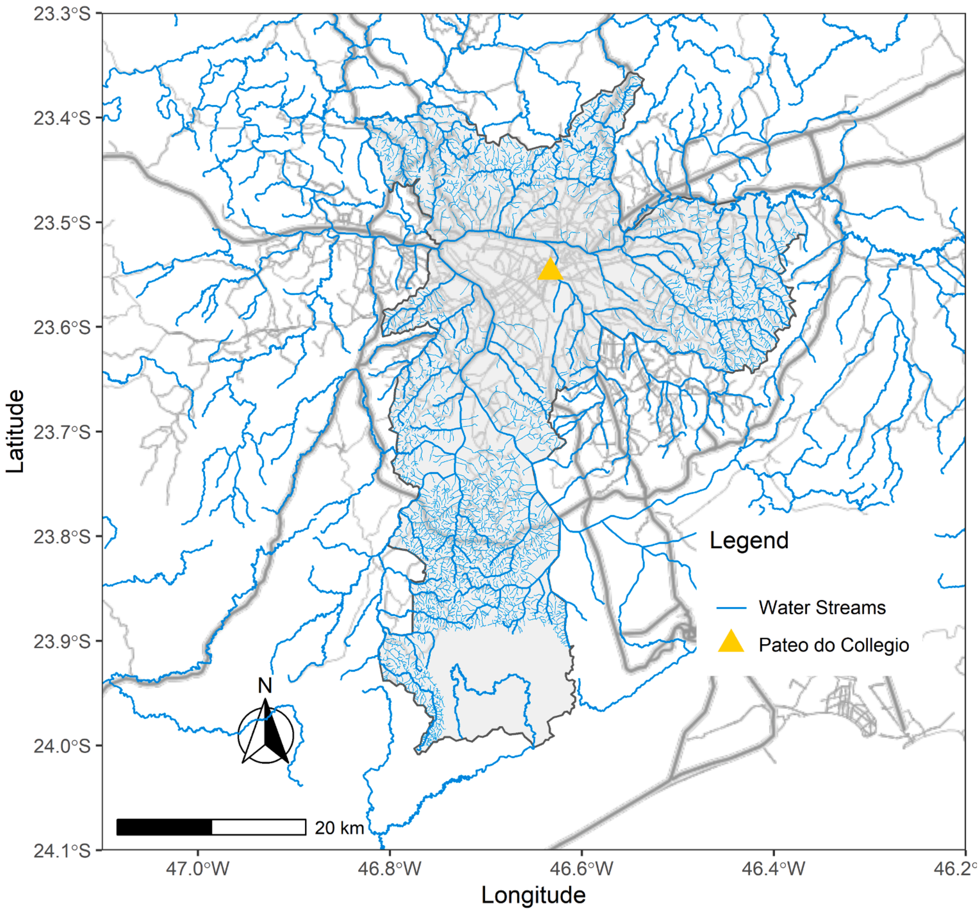

Fig. 3. Water Streams in the city of São Paulo.

metropolitan region. The proposed strategy is based on including a geographical/historical variable, the river shore distance to the first school built by the Jesuits in Sao Paulo, the city's founding location currently known as Pateo do Collegio.

The instrumental variable was calculated from a georeferenced watershed database where the municipality of São Paulo is located. The distance in kilometres from each location in the database to Pateo do Collegio by the nearest river shore was estimated using the Network Analysis tool of the QGIS software version 3.16.8. Fig. 3 presents the water streams in the municipality of São Paulo, and Pateo do Collegio location.

Source: Authors' elaboration.

The reasoning for the choice of the instrument was the same adopted by Haddad and Barufi (2017). According to the authors, geography acted as a determinant of the location of transport infrastructure in the region. Consequently, the road network presents a strong spatial correlation with the existing water streams before urbanisation. It means that the instrument Z, the distance to Pateo do Collegio by the river shore, was naturally/randomly determined by the region's geography. Haddad and Barufi (2017) further provide a historical perspective on the instrument's validity. According to the authors, in the mid-nineteenth century, the city of São Paulo started a systematic occupation of the city's floodplains due to the implementation of regional and urban rail and road infrastructure. In 1929, the Plano de Avenidas further reinforced the occupation of river floodplains by focusing on developing wide avenues along the talweg. Still, according to Haddad and Barufi (2017), this conception of using the floodplains as a preferential space for circulation prevailed in the following plans of the city. Today, talweg avenues are the main arterial roads in the town of São Paulo (Meyer et al., 2004). Based on geographical and historical justifications, the exogeneity of the instrument seems plausible.

Pearson's correlation coefficient between accessibility by public transport measured using the CUM measure with a 90-minute threshold and the distance to Pateo do Collegio by the nearest river shore was statistically significant and strongly correlated (-0.637). The correlation between the instrument and the three dependent variables (Total activities, Mandatory/Fixed activities and Discretionary/Flexible activities) and between the instrument and the estimated models' residuals presented an R-squared coefficient very close to zero (0.009 for total activities, 0.004 for mandatory activities and 0.006 for discretionary activities).

Since the model estimated in the previous section is not a linear regression model, the popular technique of applying the instrumental variable via two-stage least square (2SLS) estimation is not applicable (Cameron and Trivedi, 1998). Specifically, first-stage regression of an endogenous regressor on instruments followed by second-stage Poisson regression with the endogenous regressor replaced by its first-stage predicted value leads to inconsistent parameter estimates (Windmeijer and Silva, 1997). In this case, using the generalised method of moments (GMM) is recommended to estimate the Poisson regression model with endogenous regressors. Considering that the Poisson regression model does not present a separate error term as in linear regression (additive error term) since λ determines both the mean and variance of a Poisson random variable, it is recommended to use multiplicative errors to estimate the model (Mullahy, 1997). After treating the endogeneity of the accessibility variable, the final models were estimated using the ivpoisson tool of the Stata software version 13 with the option of multiplicative and robust errors. The final models and their results are presented in the results section of the paper.

One of the problems frequently encountered in regression models with spatial nature data is neglecting spatial dependence (LeSage and Pace, 2009). The spatial dependence leads to a simultaneity bias and compromises the consistency of the estimated coefficients. To evaluate the spatial dependence of the models, Moran's I was calculated for the three models' residuals using the two types of neighbourhood matrix (rook and queen) of first and second order. The Moran's I values found were quite low ($I \leq 0.033$), indicating that there is no need to use spatial models.

5. Descriptive statistics

The descriptive statistics of the number of activities performed are presented in Tables 1 and 2. On average, individuals perform 1.1 activities per day, with the average participation in mandatory activities equalling 0.78 and discretionary activities 0.18. Approximately 3 % of the sample participates in more than three activities.

Regarding mandatory trips (work and study), 43.3 % did not participate in any of them on the day before the OD survey, and 39.64 % participated in one mandatory activity. The vast majority of the sample (83.73 %) did not perform any discretionary trips on the day before the survey.

Table 3 characterises the sample according to sociodemographic variables. Figs. 4, 5, 6, and 7 depict the spatial distribution of accessibility, income, social vulnerability, and self-declared black people in São Paulo, respectively. These figures reveal the city's racial, economic, and social segregation. While most people living in the centre are wealthier, white and less socially vulnerable, on the city's outskirts are the poorer, black and more vulnerable. According to the TRSE literature, the transport disadvantage is not equally or randomly distributed across society but follows the well-established lines of structural social inequality (Ureta, 2008; Lucas, 2011;

Table 1
Univariate analysis of Dependent Variables.

Activity Frequency	Mean	Std.Dev	Min	Q1	Median	Q3	Max	IQR	N.Valid
Total activities	1.10	1.05	0	0	1	1	13	1	47,167
Mandatory/Fixed Activities	0.78	0.86	0	0	1	1	13	1	47,167
Discretionary/Flexible Activities	0.18	0.44	0	0	0	0	7	0	47,167

Table 2
Distribution of Dependent Variables.

Total activities	n	%
0	13,202	27.99
1	23,152	49.09
2	5,861	12.43
3	3,557	7.54
> 3	1,395	2.96
Mandatory/Fixed Activities	**n**	**%**
0	20,421	43.30
1	18,696	39.64
2	6,554	13.90
3	992	2.10
> 3	504	1.07
Discretionary/Flexible Activities	**n**	**%**
0	39,495	83.73
1	6914	14.66
2	652	1.38
3	74	0.16
> 3	32	0.07

Table 3
Characterisation of the sample sociodemographics.

