GuIA.ai

Autonomous vehicles and their socio-territorial impact in a case study: Monterrey, Mexico

Roberto Ponce López, Nélida Escobedo Ruiz, Mauricio Leal Batarse, Adolfo Arana Espíritu Santo, Rodrigo Junco López

November 2021

CETyS | LATAM DIGITAL CENTRO DE POLÍTICA DIGITAL PARA AMÉRICA LATINA | In collaboration with: fAIr LAC | BID Banco Interamericano de Desenvolvimento

Autonomous vehicles and their socio-territorial impact in a case study: Monterrey, Mexico

Authors: Roberto Ponce López, Nélida Escobedo Ruiz, Mauricio Leal Batarse, Adolfo Arana Espíritu Santo, Rodrigo Junco López

Coordinators: Carolina Aguerre y Maia Levy Daniel

Revision: Gonzalo Bustos Frati y Matías Jackson

Design: Mónica Castellanos

Translation: Verónica Penelas

Autonomous vehicles and their socio-territorial impact in a case study: Monterrey, Mexico

November 2021

Roberto Ponce López, Nélida Escobedo Ruiz, Mauricio Leal Batarse, Adolfo Arana Espíritu Santo, Rodrigo Junco López

Executive Summary

Autonomous vehicles have emerged as one of the most relevant applications of artificial intelligence in transportation and urban space; so much so that it is expected that, as has already happened with other technological innovations in mobility, they will bring social and physical transformations to many cities in the coming decades. Given this prospect, there is a need to assess their impact from different perspectives: urban form, traffic congestion, travel mode choices, accessibility to the transportation system, and social impacts. These aspects describe the spatial and social implications of such a technology, and taking them into account would allow us to exercise values of spatial justice and the right to the city for an ethical implementation of the technology. Nowadays, the effects of autonomous vehicles have been studied in high-income countries and planned urban environments, but there is no record of studies addressing them in Latin America. Our research evaluates the significance of autonomous vehicles as a high-impact artificial intelligence application in Latin American cities by using the Monterrey Metropolitan Area as a case study. The decline in the use of public transportation, a dispersed city model, social inequality and an overdependence on private automobiles present relevant conditions for this analysis. Based on the case study, and in addition to the literature review, this article also outlines scenarios for the implementation of this technology in order to improve mobility conditions in the urban periphery, as well as suggesting that the State should intervene in the development of public policies and invest in safe streets to close the socio-spatial gap in the territory.

Contents

1. Introduction 6
1.1. Research questions 7
1.2. Methodology 8
2. Literature review 9
2.1. Business model and impact on public transport 9
2.2. Social inequality and AV dilemmas 10
2.3. Autonomous vehicles and spatial justice 10
2.4. Public policies for the adoption of AVs 11
3. Analysis of the case study 13
3.1. Urban Context of Latin American Cities 13
3.2. Presentation of the Monterrey Metropolitan Area 14
3.3. Description of the case study 15
3.4. Conclusions to the case study 21
4. Prospective analysis: challenges, risks and opportunities of AVs in Latin American cities 22
4.1. Scenario 1: business model in favor of AVs for private use 22
4.2. Scenario 2: business model in favor of on-demand shared autonomous vehicles (SAVs) 23
4.3. Road safety and public policies to ensure it: prioritization of pedestrians and non-motorized means of transport 26
5. Conclusion 27
6. References 29

1. Introduction

One of the artificial intelligence applications that will significantly affect our experience of the urban environment is the autonomous vehicle (AV), and they are considered so because of the technology involved: the use of Lidar sensors, vision and video processing, cloud computing, and pattern recognition to identify obstacles and calculate routes (Gerrish, 2018). However, due to the automation of the system and the costs of implementation and necessary infrastructure, this technology opens up a number of debates and ethical dilemmas about its impacts on social equity in the city.

The arrival of AVs on the streets as a transportation solution is anticipated within 10 to 20 years, depending on adoption rates in different countries. In the Latin American and Caribbean region, it is estimated that by 2030 they will be available for purchase and by 2050 they will dominate 50% of the vehicle fleet (Catalayud *et al.*, 2020). Given their imminent arrival, it is necessary to assess their implications, especially in the context of Latin American cities characterized by institutional weakness, high inequality in income distribution, lack of urban planning, precariousness of public transportation, and slow adoption of information technologies in urban environments (Irázabal and Jirón, 2021); it is also essential to ask about the potential of this new technology and under what conditions of implementation it would be able to close urban inequality gaps. This article analyzes these dilemmas by taking the city of Monterrey in Mexico as a case study and exploring two prospective scenarios in the adoption of AVs that would have disparate social implications.

The city of Monterrey is a useful case to build scenarios for the implementation of AVs and discuss their impact on the city's equity and accessibility. This is due to the fact that, on the one hand, Monterrey is an archetypical Latin American city: it has a territorial growth marked by horizontal expansion, fragmentation of administrative boundaries, lack of planning and informality. On the other hand, it is a unique case: it has high public transportation costs and an accelerated decline in its use, unequal access to transportation, lack of quality public spaces, and dependence on private vehicles. Considering that AVs are a technology that would replace private vehicles and compete directly with public transport systems (Townsend, 2020), it is interesting to explore their implementation in this city that, with its combination of unique and archetypical elements (particularly the dependence on and decline of private transport), allows the outlining of possible implications in the Latin American context in general.

For their part, AVs have been a topic of research for academia in recent years. Attempts have been made to anticipate and quantify their impact on transport supply-demand and on the configuration of urban space; for example, Milakis *et al.* (2017) consider three levels of repercussions. In the first level, the authors break down the consequences of this new technology on travel costs, traffic congestion, and transportation mode choices. In the second level, they identify the consequences it would have on transportation infrastructure in cities; some other studies indicate that shared autonomous vehicles (SAVs) would reduce space dedicated to parking by up to 90% and free it up for other uses (Fagnant and Kochelman, 2014). And finally, at the third level, the authors encompass social implications and, even though they claim that AVs would have consequences on equity and social justice, these are still considered

to be uncertain (Milakis *et al.*, 2017). Other research has found, for example, that AVs may cause an increase in the demand for transportation by people with reduced mobility, such as older adults and differently abled people (Harper et al., 2016; Zandieh and Acheampong, 2021). However, it has also been said that these population groups encounter more barriers to the use and adoption of technologies, especially in a context of poverty and social marginalization (Fischer *et al.*, 2014, p. 624). Other authors have remarked on the aforementioned SAVs and multimodal integration as key to reducing social impact, as they would reduce transportation costs, take advantage of existing infrastructure and increase the supply of travel options (Owens *et al.*, 2019; Creger *et al.*, 2019).