Monthly Income per capita (minimum wage of U$ 285)	n	%	Gender	n	%
0	385	0.82	0. Male	21,625	45.85
< 0.5	3,175	6.73	1 - Female	25,542	54.15
0.5–1	10,249	21.73			
1–2	14,662	31.09	**Employment Status**	**n**	**%**
2–3	7,215	15.30	1 - Has a regular job	24,175	51.25
3–4	4,089	8.67	2 - Do odd-jobs	2,415	5.12
4–5	2,499	5.30	3 - On sick leave	291	0.62
5–10	4,069	8.63	4 – Retired/Pensioner	8,320	17.64
> 10	824	1.75	5 - Unemployed	4,579	9.71
			6 - Never worked	166	0.35
Age Group	**n**	**%**	7 - Housewife	3,090	6.55
13–18	2,950	6.25	8 - Student	4,131	8.76
18–29	9,082	19.25			
30–64	26,714	56.64	**Study Status**	**n**	**%**
65–75	4,915	10.42	1 - No	40,427	85.71
+75	3,506	7.43	3 - Primary/Elementary	1,232	2.61
			4 - Secondary/Middle	1,925	4.08
Educational Level	**n**	**%**	5 - Higher/University	3,038	6.44
1 - Non-Literate/Incomplete Primary I	3,071	6.51	6 - Other	545	1.16
2 - Elementary I Complete / Incomplete Secondary II	4,986	10.57			
3 - Elementary II Complete / Middle School	6,365	13.49	**Number of people in the family**	**n**	**%**
4 - Secondary Complete / Higher Education Incomplete	16,463	34.90	1	4,299	9.11
5 - Higher Education Complete	16,282	34.52	2	13,096	27.77
			3	13,119	27.81
Family status	**n**	**%**	4	10,049	21.31
1 - Responsible person	20,623	43.72	5	4,338	9.20
2 - Spouse / Partner	11,030	23.38	6	1,393	2.95
3 - Child / Stepchild	10,712	22.71	7	873	1.85
4 - Other Relative	4,045	8.58			
5 – Other Resident	510	1.08	**Private vehicle per capita**	**n**	**%**
6 - Resident Employee	242	0.51	0	16,315	34.59
7 - Relative of Resident Employee	5	0.01	< 0.25	2,497	5.29
			0.25 – 0.50	11,135	23.61
Individual Income	**n**	**%**	0.50 – 1.0	12,187	25.84
Yes	16,889	35.81	0.75 – 1.0	737	1.56
No	9,981	21.16	1.0 – 1.5	4,500	9.54
Did not answer	20,297	43.03	> 1.5	533	1.13
Paulista Social Vulnerability Index	**n**	**%**			
0 - Does not live in a high social vulnerability region	42,777	90.69			
1 - Lives in a high social vulnerability region	4,390	9.31			

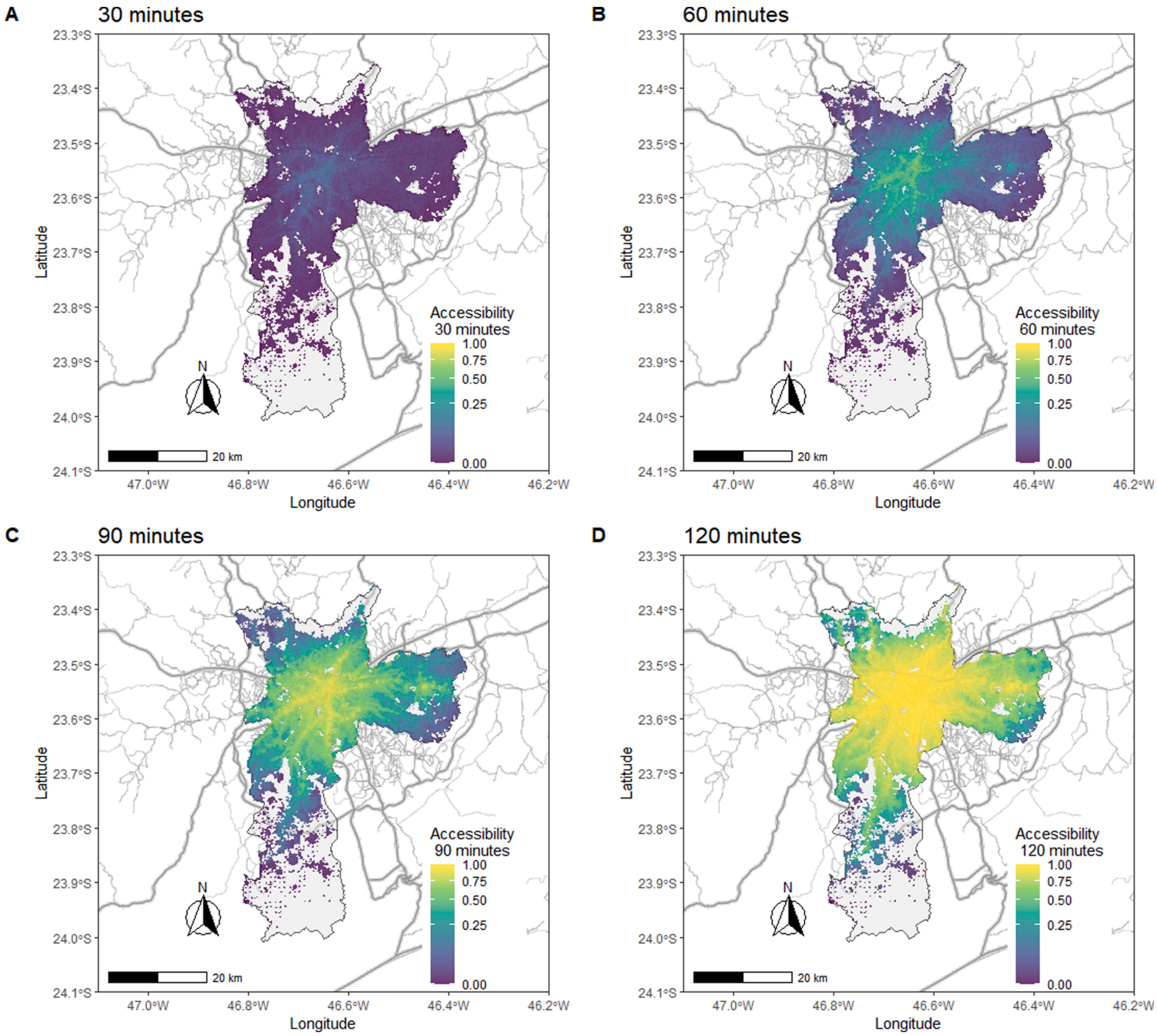

Fig. 4. Spatial distribution of accessibility measures.

Bocarejo and Hernandez, 2012; Jaramillo et al., 2012; Xiao et al., 2018). Locations with the worst levels of transport disadvantage are also those with the worst socioeconomic conditions (Jaramillo et al., 2012; Xiao et al., 2018).

6. Results and discussion

6.1. Socio-demographics and activity participation

Although we cannot infer a cause-effect relationship between the sociodemographic factors included in the model and the activity participation level, exploring the models' results for these variables can help us better understand the TRSE phenomenon (Table 4).

The per capita family income variable presented a quadratic relationship with the total, mandatory and discretionary activities variables. The quadratic relationship between the per capita family income variable and the number of total, mandatory and discretionary activities shows that the increase in income among individuals with lower per capita family income has a greater impact on activity participation. This impact decreases as income increases.

The individual income variable was included only in the total activities and discretionary activities models since simultaneity issues could emerge in the mandatory activities model. Only the "Yes" category presented statistical significance in both models in which it was included. On average, people who have an individual income participate in 9.63 % more total activities than those who did not declare whether they have income or not, and in 35.02 % more discretionary activities also compared to the reference category. These results are consistent with the TRSE literature indicating that poverty and low income represent risk factors for TRSE (Lucas, 2011; Luz and Portugal, 2021; Ureta, 2008; Walks, 2018; Bocarejo and Oviedo, 2012; Jaramillo et al. 2012.; (Kamruzzaman and Hine, 2012)).

The three models pointed out that the age variable has a quadratic association with activity participation. As age increases, the

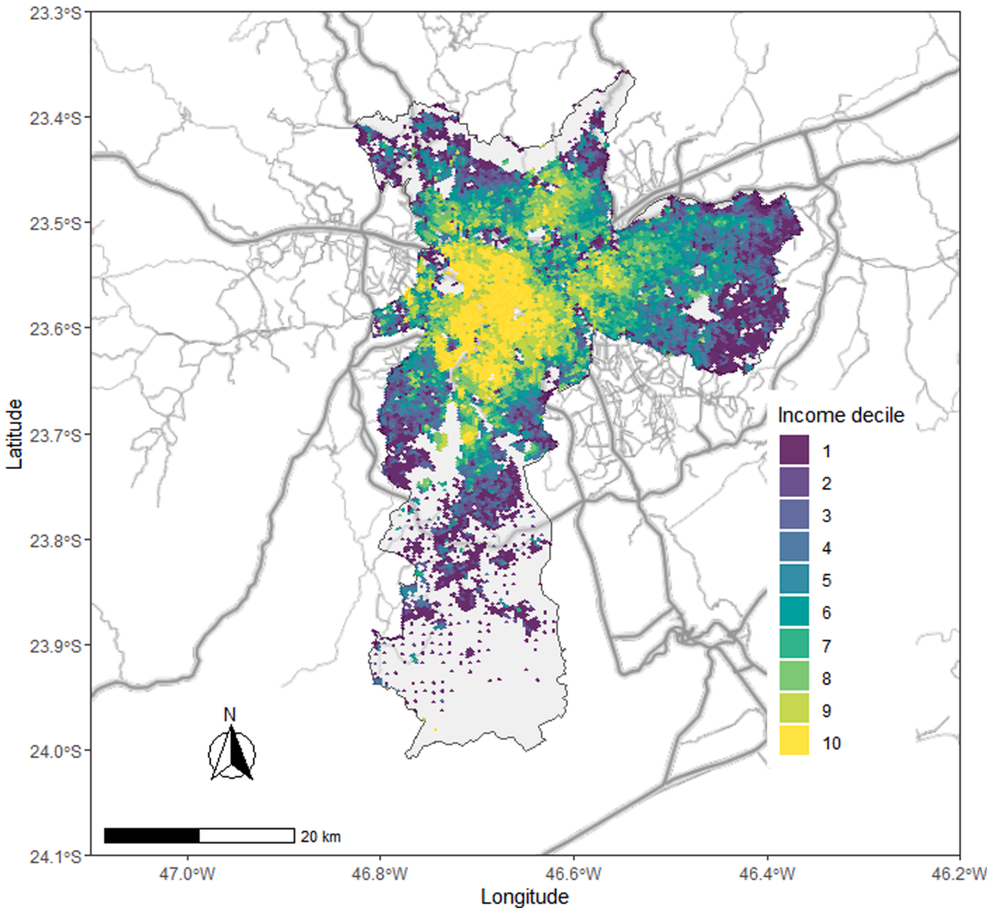

Fig. 5. Spatial distribution of family income.