Another set of consequences of this new technology will be related to the environment. Some authors claim that another important benefit would be reductions in energy consumption - up to 90% - and carbon emissions (Greenblat and Saxena, 2015; Harb *et al.,* 2020), firstly because AVs technology is integrated with electric motors, thus introducing a new generation of more efficient vehicles; and secondly, because it is believed that SAVs would reduce congestion on the streets (Greenblat and Saxena, 2015; Owens *et al.*, 2019). However, even if the technology itself is more efficient compared to internal combustion models, they could increase the energy expenditure required by dispersed cities. Some authors even warn that AVs will lead to an increase in vehicle kilometers traveled, which could further incentivize urban sprawl (Childress *et al*., 2015) and cause the metropolitan-scale effects to be counterproductive in the long term. Considering all of the above, the objectives of this article are: 1) to analyze the implications of the adoption of AVs in the context of Latin American cities in general in terms of social impacts as a conditional element in the particular morphology of urban environments in the region; 2) through the case study, to examine these implications in the city of Monterrey by exploring the ethical and social justice dimension while taking as focal points the relationship between the adoption of AVs and inequality, form and urban design; and 3) to generate prospective scenarios with public policy implications that contribute to minimizing the possible negative effects of their adoption and maximizing their benefits. In addition, with this case study we seek to outline implications that can serve as a reference or benchmark for the implementation of this technology in other Latin American cities.

Finally, in order to address these objectives after having defined the general conceptual framework of the paper, we propose the following questions and methodology to answer them.

1.1. Research questions

The research outlines the following questions, organized along three thematic lines. The first line, focused on academic sources, presents us with the question: What has been studied in relation to the urban and social implications of the adoption of AVs in general and in the Latin American context in particular? The second line, related to spatial justice, considers that new technologies often present challenges in a context where the provision of public and pedestrian spaces is limited and of poor quality, especially in marginalized neighborhoods in the urban periphery (McGuirk, 2014), in addition to the fact that it is known that Latin American cities are unequal in spatial access to transportation, access to technology services, employment, schooling level, and housing. All of the above can be synthesized in this question: How and why the use of AVs in Latin American cities, characterized by fragmentation and social inequality, can have both negative and positive effects? And finally, the third thematic line seeks to study the issue of sustainability: while it is true that the literature outlines that the new technology will bring environmental and economic benefits, it also warns that the potential negative effects are still uncertain (Milakis *et al.*, 2020); therefore, what kind of challenges, opportunities and risks

will arise in Latin American cities that intend to make a systemically sustainable and beneficial use of AVs?

1.2. Methodology

The proposed methodology includes three stages. The first stage consisted of reviewing the literature in relation to our research questions so as to understand the dilemmas identified by academia in the adoption of this technology in cities. Snowball sampling was used to find the most relevant articles. Among the key papers, the article by Milakis *et al.* (2020) was fundamental as it includes a literature review analyzing various social and public policy implications of AVs, including aspects of mobility, transportation infrastructure, land use, social equity, public health, safety and pollution. It is also worth noting the work of Harb *et al.* (2021), which includes an extensive review of scientific articles, academic and private sector reports published on AVs between 2011 and 2020.

In the second stage, a case study was developed to address the implications of the adoption of AVs to the urban context in Latin America; this approach is used to investigate complex social phenomena and to understand the how or the why of such phenomena (Yin, 2009). The city of Monterrey was selected and the unit of analysis was its metropolitan area since travel and transportation decisions respond, precisely, to a metropolitan logic that connects residential areas with the employment and leisure offer dispersed in the city; thus, if the impact of AVs in the social dimension is to be evaluated to answer the research questions, the appropriate scale of analysis is a metropolitan area. In addition to taking into account inequality, urban form, transportation, mobility and the ethical implications of social justice in relation to spatial and demographic change for this analysis, the main challenges, opportunities and risks were detected as well and prospective scenarios with public policy implications were included. As we have already pointed out, the case study is intended to illustrate some general conditions and implications for other Latin American cities.

Finally, a third stage was devoted to the formulation and description of two scenarios for prospective analysis of the adoption of this technology, with the intention of assessing its potential for social change. The two scenarios selected respond to the two business models currently being considered: 1) a model in which the technology is only adopted for private use, and 2) a model in which, despite its use by private individuals, the SAVs service on demand is predominant.

For these scenarios, the dependent variable was the degree of spatial justice achievable in a city; the independent variable was the adoption pattern of AVs under each scenario and the public policy implications they entail. In each scenario, the possible consequences were analyzed in 5 areas that affect the degree of spatial justice: accessibility, transport modal split, regulatory policy, multisectoral alliances and urban form.

2. Literature review

To understand the relationship between AVs and unequal urban environments, the specialized academic literature presents us with four areas: (a) studies regarding the business model anticipated for these vehicles and the impact they would have on urban transportation systems; (b) a subfield that has addressed the social dimension of inequality in relation to the adoption of these technologies and their impact on vulnerable groups; (c) the theory of spatial justice, which will serve as a theoretical framework to evaluate the relationship between AVs and the social dimension in the analysis section; and (d) the area regarding public policy recommendations that would be relevant to adapt AVs in Latin American cities under a people-based city model. A brief review of these four bodies of literature follows.

2.1. Business model and impact on public transport

In the mobility context, it is expected that one of the main adoption schemes of AVs will be *mobility as a service* or *on demand*, whereby users use platforms according to their specific needs, paying for the service and without the need to purchase the vehicle for exclusive use. The benefits of this scheme would be that it introduces a travel offer that is friendly, comfortable and adjusted to the user's needs (Coppola and Silvestri, 2019; Golbabaei et al., 2020), in addition to the fact that this modality could solve the connectivity problem in the last mile, i.e., in the last leg of a trip (Lang et al., 2020).

Additionally, to promote the adoption of AVs from the inclusion aspect, it is recommended that ridesharing should be economically favored within the creation of public policies (Moavenzadeh and Lang, 2018). It is key that in this typology there exists the possibility of trip customization and transparency. The first attribute would allow each user to consume according to their needs and would favor the retention of the service by the users (Yamaji, 2020), while the second attribute would facilitate the availability of AVs, offering the possibility for passengers to better plan their trips, optimize routes and reduce travel times (Moavenzadeh and Lang, 2018).

Regarding the impact on the supply and demand of public transport, the literature warns of possible opportunities and important challenges. Firstly, it is envisioned that AVs could extend the reach of public transport through a microtransit solution, thus managing to reach areas that lack good public transport infrastructure (Coppola and Silvestri, 2019; Yamaji, 2020); this possibility sounds particularly positive in the context of Latin American cities. But, on the other hand, the introduction of AVs threatens to reduce the demand for public transport, which, in turn, would reduce mobility options (Litman, 2020), increase the number of cars in circulation and, thus, affect travel times (Litman and Silvestri, 2019).

Finally, regarding the social dynamics related to the introduction of AVs, some authors have mentioned that they would make family schedules more flexible because children's mobility would no longer depend on their parents' schedule (Harb *et al.*, 2021). With this greater independence gained, Zandieh and Acheampong (2021) anticipate a positive socialization impact on older adults or people with disabilities since shared vehicles could encourage the interaction of people.

2.2. Social inequality and AV dilemmas

Although the literature recognizes that autonomous vehicles have the potential to perpetuate or produce new forms of social inequality (Bissell *et al.*, 2020; Adey, 2006; Lutz, 2014; Baerenholdt, 2013), several authors assert that the introduction of this technology could improve accessibility for people who cannot afford to buy a car or drive in an on-demand model (Claypool *et al.*, 2017; Holley-Morre and Creighton 2015; Dianin *et al.,* 2021). However, other authors warn that the expansion of cities would be incentivized with this increased accessibility to peripheral areas, thus generating new social and environmental costs (Gruel and Stanford, 2016; Dianin *et al.*, 2021; Gelauff *et al.*, 2019; Milakis *et al.*, 2020). For his part, Sperling (2018) in particular remarks that, although automation could lead to safer, cleaner, more affordable and accessible mobility, this would only be achieved if it is combined with electrification and ridesharing.

Dianin *et al*. (2021) also recognize this duality in transportation equity and in the distribution of accessibility in space and between social groups. On the one hand, they argue that this technology would exacerbate social inequalities: higher income sectors that are more attractive to the market would obtain greater benefits. On the other hand, they argue that its adoption would lead to a decrease in inequalities thanks to a greater balance in the distribution of accessibility between different social groups (by introducing high-level automated public transport or SAVs).

Milakis *et al*. (2020) analyze the implications for three vulnerable groups: low-income people, people with physical and/or sensory disabilities, and the elderly, concluding that the benefit or detriment for them will depend on the automation component of the technology and the service and business model adopted for its implementation: private or shared AVs in the *mobility as a service* and on-demand scheme.

Since lower-income households rely more heavily on public transport, another recurring theme in the literature is the impact of AVs on said public transport (Milakis *et al*., 2020; Clewlow and Mishra, 2017; Ohnemus and Perl, 2016; Brown and Taylor, 2018; Vön Morner, 2019; Abe, 2019; Coppola *et al.*, 2018). The introduction of SAVs would definitely affect the public transport system by changing the accessibility/mobility of the groups that depend on it. Therefore, buffer policies would be required to contribute to a complementary system between AVs and existing public transport, e.g., by generating feeder public services with AVs to public transport lines.

2.3. Autonomous vehicles and spatial justice

There are a number of considerations that have not yet been explored in depth in this specialized literature that are related to the changes that AVs would promote in urban form, urban design and the relationship of these factors with social elements (Harb *et al.*, 2021). Throughout the history of cities, changes in urban design and form are generated with each change in technology. Locomotives, for example, enabled the economic boom and rural-urban migration, the internal combustion vehicle favored suburbanization, and airplanes have facilitated globalized cities. Consequently, these technologies have created dilemmas that thinkers such as Soja (2013) and Harvey (2012) warn are the result and consequence of the injustice that exists in the production and social reproduction of space.

With the advent of AVs, questions remain as to how the way of life in cities will be transformed, how these changes will affect its physical form, and whether the results will reduce or increase current social inequalities. This can be seen with a direct connection between territory and

economic inequality, which tends to create a systemic structure of privilege and disadvantage, thus resulting in segregation and discrimination by class, race, gender, and age, among others (Soja, 2013).

Referring to urban sociology, we find the concept of spatial justice that reflects precisely on the geographic spatial dimension of a territorial distribution where the costs and benefits of economic development are more equitable (Soja, 2013). In other words, in the context of the city, it is a matter of the different neighborhoods having an adequate provision of public services, transportation, housing and access to employment, leisure and education opportunities. To the extent that our cities achieve this goal, the urbanization process will be more sustainable and possibly fulfill the promise of generating economic wellbeing for a majority of the population.

Additionally, the right to the city is an idea that responds to the theory of spatial justice, stating that greater equity will only be achieved if socially disadvantaged populations gain some control and participation over the political and economic processes that generate unequal urban geographies (Fainstein, 2014; Harvey, 2012). Complementary to this, Marcuse (2012) describes how the right to the city is a common cause between groups favored and disadvantaged by the system to improve social justice in a spatial range.

Given the adoption of this new technology and considering these concepts, the criticism of the city model that orients the function of urban space to privilege travel by private automobile over other uses such as socialization, belonging, building a collective identity, green infrastructure housing and safety remains valid (Borja and Muxí, 2003). Under the current model, the consequences of the prioritization of the automobile have deteriorated the human quality of the city, especially for marginalized groups such as women, people with disabilities, the elderly and children. In order to reduce the gaps and maximize the social benefits of AVs, the development of policies based on the search for human dignity, together with factors that derive from the representativeness and value of the territory, will be fundamental (Iveson, 2011).

In summary, the impacts that the adoption of AVs will have on the spatial reconfiguration of cities are still uncertain, especially from the perspective of Latin American cities characterized by marked social inequality and the marginalization of vulnerable groups.