activity participation rate increases for all types of activity up to a certain threshold, where increasing age leads to a reduction in the number of activities undertaken by the individual. The age at which individuals participate in more activities is approximately 37 years for total activities, 38 years for mandatory activities and 40 years for discretionary activities. For the elderly, the TRSE literature points out that their physical and cognitive difficulties in using public transport may put them at risk of social exclusion (Denmark, 1998; Engels and Liu, 2011; Shergold and Parkhurst, 2012; Luz and Portugal, 2021). On the other hand, younger individuals often lack the independence and safety to travel alone or are not allowed to drive and, therefore, have their ability to participate in activities limited (Denmark, 1998; Kenyon et al., 2002; Luz and Portugal, 2021).

The number of family per capita private vehicles positively correlates with activity participation. The results align with the TRSE literature, which points out that households with fewer cars participate in fewer activities. The impact of lack of a car is even more significant in car-dependent societies (Hine, 2004; Delbosc and Currie, 2011; Shergold and Parkhurst, 2012; Jaramillo et al., 2012; Kamruzzaman and Hine, 2012; Mattioli, 2014).

The gender variable was only statistically significant in the mandatory and discretionary activities model. Women participate in 6.02 % and 6.10 % less mandatory and discretionary activities than men, respectively. Although the gender variable is not statistically significant in the total activities model, people in the category Spouse / Partner, composed mainly of women, participate in 13.80 % fewer activities than the reference category Responsible person, composed chiefly of men. We also found that retired individuals, unemployed individuals or individuals who have never worked participate in less total and mandatory activities but in more discretionary activities than those with a regular job. It may indicate that time availability is crucial for participation in non-discretionary activities (Fransen et al., 2018; Landau et al., 1982).

The number of family members is associated with the mandatory and discretionary activity participation level. The relationship between the number of family members and participation in activities is quadratic for mandatory activities. The number of mandatory activities in which the individual participates increases as the number of people in the family increases, reaching the inflexion point at eight members. The variation in the rate of increase in discretionary activities is constant. One more individual in the family is associated with 6.29 % lower participation in discretionary activities. These findings may suggest that the more people in the family, the less the individual's need for social interaction since they can partially fulfil it at home.

We also found that individuals over 18 and under 65 years old who live with a dependent child participate in 50.81 % more

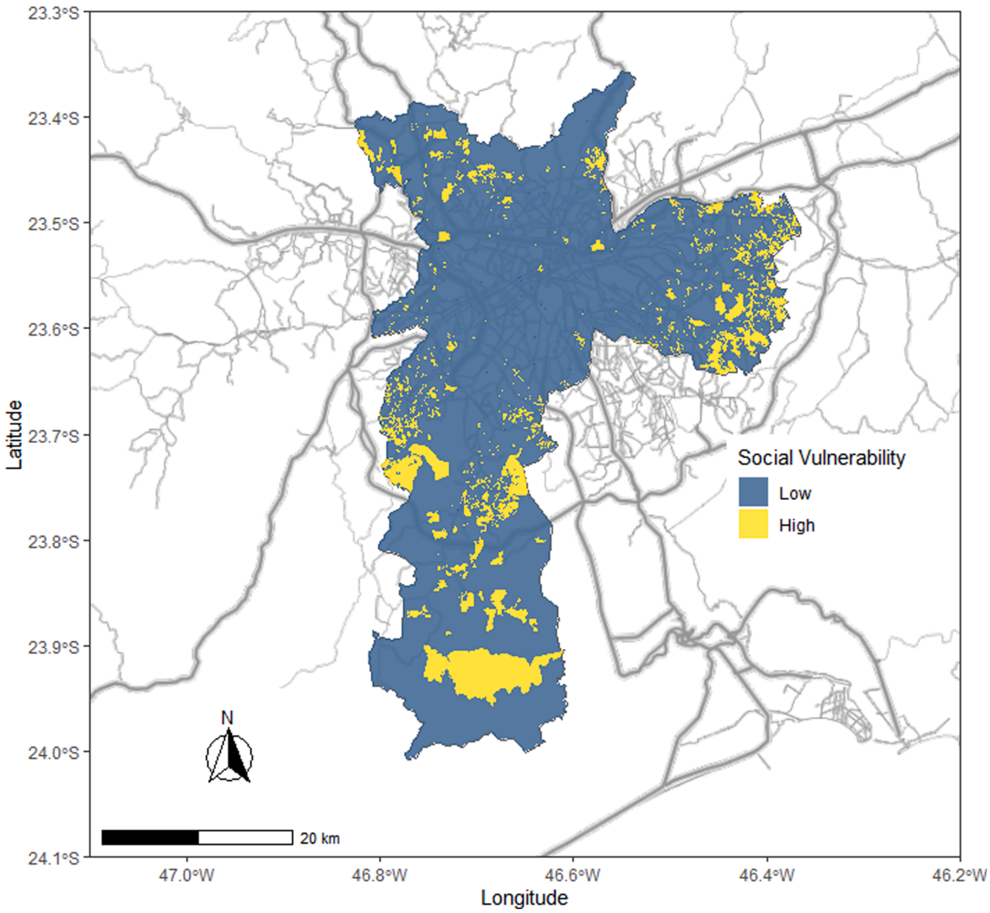

Fig. 6. Spatial distribution of social vulnerability.

mandatory activities than those who do not. At the same time, this group of individuals who live with a dependent elderly person participates in 20.20 % fewer mandatory activities and 23.88 % more discretionary activities. These results may indicate that individuals with a dependent child must work to maintain their kids. Having children does not necessarily compromise the time available to work since the children will be at school during the same period. On the other hand, those who live with a dependent elderly person need to be present throughout the day with her since the elderly do not have an occupation for the whole day as kids do. In addition, seniors often have pensions and participate in more discretionary activities than those who work. It may be that the greater participation in discretionary activities by those who live with a dependent elderly person is accompanying such individuals.

The proportion of self-declared black people was not significant in the three models. The results may suggest that the metric adopted is inadequate to capture difficulties in activity participation due to an individual's race, possibly because we did not have the individual's race but only the share for each neighbourhood. Although we did not find statistical significance, past work conducted in São Paulo's context has pointed out that travel times, costs and transfers have a greater impact on job accessibility among blacks than among whites and that race is a factor that matters even more than social class in post-colonial societies marked by slavery, such as Brazil (Bittencourt and Giannotti, 2021).

The models indicate that people who study, on average, perform more total and mandatory activities than those who do not study. In addition, the activity participation level decreases as the schooling level increases. Regarding the employment status, all categories, on average, participate in fewer activities than individuals who work regularly. In the discretionary activities model, Retired and pensioners, people without work and housewives present a higher level of participation than those who work regularly and study. People who live in socially vulnerable regions participate in fewer total, mandatory and discretionary activities. The number is especially high for discretionary activities, in which those who live in vulnerable areas participate in 22.39 % fewer activities than those who do not. This finding is aligned with TRSE literature (Lucas, 2011; Ureta, 2008).

The lower the level of education, the fewer total and discretionary activities the individual engages in. These results are consistent with the TRSE literature, which indicates that illiterate or cognitively impaired individuals often find using public transport confusing (Denmark, 1998; Luz and Portugal, 2021). It is worth noting that low educational level is correlated with the category of youth and low-income adults.

The population density was statistically significant for the total and discretionary activity models. Despite the small magnitude, this

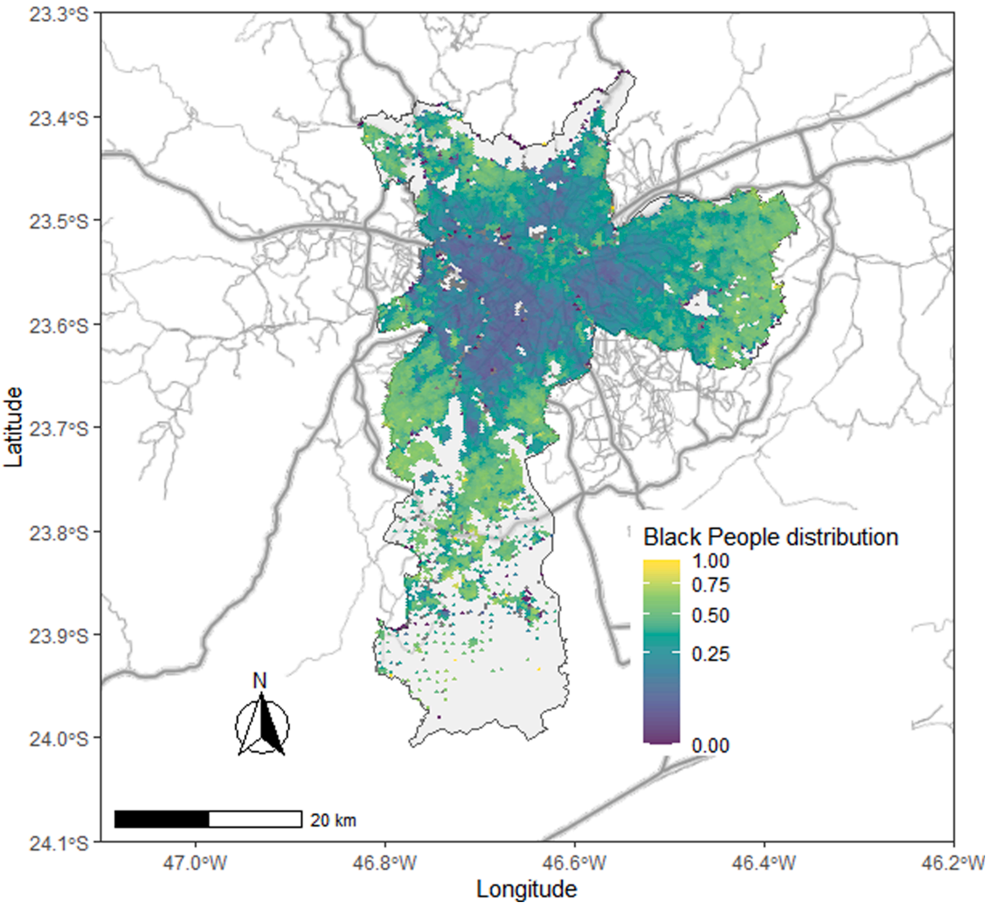

Fig. 7. Spatial distribution of self-declared black people in the city of São Paulo,

result is in line with other studies (Cheng et al., 2019; Merlin, 2015). The literature suggests that denser locations make the urban environment livelier and more attractive to undertake trips on foot(Ewing et al., 1996; Ma et al., 2018). In addition, denser places may be associated with less need to use private vehicles to carry out activities.

6.2. The relationship between accessibility and activity participation

The relationships between accessibility measured by the cumulative opportunities measure (CUM) with a threshold of 90-minute travel time by public transport and the number of total, mandatory and discretionary activities participated in were analysed with a maximum likelihood estimation of a Poisson regression model. As mentioned earlier, other travel times by public transport were tested; however, the accessibility measure with the cut-off time of 90 min was the one that best explained the dependent variable (higher residual deviance after its introduction) in all three models. The instrumental variable strategy was used to overcome any possible endogeneity issue caused by omitted variables and, therefore, infer causality between accessibility and activity participation.

Although the cumulative opportunities measure of accessibility does not capture several nuances that may influence individuals' ability to engage in activities, the models indicated that it still has a causal effect on activity participation. It means that higher levels of accessibility cause greater activity participation, regardless of the type of activity.

The three estimated models (Table 4) indicate that accessibility is highly significant, at least at the 99 % significance level. However, the impact of accessibility is not the same for the three categories of activities. The increment of one percentage point in the number of jobs that the individual can access by public transport within 90 min causes a 0.45 % increase in the total activities carried out, 1.08 % in the mandatory activities, and 0.75 % in the number of discretionary activities, on average. On average, one standard deviation on accessibility (0.24) increases 10.75 % in total activities, 25.81 % in mandatory activities, and 17.89 % in discretionary activities. It means that a transportation policy or project that provides a 24 percentage point increase in the number of jobs an individual can access in the city of São Paulo will cause an average increase in individuals' participation of 10.75 % % in total activities, 25.81 % in mandatory activities, and 17.89 % in discretionary activities. It is worth noting that the impact of accessibility on the total number of activities is not equal to the sum of the impacts on the mandatory and discretionary activities models because the total activities category includes other types of activities not covered by the other categories.

Table 4
Activity participation models after IV introduction.

Independent Variable	Total Activities (n = 47,167) IRR	Robust Std. Error	Z	P-value		Mandatory Activities (n = 47,167) IRR	Robust Std. Error	Z	P-value		Discretionary Activities (n = 47,167) IRR	Robust Std. Error	Z	P-value	
Accessibility (90 min)	1.448	0.063	5.92	0	***	2.076	0.173	4.23	0.000	***	1.745	0.183	3.04	0.002	**
Family per capita monthly income (in thousand reais)	1.046	0.004	10.48	0	***	1.033	0.014	2.41	0.016	*	1.126	0.010	11.44	0.000	***
(Family per capita monthly income (in thousand reais))^2	0.999	0.000	−7.37	0	***	0.999	0.000	−1.83	0.067	.	0.997	0.000	−6.94	0.000	***
Age	1.015	0.002	6.83	0	***	1.065	0.007	9.61	0.000	***	1.012	0.005	2.24	0.025	*
(Age)^2	1.000	0.000	−8.79	0	***	0.999	0.000	−11.46	0.000	***	1.000	0.000	−2.94	0.003	**
Family per capita private vehicles	1.137	0.016	7.85	0	***	1.317	0.049	5.67	0.000	***	1.258	0.042	5.48	0.000	***
Gender (reference “Male”)															
Female	0.988	0.010	−1.13	0.257		0.940	0.033	−1.91	0.056	.	0.939	0.030	−2.08	0.038	*
Number of people in the family	0.990	0.014	−0.72	0.474		1.502	0.042	9.73	0.000	***	0.937	0.015	−4.24	0.000	***
(Number of people in the family) ^2	1.002	0.002	1.38	0.169		0.975	0.005	−5.37	0.000	***	–	–	–	–	
Proportion of self-declared black population in the region	1.085	0.066	1.25	0.212		1.288	0.192	1.32	0.187		0.791	0.185	−1.27	0.206	
Study Status (reference “No”)															
Primary/Elementary	2.394	0.035	24.98	0	***	4.165	0.096	14.90	0.000	***	0.831	0.184	−1.00	0.315	
Secondary/Middle	2.203	0.030	26.33	0	***	3.784	0.068	19.65	0.000	***	1.097	0.154	0.60	0.550	
Higher/University	1.669	0.016	31.27	0	***	2.632	0.040	24.02	0.000	***	0.891	0.072	−1.61	0.107	
Other	1.629	0.029	16.75	0	***	3.539	0.111	11.42	0.000	***	1.038	0.119	0.31	0.753	
Employment status (reference “Has a regular job”)															
Does odd-jobs	0.760	0.022	−12.51	0	***	0.691	0.038	−9.69	0.000	***	1.038	0.071	0.53	0.598	
On sick leave	0.338	0.092	−11.8	0	***	0.062	0.220	−12.66	0.000	***	0.896	0.182	−0.61	0.544	
Retired/Pensioner	0.529	0.022	−29.38	0	***	0.073	0.074	−35.40	0.000	***	1.657	0.046	10.91	0.000	***
Unemployed	0.469	0.030	−25.06	0	***	0.146	0.051	−37.86	0.000	***	1.387	0.071	4.59	0.000	***
Never worked	0.311	0.155	−7.52	0	***	0.045	0.477	−6.49	0.000	***	1.040	0.311	0.13	0.900	
Housewife	0.553	0.035	−16.88	0	***	0.191	0.064	−26.01	0.000	***	1.828	0.078	7.70	0.000	***
Student	0.630	0.029	−16.07	0	***	0.397	0.038	−24.46	0.000	***	0.816	0.121	−1.68	0.093	.
Live in a high social vulnerability region (reference “No”)															
Yes	0.940	0.020	−3.08	0.002	**	0.901	0.044	−2.37	0.018	*	0.776	0.069	−3.69	0.000	***
Level of Education (reference “Higher Education Complete”)															
Non-Literate/Incomplete Primary	0.698	0.030	−12.01	0	***	0.807	0.103	−2.09	0.036	*	0.489	0.075	−9.53	0.000	***
	0.771	0.025	−10.48	0	***	0.888	0.084	−1.41	0.159		0.591	0.062	−8.48	0.000	***

(*continued on next page*)

Table 4 (*continued*)