2.4. Public policies for the adoption of AVs

The use of new technologies for transportation reaffirms the need for new legislative bases to regulate road behavior, guarantee safety and resolve market asymmetries. However, the progress in legislative and regulatory processes does not match that of technological development, which is generally faster (Catalayud *et al*., 2020). Given the ethical complexity of automated technology, since 2011 there have been regulations in the United States and the European Union to attribute civil liability within road traffic: it was determined that it would be given by the level of autonomy that the vehicle had, with the programming companies taking greater responsibilities the higher the level of autonomy (Myers, 2016). Over the years, international institutions such as the UN have begun to set the standard with safety parameters through maximum speed ranges, for example 30 km/h for vehicles with a higher level of autonomy. Controls have also been established that require disabling the autonomous system on pedestrian roads or roads shared with cyclists as a measure to protect these users. Other regulations have included having a cyber security system and a black box to help record actions (Fuentes, 2020).

In 2020, the company KMPG ranked the 30 countries with the highest likelihood of implementing this technology and, taking into account consumer acceptance, infrastructure, technology and innovation as well as policies and legislation, created the "Autonomous Vehicle Readiness Index". Due to the lack of specific regulations and the inability of the national government to adapt to changes, Mexico was ranked 28th. Other Latin American countries such as Chile and Brazil were ranked 27th and 30th, respectively (KPMG, 2020). These positions show that the challenge of adopting this technology is widespread for Latin American cities. Cremata (2016), for example, observes large legal gaps in the countries of the region, including the lack of definitions of moral and ethical responsibility in the event of a fatal accident; without the necessary infrastructure, accidents could go unpunished (McCulloug and Colle, 2016).

In addition to the abovementioned problems, there are neither regulations nor legislation that can foresee the possible consequences on urban form, territorial expansion or road congestion. In addition, AVs could promote social disarticulation by enclosing society in "automated bubbles" that do not interact with the environment, thus modifying sociability (Metz, 2018).

In summary, the literature review reveals that there is no academic work that brings together the four literatures referred to here. That is, to the best knowledge of the authors, there is no rigorous academic work that analyzes whether the contexts of the adoption of AVs in Latin American cities could increase or reduce inequality and spatial justice gaps. This is relevant because the literature review shows that several authors have extensively discussed the social and ethical dilemmas that the adoption of this technology may outline for our society, as well as the need to establish public policies aimed at minimizing risks. However, these authors analyze cases of highly industrialized countries without a direct link to the spatial and social context of other regions. The literature found refers to case studies in cities with high income levels and planned urban environments. There is no record of studies that address this issue in Latin America. This research paper seeks to fill some of these gaps in the literature by means of a case study.

3. Analysis of the case study

3.1. Urban Context of Latin American Cities

Latin American countries are characterized by an unequal income distribution among their population; according to the Human Development Report of the United Nations Development Program, the richest 10% of the population concentrates 32% of the income, a figure higher than any other region on the planet (UNDP, 2013). Table 1 shows the Gini index of inequality: values close to 1 indicate greater concentration of wealth in fewer people.

This inequality in income distribution is reproduced in the territorial and spatial context of the urban environment through economic segregation and the agglomeration of high concentrations of poverty in specific areas of the city known as ghettos or favelas. Spatial segregation has a negative impact on the creation of opportunities for socially disadvantaged households. Several authors have discussed the social effects of growing up in a ghetto and the way in which this reduces access to opportunities throughout life (Perlman, 2010; Sampson, 2012).

Table 1. Comparison of income level, inequality and urbanization in Latin American countries

Country	Per capita GDP 2020	Percentage of Urban Population	Percentage of Urban Population in Informal Settlements	Gini Index
Mexico	$8,346.70	81%	16%	0.45
Colombia	$5,322.80	81%	28%	0.51
Peru	$6,129.90	78%	33%	0.41
Chile	$13,231.70	88%	9%	0.44
Brazil	$6,796.80	89%	16%	0.53

Source: prepared by the authors with World Bank data

In addition to inequality, Latin American cities manifest two other key elements in their development patterns: a high percentage of urban population and the prevalence of informal settlements. Between 1950 and 2010, the region's urban population multiplied seven times from 69 million to 480 million. This occurred in an accelerated manner, fostered among several factors by the migration of rural residents to urban areas and improvements in sanitary conditions (Libertún de Duren, 2014). However, the inability to associate the pace of urbanization with productive activities generated an "over-tertiarization", i.e., a growth of the tertiary sector and the informal sector of the economy, which aggravated socioeconomic polarization and territorial disintegration (Almandoz, 2008). In addition to this process, the

institutional and financial weakness of the region caused the State to be unable to respond in a planned and anticipated manner to the rapid population growth, generating processes of informal occupation of the territory in irregular settlements lacking adequate basic services and facilities far from work centers (Trejo, 2019). Table 1 shows that, depending on the country, between 9 and 33% of households live in informal settlements (World Bank, 2021).

Trejo (2019) argues that the Anglo-Saxon literature on economic development associates higher rates of urbanization with higher rates of social welfare and economic growth. However, the same author states that Latin America is an exception, as it is a region with a very high rate of urbanization but with severe social lags and economic stagnation. In this region, high urbanization rates have not translated into improvements in the quality of life and welfare opportunities for most households; in most metropolitan areas, urban sprawl presents a landscape of informality, poverty and lack of basic services and infrastructure in the peripheries. In spatial terms, these conditions result in fragmented, disconnected cities with insufficient and poor quality public spaces (streets, parks and squares). This model again contrasts with the patterns observed in developed countries such as the United States, where urban sprawl is characterized by the creation of suburban residential areas for the middle or upper classes and where the greatest concentration of poverty is found in the central area (Lungo, 2001). In Latin American cities, the spatial pattern is the reverse: the most precarious areas are located in the urban periphery and impose challenges for the mobility of lower-income households living there (Lungo, 2001).