Independent Variable	Total Activities (n = 47,167) IRR	Robust Std. Error	Z	P-value		Mandatory Activities (n = 47,167) IRR	Robust Std. Error	Z	P-value		Discretionary Activities (n = 47,167) IRR	Robust Std. Error	Z	P-value	
Elementary I Complete/Incomplete Elementary II															
Elementary II Complete/High School Incomplete	0.797	0.022	−10.52	0	***	0.865	0.061	−2.37	0.018	*	0.602	0.059	−8.58	0.000	***
High School Complete / Higher Education Incomplete	0.866	0.013	−10.73	0	***	0.904	0.041	−2.47	0.013	*	0.675	0.034	−11.62	0.000	***
Individual income (reference “Did not answer”)															
Yes	1.096	0.011	8.6	0	***	–	–	–	–		1.350	0.030	10.03	0.000	***
No	0.964	0.029	−1.27	0.204		–	–	–	–		1.024	0.070	0.34	0.735	
Populational Density	1.001	0.000	2.23	0.026	*	1.002	0.002	1.14	0.254		1.003	0.001	2.17	0.030	*
Family status (reference “Responsible person”)															
Spouse / Partner	0.862	0.014	−10.38	0	***	0.784	0.040	−6.03	0.000	***	0.777	0.036	−7.00	0.000	***
Child / Stepchild	0.769	0.018	−14.59	0	***	0.646	0.044	−10.02	0.000	***	0.678	0.055	−7.02	0.000	***
Other Relative	0.647	0.025	−17.17	0	***	0.604	0.081	−6.21	0.000	***	0.550	0.066	−9.14	0.000	***
Other Resident	0.817	0.039	−5.15	0	***	0.622	0.057	−8.32	0.000	***	0.992	0.116	−0.07	0.947	
Resident Employee	0.277	0.108	−11.88	0	***	0.054	0.300	−9.74	0.000	***	0.866	0.173	−0.83	0.407	
Relative of Resident Employee	0.291	0.574	−2.15	0.032	*	0.288	0.560	−2.23	0.026	*					***
Living with a dependent child (under 18 years old)	1.358	0.014	21.99	0	***	1.508	0.041	10.08	0.000	***	1.057	0.042	1.330	0.183	
Living with a dependent elderly person (over 65 yeards old)	1.043	0.016	2.6	0.009	**	0.798	0.038	−6.00	0.000	***	1.239	0.045	4.770	0.000	***
Constant	0.798	0.080	−2.82	0.005	**	0.097	0.230	−10.14	0.000	***	0.111	0.216	−10.200	0.000	***
Note: (.) $p < 0.1$; (*) $p < 0.05$; (**) $p < 0.01$; (***) $p < 0.001$															

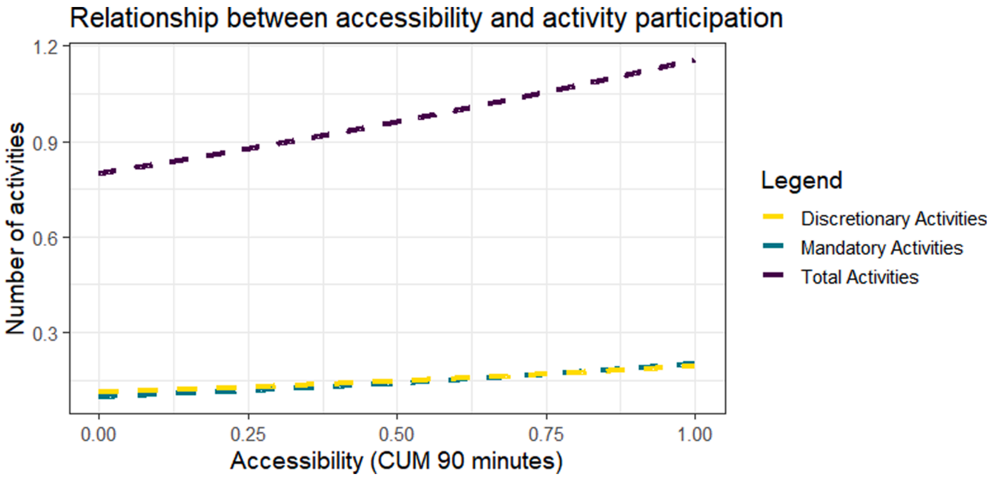

Fig. 8. The shape of accessibility-activity participation relationship.

The effect of accessibility on activity participation is more prominent in the models in which the instrumental variable was included than in the model in which endogeneity was not addressed (Appendix B). In models before the introduction of the instrumental variable, a one percentage point increase in the number of accessible jobs by public transport, within 90 min, is up to three times smaller for total activities (0.16 %), ten times smaller for mandatory activities (0.10 %) and two times smaller (0.38 %) for discretionary activities, than the model that addresses endogeneity.

These findings suggest that a large part of the studies which have assessed the relationship between accessibility and participation in activities may be underestimated. Moreover, impact evaluations and public policies based on accessibility may also have their benefits underestimated. The difference between the effect of accessibility in the models in which endogeneity was ignored and those in which the instrumental variable was introduced seems to follow the literature findings in general. Much of the literature found that discretionary activities are more elastic to variations in accessibility than the other types of activities. Perhaps this finding is more common because of the smaller bias generated by the endogeneity for this kind of activity.

Although the relative impact of accessibility is higher for mandatory-type activities, the absolute impact on the number of activities is higher for the total activities category, followed by mandatory and discretionary activities. This result goes against many studies on the relationship between accessibility and trip making, suggesting that trip making and activity participation for discretionary purposes are more elastic than mandatory. Nevertheless, the sample characteristics may be influencing the results. The São Paulo OD Survey registers only trips made during weekdays, when the proportion of activities for discretionary purposes is limited. Also, although the São Paulo OD Survey captures the trip chaining, we only consider the trip's primary purpose in our analysis. In this sense, it may be possible that the impact of accessibility on discretionary activities is greater than we found due to the sample restrictions. The findings suggest that greater accessibility levels cause greater participation in mandatory activities.

Considering that individuals participate in only one employment activity per day, it is possible that as an individual's accessibility level increases, individuals may move from 0 to 1 mandatory activity performed. In this way, we can speculate that higher levels of accessibility may be associated with a higher probability of getting a job. This hypothesis was confirmed by Bastiaanssen et al. (2021) in the Great Britain context. Likewise, we can speculate that individuals with low levels of accessibility may have limited access to education. In other words, low levels of accessibility can considerably restrict an individual's life chances.

Fig. 8 shows the relationship between accessibility and activity participation. The intercepts in the plot are the constants of the models in Table 4. Although the curve shape of the models fits the activity participation distribution very well, it fails to capture the diminishing effect on participation for the highest levels of accessibility suggested by Martens (2016b) and Allen and Farber (2020). A quadratic specification and a logistic transformation of the accessibility variable were tested in order to capture this effect; however, without success. According to our model, participation increases exponentially (albeit at a minimal rate) when accessibility increases, which contradicts the widely held belief in the literature that improvements in the low end of accessibility should result in larger increases in participation. This finding is similar to Fransen et al. (2018)'s findings for the accessibility-activity participation curve.

Some possible explanations for the shape of the curve found can be raised. Even though Fig. 8 suggests an exponential relationship between accessibility and participation in activities, the slope increases at a minimal rate, fitting almost a linear relationship between the variables. This may suggest that accessibility and activity participation have a linear relationship, as assumed by most of the studies about the theme. Another possible explanation is that the asymptotic nature of the relationship between accessibility and activity participation is being hidden by cumulative opportunities accessibility measure, which equates accessibility over large areas of the central part of the city. It is worth noting that the city of São Paulo is considerably larger than other cities in which similar studies have been carried out. A third explanation for our results may be the characteristics of the sample. The São Paulo OD survey collects data for a 24-hour period. Perhaps a more apparent pattern of a sigmoid curve or a curve with diminishing gains in activity participation would be obtained using a more extended time window, such as a week.

Finally, the individuals' gains from greater accessibility levels may be underestimated. Individuals may be interested not only in the number of activities they participate in but also in the quality of those activities. It is unlikely that individuals will participate in more than one work or education activity because of increased levels of accessibility. However, this individual may get a better-paid job or access better quality education because of higher levels of accessibility, as indicated by Pizzol et al. (2021). As a result, all else being equal, a better level of accessibility is likely to allow people to obtain more benefits from participating in activities.

7. Conclusions

The relationship between accessibility, participation in activities, and risk of social exclusion is complex. Physical accessibility is shaped by four components which, in turn, are composed of numerous sub-components. In addition, physical accessibility conditions interact with the individual's virtual accessibility, the political, economic, and social environment in which they are inserted, and their access needs and choice alternatives. The interaction of all these elements may enable the individuals to travel to and participate in the desired activity or create impediments to their participation. The latter situation suggests that individuals are at risk of TRSE.

Most studies on assessing TRSE or transport equity assume that more accessibility leads to greater participation in activities and, consequently, lower risk of TRSE. However, we verified that the available empirical evidence on this relationship is insufficient to validate this assumption. The 38 studies selected from a systematic literature review on the subject do not point to a consensus. Furthermore, through the systematic literature review, we identified some gaps that we addressed in the empirical part of the paper. The first gap was that few studies investigated the relationship between accessibility and participation in activities from TRSE and equity perspectives. A large part of the studies apply aggregate accessibility measures by zone and do not adequately control for interpersonal characteristics of individuals. The vast majority of studies on the subject were conducted in a Global North context, where cities and social realities are entirely different from the Global South's unequal cities. Finally, none of the studies assessed the causality of accessibility measures on activity participation, restricting themselves only to the correlational relationship.