3.2. Presentation of the Monterrey Metropolitan Area

With the context of the region having been provided, the case study of the Monterrey Metropolitan Area (ZMM), located in northeastern Mexico, is representative of the rapid urbanization process and a dispersed city pattern with peripheral areas devoid of basic services and marked by poverty. According to the latest INEGI census, published in 2019, the city has 4.96 million inhabitants, making it the second largest metropolitan area by population size in the country after Mexico City. Thirty-six percent of its economy is related to the manufacturing and industrial sector and comprises an urbanized area of 18 municipalities, extending over an area of 1,011 square kilometers. In the last 30 years, the ZMM's population has grown 1.7 times, but its territory has expanded 2.7 times. As a result, it has lost 39% of its population density.

According to our analysis of census data from 1990 to 2020, in 30 years the city registered a population loss in the central area of up to 250,000 inhabitants. Demographic and territorial growth is occurring in the urban periphery: in the absence of a national land policy, the provision of housing occurs where land is cheapest, i.e., in areas far from services, equipment and transportation. Consequently, Monterrey's growth process has been marked by an increase in the fragmentation of urban space. On the one hand, lower-income households face the most adverse conditions for commuting because they live on the urban periphery in areas disconnected from the areas where jobs are concentrated. On the other hand, more affluent households with cars can pay to live in areas closer to jobs and leisure. These conditions, coupled with the continuing decline in the supply of transportation (which will be discussed in more detail in the next section), make this metropolitan area a relevant case for exploring patterns of AV adoption in the region.

If we take into account some indicators of population, density and inequality (Gini Index), we can see that there are some relevant points of comparison between our case study and other Latin American cities. For example, Monterrey has a territorial extension comparable to Lima

and Santiago, but smaller than Sao Paulo and Mexico City; its population density is similar to Santiago de Chile and Sao Paulo; and the per capita GDP is comparable to Santiago and Mexico City (well above Bogotá). In terms of wealth distribution, Lima would be the least unequal city and Sao Paulo the most unequal in terms of income distribution.

Table 2. Comparison of Latin American cities in urban and income elements.

City	Population (millions)	Surface (km²)	Urban Density (inhabitants per km²)	Per capita GDP (Dollars 2018)	Gini Index
Monterrey	4.96	1,011	5,535.71	$33,340.93	0.44
Mexico City	21.92	2,385	9,190.78	$ 24,041.38	0.53
Bogotá	11.17	562	19,875.44	$ 18,152.91	0.50
Lima	10.88	891	12,211.00	-	0.33
Santiago	6.81	1,147	5,937.23	$24,646.26	0.53
São Paulo	22.24	3,237	6,870.56	-	0.57

Source: prepared by the authors with data from Macrotrends, Demographia, OECD, ECLAC, CONEVAL, SEMARNAT, INEI, IBGE and the Mayor's Office of Bogotá.

In summary, Tables 1 and 2 show that there is a certain convergence in the urbanization process in Latin America, an accelerated process accompanied by strong social disparities. They also illustrate that Monterrey is, in effect, a representative case of a metropolitan area that experienced rapid population and economic growth; and yet, it is marked by a lack of planning in the provision of necessary services and land use management to locate lower income housing in areas accessible to transportation and services. In the urban context, inequality and informality are expressed territorially and spatially through socio-spatial segregation and fragmentation of urban space by income level. It is precisely in this particular context of the region that we are interested in asking ourselves what would happen to inequality and access to opportunities in the event of the eventual adoption of AVs; to study whether this adoption would improve or worsen the livability of our cities; and to analyze whether they would promote results towards greater spatial justice.

3.3. Description of the case study

This section returns to the concepts previously addressed: the right to the city and spatial justice to link the particular elements of our case study with the attributes that affect the adoption of this new transportation technology. In order to organize them, we will start with the analysis of economic inequality, then we will mention the urban form and transportation, and finally the social and demographic implications.