We proposed three Poisson regression models associated with an instrumental variable identification strategy to fill the gaps identified in the literature. The three models revealed a highly significant strong correlation between individuals' accessibility level and their actual participation in total, mandatory and discretionary activities. We tested four different time thresholds and different specifications and transformations for the accessibility measure. We found that the one that best explains the dependent variable variability is the linear cumulative opportunities measured with a 90-minute travel time threshold by public transport.

Our results suggest that low accessibility levels may severely restrict individuals' life chances and shed light on the importance of including the accessibility dimension in transport policies. Previous studies and public policies based on accessibility that ignored the endogeneity in the relationship between accessibility and activity participation may have underestimated their results in terms of activity participation up to ten times. Furthermore, our findings point out that accessibility, even accounting only for transport and land use components, such as CUM measure, is critical in enhancing individuals' capabilities. We also consider that individuals may be interested not only in the number of activities they participate in but also in the quality of those activities. In this sense, the gains provided by accessibility improvements may be much higher than those estimated.

The three models we proposed fit the distribution of the dependent variables very well. However, the models failed to capture the diminishing increase in participation for individuals with high accessibility levels. We speculate three possible explanations for our findings. Poisson regression suggests an exponential relationship between independent and dependent variables. However, our models indicate that the exponential relationship between accessibility and activity participation is almost nonexistent and that the relationship between both variables approaches a linear relationship. In this sense, the first explanation for our results is that accessibility and activity participation may actually have a linear relationship. Second, the asymptotic relationship between accessibility and activity participation is hidden by how accessibility was measured. Third, a 24-hour data collection period is too short to reveal a sigmoid or a curve with diminishing gains in activity participation.

Although we cannot infer causality from the relationship between activity participation and socioeconomic and locational variables, our results proved consistent with the TRSE literature. Only the race variable had divergent results from the theory. Further research using proper metrics to capture difficulties in activity participation due to an individual's race is needed.

Although this paper has advanced compared to previous studies in this field, further research lines may stem from it. A longer time horizon in data collection may also capture fluctuations in activity participation patterns. Including weekend trip-making information in OD Survey may help better estimate the relationship between accessibility and discretionary activity participation. Additionally, we recommend the introduction of race-related variables in OD surveys to capture activity participation inequality due to race issues. We used an accessibility measure that accounts only for formal jobs and the travel time by public transport. Adopting an accessibility approach that differentiates between opportunities type and transport modes could provide different insights into the impact of accessibility on participation. Also, other accessibility measures should be tested in a causal inference framework to capture the diminishing effect on participation for the highest levels of accessibility, as suggested by Martens (2016b) and Allen and Farber (2020).

We have provided causal evidence of a relationship between accessibility and activity participation, which may help policymakers better predict and explain the impacts of inclusive transport policies based on accessibility planning. However, there is still much debate in the literature about whether this relationship is valid. Therefore, more evidence on the validity of this relationship is needed, especially in the context of the Global South. Such evidence must use identification strategies to ensure the validity of the cause-and-effect relationship between accessibility and activity participation. We have used an instrumental variable identification strategy; however, this is one of the least robust methods for inferring causality. Randomised experiments are desirable to obtain more robust results.

Our models do not address the endogeneity caused by residential self-selection. Residential self-selection refers to the tendency that people intentionally choose residential locations to meet their travel needs and preference (Mokhtarian and Cao, 2008, p.5; van Wee and Cao, 2022). The existence and the size of the effect of self-selection strongly vary according to the availability of mobility instruments (van Wee and Cao, 2022) and the housing market conditions, and it is a result of the socio-economic and demographic characteristics and attitudinal factors (Mokhtarian and Cao, 2008). Although we have inserted many socio-economic and demographic variables in our models, we could not include attitudinal factors. Also, although the instrumental variables included in the models control the bias generated by the sources of endogeneity described in section 2.1, a small share of bias may be still present due to residential self-selection. Further research must have this issue in mind and, ideally, use instruments or other research designs able to address the issue.

Although the concept of accessibility has been increasingly and widely discussed by researchers, its adoption in policies and practice is still limited. Boisjoly and El-Geneidy, (2017b) found that only 55 % of the 343 interviewed practitioners worldwide confirmed that they use accessibility metrics in their practice. Vecchio et al. (2020) shed light on this issue in Latin America. We may say that Sao Paulo is one of the examples of a big city with huge inequalities that do not even suggest the use of accessibility measures in its transportation planning instruments. The two latest transportation planning documents, the PITU 2025 (Plano Integrado de Transportes Urbanos, 2006), which is the last available transportation plan for the Metropolitan Region from 2006, and the Mobility Plan (2015) prepared for the city, rarely even mention the concept of accessibility, and when it does it is related to the universal accessibility of people with a mobility restriction, or it is mentioned in a broader and generic sense. Both plans did not present, compute or use accessibility metrics within their proposal. So hopefully, this paper, with a robust method to infer causal relation, may help convince practitioners of the importance of using accessibility metrics and including them in the following transportation plans to support better and more inclusive policies.

CRediT authorship contribution statement

Gregório Luz: Conceptualization, Methodology, Software, Validation, Investigation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization, Project administration, Supervision. **Matheus H.C. Barboza:** Software, Validation, Formal analysis, Writing – review & editing. **Licinio Portugal:** Writing – review & editing, Supervision, Funding acquisition. **Mariana Giannotti:** Writing – review & editing. **Bert van Wee:** Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Overview of the studies and empirical evidence about the relationship between accessibility and activity participation and trip making Table A.

Table A
Overview of the studies and empirical evidence about the relationship between accessibility and activity participation and trip making.

Author	Study Area	Accessibility Measure	Method	Study focus	Trip / Activity Purpose	Transport Mode	Findings
Vickerman (1974)	Oxford, United Kingdom	Place-based (Gravity-type)	Multivariate linear regression	Trip making	Shopping; Leisure	All travel modes, Auto, Public Transit and Walk	Positive effect. The cost component of accessibility measure positively impacts shopping trips, while the attraction component has a dominant influence on leisure trips.
Robinson and Vickerman (1976)	Sussex, United Kingdom	Place-based (Gravity-type)	Multivariate linear regression	Trip making	Shopping	Auto and Public Transit	Positive effect. The availability of shopping locations in a given area and their transport characteristics positively influence shopping activity.
Koenig (1980)	Lemans, Marseilles, Rouen, Nice, Grenoble - France	Utility-based	Basic descriptive statistics	Trip making	Work	Auto and Public Transit	Positive effect. Accessibility is a powerful determinant of trip rate.
Leake and Huzayyin (1980)	Middlesbrough, United Kingdom	Place-based (Minimum distance; Minimum time) and Infrastructure-based (Headway; Transport Network structure)	Multivariate linear regression	Trip making	Work; Education; Others; General	All travel modes, Auto and Public Transit	Positive effect. The most affected trip types were public transport trips followed by "all mode" trips. The more negligible impact was for trips by private transport. The most significant effect by trip purpose was on home-based other trips, regardless of travel mode.
Landau et al. (1981)	Tel-Aviv, Israel	Spatial-temporal (Possible activity duration) and Place-based (Container-type)	Linear probability model	Trip making	Maintenance; Leisure	Auto and Public Transit	Mixed effect. Time constraints were significant in the leisure trip models and not in the maintenance trips models. The number of employees in commerce and services in residential areas positively influences the number of maintenance trips but negatively influences leisure trip making.
Downes and Morrell, (1981)	Reading, United Kingdom	Place-based (Distance to CBD)	Descriptive statistics	Trip making	General	Auto, Public Transit, Bicycle and Walk	No significant effect. Household locations do not affect the aggregate trip frequency by all modes.
Wermuth, (1982)	Rhine-Neckar (Germany) and Salzburg (Austria)	Place-based (Area characteristics)	Nested ANOVA	Activity participation	Work; Education; Shopping; Leisure; Others	All travel modes	No significant effect. The accessibility to central facilities and the characteristics of the residential neighbourhood is negligible.
Hanson and Schwab (1987)	Uppsala, Sweden	Place-based (Gravity-type)	Multivariate linear regression	Trip making	Discretionary (Non-work; Shopping; Social)	Auto, Walk and Bicycle	Weak effect. The relationship between accessibility and the number of discretionary trips is statistically significant only for men. The correlation coefficients are not very expressive.
Williams (1989)	Hamilton, Canada	Place-based (Gravity-type)	Pearson correlation coefficient and ANOVA	Trip making and Activity participation	General	Auto	Negative effect. The activity participation reduces as accessibility increases. No association was found between the number of trips made and the accessibility conditions.
Handy (1993)	San Francisco Bay Area, United States	Place-based (Gravity-type)	Pearson correlation coefficient	Trip making	Shopping	Auto	No significant effect. The relationship between regional accessibility and

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Table A (*continued*)