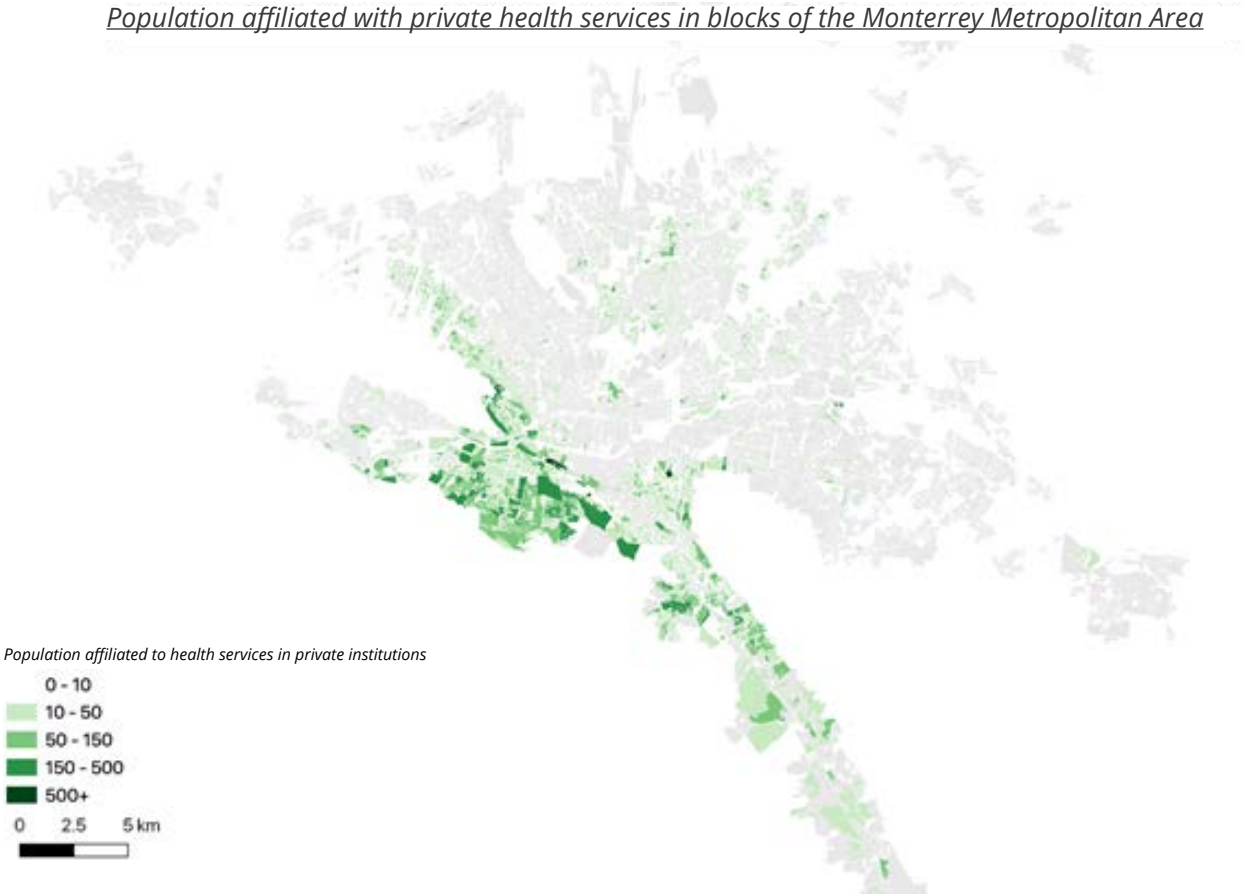
3.3.1. Inequality

In the context of Mexico, some studies have already reported the relationship between inequality, purchasing power and access to health care: the most affluent households are those with access to private health care (Tamez and Eibenschutz, 2008). Therefore, the variable that quan-

tifies population with private health insurance is a good approximation of the average income at the block level, which is why we use it; the census does not report the income variable at this level of geographic detail.

Figure 1 illustrates the blocks in the urbanized area of the ZMM in which the more intense green color represents a higher concentration of the population that does have private health insurance. According to these data, the darker color indicates a higher concentration of affluent households.

Figure 1. Population affiliated with private health services at the block level.



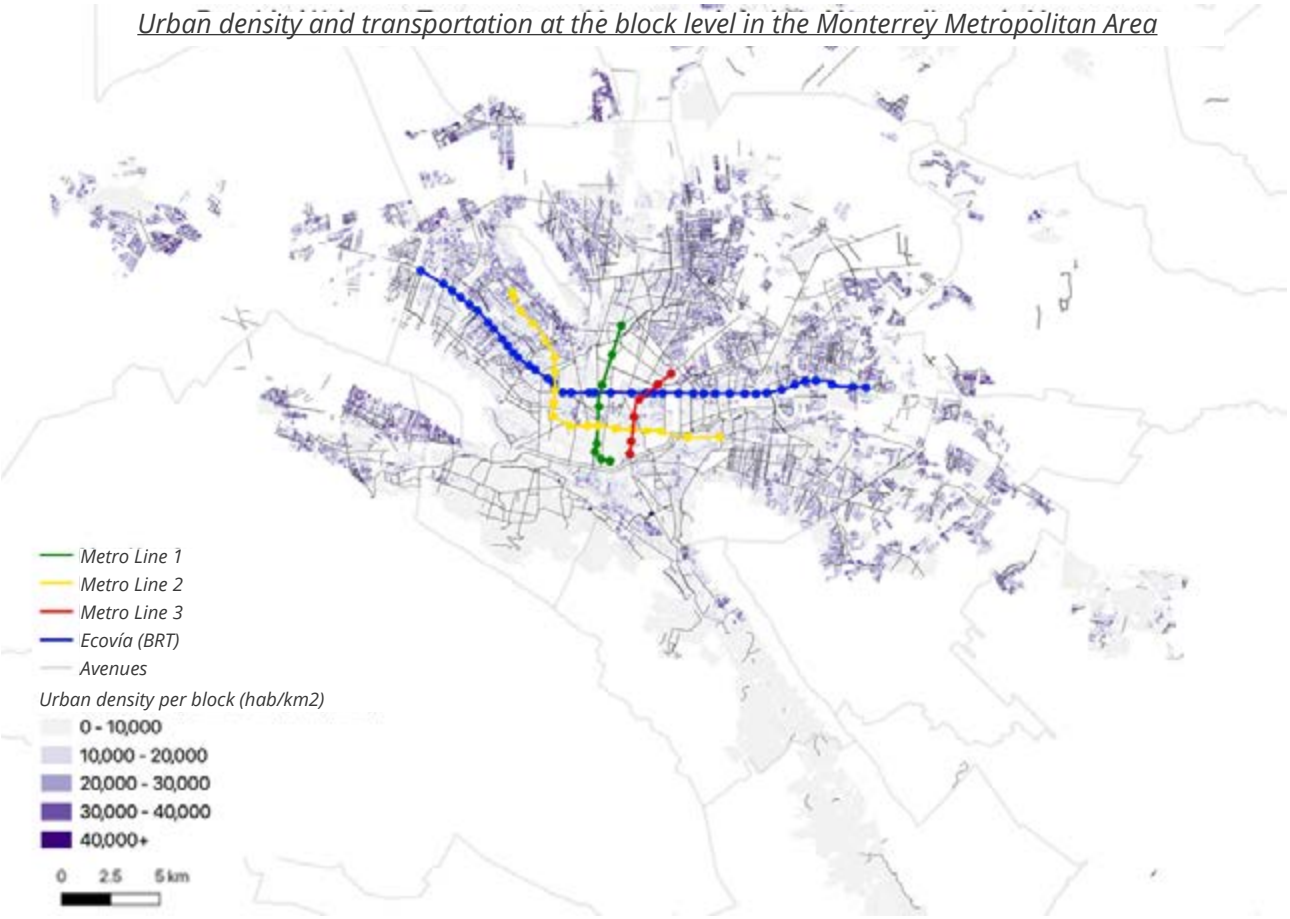
Source: Prepared by the authors with data from the 2020 INEGI Population and Housing Census.

It can also be observed that the darkest shades of green - denoting a higher density - are in the southwestern part of the metropolitan area and that, as we move towards the northeast, the population with private health services decreases, i.e., income decreases. There is a very clear pattern of spatial and social fragmentation in the city: the areas with the greatest affluence are located closer to the urban center, have a greater provision of services, better road infrastructure and a higher density of jobs in the tertiary sector of the economy.

3.3.2. Urban Form

As we have seen, in general terms, the ZMM has a social distribution in which higher-income households live in functional zones with better access to employment and services, while lower-income households live predominantly in the urban periphery or in areas of adverse geography. In detail, the current urban form is composite polycentric: there is a dominant center in the concentration of employment, but new sub-centers of activity are beginning to consolidate in the periphery. However, this consolidation process has been gradual and uneven, with these new sub-centers of activity lagging behind in terms of social infrastructure and public transportation. Figure 2 shows the density of inhabitants per block: the darkest gradient corresponds to the highest densities. If we compare this map with the income map in Figure 1, it is possible to notice that the highest densities are located as we move to the northern and eastern periphery, coinciding with the least affluent areas. The highest density zones in the urban periphery correspond to new activity centers located in the municipalities of García, Escobedo and Apodaca. The central area of the municipality, which corresponds to the historic part of the city and is nowadays a commercial and government area, has the lowest densities of inhabitants.

Figure 2. Urban density and transportation at the block level (number of inhabitants per square kilometer)



Source: prepared by the authors with data from the INEGI Population and Housing Census 2020.

One of the challenges for Monterrey - and for most Latin American cities - is to bring jobs and public transportation to the urban periphery while generating a supply of affordable residential housing for lower-income households in the central area, which is generally better served by services and jobs.

Consequently, urban form and social inequality are closely related to transportation. In other words, to the extent that the city offers safe and affordable mobility and transportation for the entire population, the possibilities of access to services and jobs increase even for lower-income households. Figure 2 illustrates how this condition is not met in the ZMM, since there is a disconnection between the areas with the highest density per block and the location of the subway lines. In addition, when comparing census information by decade from 1990 to 2020, the urban center of the city is in a process of population loss and an increase in the concentration of older adults, while in the peripheral areas there is a greater presence of young households without sufficient coverage of the transportation infrastructure.

3.3.3. Transportation and mobility

A relevant characteristic in Monterrey, typical of the dispersed city model and which makes it an exemplary case for the analysis of the possible adoption of AVs, is the inadequate supply of public transportation (López, 2021); this situation has repercussions on the preference for the automobile for commuting as travel times are shorter. According to the 2018 *Así Vamos Nuevo León* survey, the average round trip travel times to work for the ZMM by private car are 53 minutes, while by public transport are 103 minutes (Cómo Vamos Nuevo León, 2018), i.e., travel time is on average twice as long for a household without a private vehicle. This is without considering other additional factors such as weather, transfers, safety on the streets and the comfort of the units that could further incentivize car use. Lower-income households that do not own a private vehicle live mostly in the urban periphery. In other words, the most socially disadvantaged households face the highest costs of commuting to the areas where employment is concentrated.

To illustrate this situation, let us look at Table 3: the average commuting time for residents of San Pedro Garza García (the most affluent municipality of the ZMM, well connected with highways and whose residents own private vehicles) is 53 minutes. In contrast, the average time of two peripheral municipalities with the highest proportions of lower income households and social housing, Juarez and García, is 95 minutes. These two figures show a marked inequality in transportation: traveling by private vehicle is faster than by public transportation; lower income households living in the urban periphery face longer travel times and lower levels of accessibility.

Table 3. Average travel time by municipality

Municipality	Average Travel Time
San Pedro Garza García (central affluent zone)	53 minutes
Juárez (peripheral and socially disadvantaged zone)	95 minutes
García (peripheral dormitory town)	95 minutes

Source: prepared by the authors with data from Cómo Vamos Nuevo León, 2018.

Evidently, shorter travel times make it more attractive to travel by private car to the detriment of the use of the public transportation system. According to data provided by the Comprehensive Plan for Sustainable Urban Mobility (PIMUS) in the ZMM in 2020, 47% of trips were made by automobile while 20% by public transport (Transconsult, S. A. de C.V., 2021, see Table 4). It is worth noting that from 2005 to 2020 there was a decline in public transport trips and an increase in the use of private cars: in 2005, more than 40% of trips were made by public transport and approximately 35% in private cars (Transconsult, S. A. de C.V., 2021).

Table 4. Modal split in 2005 and 2020.

Year	Trips Made by Car in the ZMM	Trips Made by Public Transportation in the ZMM
2005	35%	>40%
2020	47%	20%

Source: prepared by the authors with data from Transconsult, 2021.

In addition, the number of public transport trips went from representing 68% of all trips made in 1990 to 31% in 2019 (Lopez, 2021), and this drop in demand has been accompanied by a reduction in the supply of public transport. The number of units providing the service went from 6,600 to 5,255 in the period from 2009 to 2019 (Lopez, 2021). The loss of demand and the drop in supply generates a vicious circle: fewer transport units on the streets cause longer waiting times for passengers and encourage more people to consider switching to private vehicles. This results in fewer fares and less revenue for carriers, who, in turn, react by cutting routes, reducing quality standards and reducing the number of service units in circulation. The households most affected by this phenomenon are again those with lower incomes living in the periphery with young families, and who depend on this mode of transport to carry out their daily activities.

This change in the modal split shows us a city with a metropolitan area dependent on the private car as the main travel mechanism. The paradox is that lower income households that cannot afford it generally live in areas with less public transportation coverage, facing really adverse conditions to access employment, education, health and leisure opportunities.

In addition, this vicious circle cascades into the current public transportation supply. The ZMM has a mass public transportation system: three subway lines and one Bus Rapid Transit (BRT) line. However, these systems are under-utilized and lack feeder lines to connect residential areas and commuter travel. For example, the BRT system, two years into service, "operated at 50-60% of the originally planned demand" and, although the metro was planned to carry 15% of all trips in the ZMM, by 2020 it barely carried 2% (Lopez, 2021).

Furthermore, in a sparsely populated and dispersed city like Monterrey, the transportation economics are not adequate for the system to operate without economic subsidies. That is, having routes in the urban periphery is not profitable for concessioned carriers due to low density and spatial fragmentation. Thus, there is a lack of a feeder system from the concessioned service to the mass transit stations so that the subway can aspire to carry the 15% of trips for which it was planned. If this existed, the subway and BRT would be used to a greater capacity

and would return to a modal split with a greater presence of public transport. In short, the lack of a multimodal transport system exacerbates inequalities and discourages the use of public transport. Everything we have seen here illustrates that access to public transport in the context of the Latin American city is an issue directly related to social inequality and access to opportunities.