Author	Study Area	Accessibility Measure	Method	Study focus	Trip / Activity Purpose	Transport Mode	Findings
							shopping trips was practically non-existent, as was the relationship between local accessibility and shopping trips.
Ewing et al. (1996)	Palm Beach and Dade counties, Florida, United States	Place-based (Gravity-type)	ANOVA	Trip making	Mandatory (Work) and Discretionary (Shopping; Social; Recreation; Others)	Auto, Walk and Bicycle	No significant effect. Accessibility seems to have negligible effects on home-based trip generation.
Handy, (1996)	San Francisco Bay Area, United States	Place-based (Cumulative Opportunities; Weighted time; Minimum time)	Descriptive data analysis and ANOVA	Trip making	Discretionary (Shopping; Supermarket; Having Meal)	Auto and Walk	Positive effect. Greater accessibility, both in terms of short distances and a greater variety of potential destinations, is associated with higher trip frequencies to convenience stores and regional trips to shopping centres.
Purvis et al., (1996)	San Francisco Bay Area, United States	Place-based (Minimum time)	Multivariate linear regression	Trip making	Shopping; Leisure	Auto, Walk and Bicycle	Positive effect. There is an inverse relationship between work trip duration and trip frequency for reasons other than work.
Lee and Goulias, (1997)	Centre County, Pennsylvania, United States	Place-based (Minimum distance; Minimum time; Distance sum; Weighted distance; Gravity-type)	Logit	Trip making	Shopping	Auto	Positive effect. The shortest path (minimum distance) measure and the gravity-type with a Gaussian deterrence function accessibility measure are the ones that best explain travel behaviour.
Kitamura et al. (1997)	San Francisco Bay Area, United States	Place-based (Minimum distance to transport; Minimum distance; Household Density)	Multivariate linear regression	Trip making	General	Public transit, Walk and Bicycle	Weak effect. The number of public transport trips increases with better accessibility to railway stations and is associated with residential density. The presence of sidewalks is positively associated with the number of non-motorised trips. Attitudes are more strongly associated with travel than are land use characteristics
Golob (2000)	Portland, Oregon, United States	Place-based (Cumulative Opportunities) and Utility-based	Structural Equation Modelling	Activity participation	Work, Maintenance and Discretionary (Leisure)	All travel modes	Positive effect. Accessibility levels are positively related to participation in out-of-home non-work activities, simple home-based trip chains for non-work purposes, and negatively related to work travel time.
Kitamura et al. (2001)	Kyoto-Osaka-Kobe Metropolitan Area, Japan, and Southern California, United States	Place-based (Gravity-type) and Spatio-temporal (Number of activities in the Space-time Prism; Volume of Space-time Prism)	Pearson correlation coefficient and structural equation modelling	Trip making and Activity participation	Shopping and Leisure	Auto and Public Transit	Mixed effect. The size of the space–time prism, not the number of opportunities it contains, is the critical determinant of activity participation. Time availability is more influential than the opportunities distribution in activity participation and trip making (Japan).
Thill and Kim, (2005)	Minneapolis-St. Paul, Minnesota, United States	Place-based (Gravity-type; Cumulative Opportunities)	Poisson Regression	Trip making	Work; Shopping; Education and Others	Auto	Mixed effect. Half of the statistically significant accessibility variables revealed a positive relationship with the trip making. The other half indicated a negative relationship. The

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Table A (*continued*)

Author	Study Area	Accessibility Measure	Method	Study focus	Trip / Activity Purpose	Transport Mode	Findings
							combined effect of significant accessibility measures on travel demand is complex and non-linear.
Zhang (2005)	Boston, United States	Place-based (Gravity-type)	Logit Regression	Activity Participation	Non-work (school, shopping, social, personal, pick up/drop off and other)	Auto and Public Transport	Mixed effect. Accessibility was positive, statistically significant to activity–travel frequency for school and social activities. Increase in accessibility was associated with lower odds of making additional shopping trips.
Næss (2006)	Copenhagen Metropolitan Region, Denmark	Place-based (Distance to CBD)	Interviews and multivariate linear regression	Trip making and Activity participation	Leisure; Maintenance; Visiting friends and Work	Auto, Public Transit, Walk and Bicycle	Mixed effect. The results indicate that respondents from the more peripheral residential area tend to make 1.5 more daily trips than their peers living in the area closer to the Copenhagen CBD. At the same time, better accessibility is associated with more activity participation.
Schwanen et al. (2007)	Amsterdam - Utrecht, Netherlands	Place-based (Cumulative Opportunities; Minimum time to transport)	Structural Equation Modelling	Trip making and Activity participation	General; Shopping; Personal Business and Others	Auto	Mixed effect. Accessibility positively influences between-partner interactions in maintenance activity participation. They suggest that in a neighbourhood with good accessibility to shops, men may take care of more household tasks due to fewer space–time constraints. The travel time to the nearest shopping centre for clothing or footwear suggest that individuals participate more frequently in shopping for convenience goods independent of their spouse, as the travel time rises.
Wu et al., (2012)	San Francisco, United States	A mix of Place-based with Infrastructure-based (Distance to Transport and Headway).	Multivariate linear regression	Trip making	General	Auto	Negative effect. Higher levels of walking and public transport accessibility are associated with fewer trips by car.
Bhat et al., (2013)	Los Angeles Region, United States	Place-based (Cumulative Opportunities; Gravity-type)	Multiple Discrete Continuous Extreme Value (MDCEV)	Activity Participation	Maintenance (shopping, non-shopping, social, entertainment, visiting friends and family, active recreation, eat-out, work-related)	Auto	Mixed effects.
Seo et al. (2013)	Seoul, South Korea	Utility-based (Logsum) and Infrastructure-based	Multivariate linear regression	Trip making	Shopping, personal business and leisure	Auto and Public Transit	Mixed effect. Maintenance trips are negatively related to accessibility, while other purpose trips are positively related. Higher accessibility does not always lead to more activity participation.

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Table A (*continued*)

Author	Study Area	Accessibility Measure	Method	Study focus	Trip / Activity Purpose	Transport Mode	Findings
Krasić and Novačko, (2015)	Zagreb, Croatia	Place-based (Distance to transport)	Multivariate linear regression (MLR)	Trip making	General	Auto and Public transport	Positive effect
Merlin (2015)	United States	Place-based (Household and Job density)	Negative Binomial Regression	Activity Participation	Non-work activities	All travel modes	Positive effect. Greater residential and employment densities have a sizeable effect on levels of household non-work activity, with the most significant influence on households with the fewest vehicles.
Ding et al. (2016)	Beijing, China	Space-time (Aggregated utility of opportunities)	Logit and Multivariate Linear Regression	Activity Participation	Shopping	Auto	Positive effect. Greater person-based accessibility positively affects the frequency and duration of shopping activity participation.
Cordera et al. (2017)	Santander, Spain	Place-based (Gravity-type; Time to CBD)	Multivariate linear regression, Spatial autoregressive models, Spatial autoregressive models in the error term, and spatially filtered Poisson regression Models	Trip making	Work, Study, Others (Non-discretionary)	Auto, Motorcycle and Public Transit	Mixed effect. More accessibility to opportunities decreases trip making in private vehicles for work purposes, whereas it increases trip production in other transport modes for non—mandatory purposes.
Tian and Ewing, (2017)	Portland, Oregon, United States	Place-based (Cumulative Opportunities; Minimum distance to transport)	Zero-Inflated Negative Binomial Regression	Trip making	General	Walk	Positive effect. Transit stop density and employment accessibility are good predictors of the number of walk trips.
Wang and Cao (2017)	Hong Kong, China	Place-based (Gravity-type)	Propensity Score Match	Trip making	General	All travel modes	No effect.
Kröger et al., (2018)	Germany	Place-based (Minimum time)	Linear regression and Logit	Trip making	Mandatory (Work) and Discretionary (Shopping)	Auto	Mixed effect. Accessibility to the nearest business district positively impacts home-based shopping trips but not home-based work trips.
Fransen et al. (2018)	Wasatch Front region, Utah, United States	Spatial-temporal (Possible activity duration) and Place-based (Gravity-type)	Zero-Inflated Negative Binomial Regression	Activity Participation	Discretionary (Exercise, Having a Meal, Personal Business, Religious, Shopping, Social, Leisure, Others)	Auto	Mixed effect. There is a moderate positive correlation between the spatial–temporal accessibility measure and participants' surveyed partaking in discretionary activities. The gravity-type measure shows a negative and highly significant relationship to activity participation.
Lavieri et al. (2018)	Great Britain	Virtual Accessibility and Place-based (Minimum time)	Structural Equation Modelling	Activity Participation	Mandatory (Work), Maintenance, Discretionary	Virtual	Negative effect. Virtual accessibility reduces both the number and the duration of work episodes. Virtual accessibility negatively impacts the number of maintenance activities but does not seem to affect the duration of out-of-home maintenance activities. Physical accessibility negatively impacts the number of maintenance activities. Individuals who perceive ease of access to opportunities tend to concentrate their maintenance activities in fewer and longer episodes

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Table A (*continued*)

Author	Study Area	Accessibility Measure	Method	Study focus	Trip / Activity Purpose	Transport Mode	Findings
Zhang et al. (2019)	Portland, Oregon, United States	Place-based (Household density and Container measure)	Negative Binomial Regression	Trip making	General, Mandatory (Work, Education), shopping, recreation, and Other	All travel modes	Mixed effect. People who live in denser neighbourhoods are more likely to make more trips. Workers who live in denser areas will likely generate more home-based work trips. Higher urban living infrastructure density is associated with more shopping trips. Household density has a negative impact on entertainment or social activities.
Cheng et al. (2019)	Nanjing, China	Place-based (Jobs density; Population density)	Structural Equation Modelling	Trip making and Activity participation	Mandatory (Work, Education or Bureaucracy), Maintenance (Shopping, visiting friends, Seeing a doctor), and Discretionary	Auto, Motorcycle, Walk, Public Transit, Bicycle	Mixed effect for trip making. Population density significantly affects trip generation, and the employment density variable does not indicate any substantial effects on trips generation. No significant effect on activity participation. Population and employment density variables show insignificant impacts on activity participation.
Calvo et al. (2019)	Madrid, Spain	Place-based (Job density; Container-type)	Geographically Weighted Regression	Trip making	General	Metro	Positive effect. The number of daily trips increases with the increase of job density. The accessibility measure that accounts for the number of residents at<600 m to a metro station is statistically significant only for suburban zones.
Allen and Farber, (2020)	Greater Toronto and Hamilton Area, Canada	Place-based (Gravity-type)	Negative Binomial Regression	Activity Participation	General	All travel modes	Positive effect. Improvements in accessibility by public transport are associated with people participating in a greater number of daily activities. Accessibility and activity participation presents a sigmoidal relationship.
Masoumi, (2021)	(Cairo, Istanbul, Tehran), Middle East and North Africa	Place-based (Container measure, Distance to activities)	ANOVA and Weighted Least Squares	Trip making	Mandatory (work and study) and non-work	All travel modes	Mixed effect. Higher value of accessibility measured by container measure is associated with less mandatory trips. Shorter distance to activities is associated with more mandatory trips.

Appendix B

Activity Participation models before IV Table B.

Table B
Activity Participation models before the introduction of the IV.

	Total Activities (n = 47,167)					**Mandatory Activities (n = 47,167)**					**Discretionary Activities (n = 47,167)**				
	R^2 McFadden: 0.089					R^2 McFadden: 0.195					R^2 McFadden: 0.067				
	AIC: 115,160.700					AIC: −43,663.930					AIC: −22,318.100				
	Log pseudolikelihood: −57,542.340					Log pseudolikelihood: 87,399.850					Log pseudolikelihood: 44,710.210				
Independent Variable	**IRR**	**Robust Std. Error**	**Z**	**P-value**		**IRR**	**Robust Std. Error**	**Z**	**P-value**		**IRR**	**Robust Std. Error**	**Z**	**P-value**	
Accessibility (90 min)	1.165	0.028	6.450	0.000	***	1.097	0.025	3.730	0.000	***	1.383	0.100	4.47	0.000	***
Family per capita monthly income (in thousand reais)	1.054	0.005	11.000	0.000	***	1.029	0.004	7.110	0.000	***	1.150	0.021	7.71	0.000	***
(Family per capita monthly income (in thousand reais))^2	0.998	0.000	−5.910	0.000	***	0.999	0.000	−3.790	0.000	***	0.994	0.001	−4.77	0.000	***
Age	1.009	0.002	5.480	0.000	***	1.008	0.002	4.020	0.000	***	1.014	0.004	3.37	0.001	***
(Age)^2	1.000	0.000	−7.520	0.000	***	1.000	0.000	−6.750	0.000	***	1.000	0.000	−4.2	0.000	***
Family per capita private vehicles	1.089	0.015	6.380	0.000	***	1.067	0.014	4.770	0.000	***	1.143	0.038	3.96	0.000	***
Gender (reference "Male")															
Female	0.986	0.008	−1.710	0.088	.	0.969	0.008	−3.780	0.000	***	0.949	0.023	−2.19	0.029	*
Number of people in the family	1.045	0.011	4.210	0.000	***	1.154	0.013	11.210	0.000	***	0.944	0.012	−4.67	0.000	***
(Number of people in the family) ^2	0.997	0.001	−2.780	0.005	**	0.988	0.002	−7.800	0.000	***					***
Proportion of self-declared black population in the region	0.894	0.032	−3.120	0.002	**	0.847	0.037	−4.450	0.000	***	0.678	0.074	−3.54	0.000	***
Study Status (reference "No")															
Primary/Elementary	2.027	0.059	24.190	0.000	***	2.097	0.031	23.650	0.000	***	0.821	0.147	−1.1	0.272	
Secondary/Middle	1.909	0.047	26.000	0.000	***	2.012	0.026	26.710	0.000	***	0.949	0.128	−0.39	0.698	
Higher/University	1.508	0.021	28.920	0.000	***	1.643	0.014	36.050	0.000	***	0.882	0.056	−1.98	0.047	*
Other	1.424	0.042	12.100	0.000	***	1.504	0.030	13.560	0.000	***	1.089	0.108	0.86	0.391	
Employment status (reference "Has a regular job")															
Does odd-jobs	0.753	0.016	−13.370	0.000	***	0.632	0.025	−18.350	0.000	***	0.988	0.061	−0.2	0.844	
On sick leave	0.335	0.030	−12.100	0.000	***	0.100	0.212	−10.850	0.000	***	0.719	0.122	−1.94	0.053	.
Retired/Pensioner	0.529	0.011	−30.510	0.000	***	0.070	0.072	−36.800	0.000	***	1.513	0.056	11.13	0.000	***
Unemployed	0.499	0.014	−24.660	0.000	***	0.220	0.038	−39.700	0.000	***	1.337	0.086	4.53	0.000	***
Never worked	0.284	0.041	−8.770	0.000	***	0.072	0.338	−7.770	0.000	***	0.925	0.262	−0.28	0.783	
Housewife	0.575	0.018	−17.230	0.000	***	0.279	0.047	−27.070	0.000	***	1.648	0.108	7.63	0.000	***
Student	0.641	0.016	−18.070	0.000	***	0.530	0.016	−40.210	0.000	***	0.879	0.094	−1.2	0.230	
Live in a high social vulnerability region (reference "No")															
Yes	0.937	0.014	−4.250	0.000	***	0.939	0.016	−3.920	0.000	***	0.761	0.047	−4.42	0.000	***

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Table B (*continued*)

Level of Education (reference "Higher Education Complete")															
Non-Literate/Incomplete Primary	0.719	0.017	−13.690	0.000	***	0.840	0.028	−6.180	0.000	***	0.573	0.038	−8.31	0.000	***
Elementary I Complete/Incomplete Elementary II	0.785	0.016	−12.110	0.000	***	0.873	0.023	−6.010	0.000	***	0.647	0.036	−7.75	0.000	***
Elementary II Complete/High School Incomplete	0.806	0.014	−12.160	0.000	***	0.882	0.020	−6.420	0.000	***	0.633	0.033	−8.7	0.000	***
High School Complete / Higher Education Incomplete	0.881	0.010	−11.400	0.000	***	0.932	0.011	−6.140	0.000	***	0.717	0.023	−10.56	0.000	***
Individual income (reference "Did not answer")															
Yes	1.086	0.009	9.460	0.000	***	–	–	–	–		1.247	0.030	9.22	0.000	***
No	0.955	0.023	−1.930	0.054	.	–	–	–	–		0.915	0.056	−1.46	0.144	
Populational Density	1.002	0.000	4.610	0.000	***	1.001	0.000	3.790	0.000	***	1.002	0.001	2.19	0.029	*
Family status (reference "Responsible person")															
Spouse / Partner	0.892	0.010	−9.780	0.000	***	0.939	0.013	−5.000	0.000	***	0.812	0.025	−6.88	0.000	***
Child / Stepchild	0.831	0.012	−13.030	0.000	***	0.851	0.015	−11.050	0.000	***	0.754	0.035	−6.13	0.000	***
Other Relative	0.737	0.014	−16.160	0.000	***	0.840	0.019	−9.190	0.000	***	0.584	0.034	−9.3	0.000	***
Other Resident	0.884	0.031	−3.520	0.000	***	0.877	0.030	−4.430	0.000	***	1.050	0.105	0.49	0.622	
Resident Employee	0.290	0.031	−11.640	0.000	***	0.083	0.263	−9.500	0.000	***	0.896	0.138	−0.71	0.477	
Relative of Resident Employee	0.494	0.214	−1.630	0.103		0.677	0.352	−1.110	0.268		0.000	0.000	−26.1	0.000	***
Living with a dependent child (under 18 years old)	1.281	0.014	22.740	0.000	***	1.305	0.011	24.110	0.000	***	1.068	0.036	1.96	0.050	.
Living with a dependent elderly person (over 65 years old)	1.014	0.013	1.080	0.279		0.956	0.013	−3.360	0.001	***	1.159	0.043	3.97	0.000	***
Constant	0.933	0.046	−1.420	0.157		0.725	0.056	−5.740	0.000	***	0.125	0.017	−15.36	0.000	***
Note: (.) $p < 0.1$; (*) $p < 0.05$; (**) $p < 0.01$; (***) $p < 0.001$															

Table 7
Descriptive statistics of dependent variables.

Dependent Variable	x	s	s^2	Min	Max	Skewness	n	% zeros
Total Activities	1.10	1.10	1.00	0	13	1.58	47,167	28 %
Mandatory / Fixed activities	0.78	0.86	0.74	0	13	1.39	47,167	43 %
Discretionary / Flexible activities	0.18	0.44	0.19	0	7	2.88	47,167	84 %

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