It is worth pausing briefly to reflect on two possible contributions of AVs in this context. On the one hand, they could help with this crisis through shared fleets that feed the public transport system, generating better access to urban services and job opportunities. On the other hand, they could bring us closer - considering the concept of the right to the city - to an ideal of spatial justice to the extent that marginalized communities have the power to participate in the adoption of the technology in their communities and that this implementation contributes to solving their mobility needs without hindering them.

3.3.4. Social and demographic implications of spatial change

According to the literature on spatial justice, not only does the territory spatially translate unequal power dynamics between social agents - for example, manifested through inequality in the distribution of urban services - but also these inequalities are perpetuated in patterns of discrimination against social groups based on age, gender or identity (Young, 1990, p. 47 cited by Fainstein, 2014). In this sense, the analysis of the ZMM shows that there are practically no young households in the central area with greater coverage of urban services. Figure 4 illustrates this spatial shift by showing the concentration of young households with children aged 0-14 years in the periphery. The explanation for this phenomenon is that most households with children move to places where they find an affordable housing supply. This particular geographic pattern outlines a series of challenges for the eventual adoption of autonomous vehicles because it is precisely in the periphery where there is a higher density of children and where there are greater challenges in terms of social infrastructure (including sidewalks and road safety) due to the rapid urbanization process that has occurred.

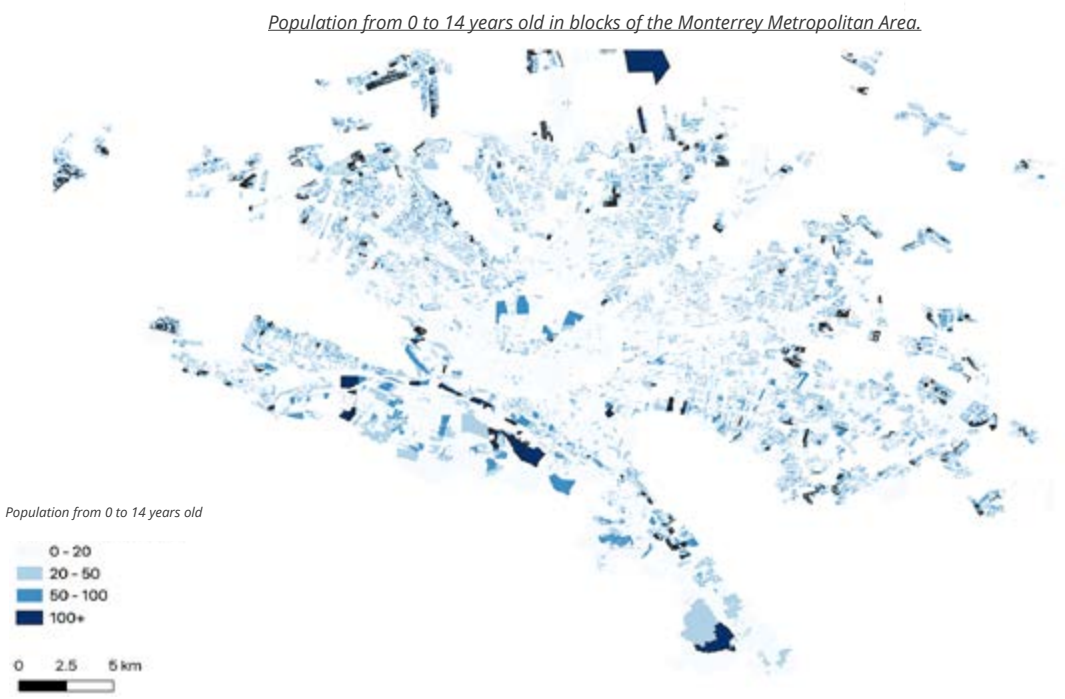


Figure 4. Population from 0 to 14 years old per block. Source: prepared by the authors with data from the 2020 INEGI Population and Housing Census.

3.4. Conclusions to the case study

In summary, the way in which Monterrey exemplifies the conditions of the Latin American city experience has been illustrated: social fragmentation and a disorderly urbanization process that reproduces poverty and the lack of opportunities for access to services. We observe that in this growth process, the situation of public transportation is a downward spiral of deterioration, deficient and declining, its coverage is limited in the expansion zones and despite being subsidized by the government, it is underutilized and operating with a demand below what was planned when it was implemented. Likewise, newly formed households with children are forced to live on the periphery because that is where they can afford to live, in environments that are not very pedestrian-friendly, totally car-oriented and with little supply of services. The structural conditions of transportation, plus the distance of residential areas from employment centers, will force a proportion of these households to purchase a car.

This distribution of young households and by income follows an unbalanced geographic pattern that responds to a social hierarchy. Access to transportation is expressed geographically through socioeconomic criteria that determine the place of residence and the destination of trips. In other words, if a person is from an affluent household, they are more likely to own a private vehicle, live in an accessible area, be close to sources of employment and be well connected to the rest of the city.

This urbanization context of Monterrey - and of Latin American cities - is very different from that discussed in the predominant AV literature, for which there is a large field of pending research. In the literature from the United States, Southeast Asia or Australia, road safety considerations and vulnerable populations are discussed in contexts of more egalitarian societies, a more generous welfare state and better planned cities. In a city like Monterrey, what role will AVs play in relation to the challenges of urbanization and inequality? What implications for spatial justice and the right to the city will autonomous vehicles have? We can anticipate that adoption rates of new technologies will be higher in higher income areas because new technologies are expensive (Udell and Potter, 1989). Based on these criteria, we would expect early adoption in residential areas located to the south and southwest of the city since these are affluent areas with good road infrastructure and whose residents currently rely on private vehicles as their primary mode of transportation. However, we are left with two questions: What can we expect to happen in the urban periphery with lower-income households? and How can we benefit from technology to achieve greater spatial justice? The answer to both involves two future scenarios: one in which AVs are adopted late in vulnerable communities, and one in which adoption takes place with the participation of suburban neighborhoods. In the following section, we will study both scenarios.

4. Prospective analysis: challenges, risks and opportunities of AVs in Latin American cities

By this point of the argument it has already become clear that AVs have the potential to improve or worsen spatial equality and justice in cities, especially in those with deep spatial inequality gaps such as Monterrey, and that the final outcome will depend on the regulatory framework, business model and public policies that are implemented to maximize their benefits and mitigate their negative externalities.

However, due to the fact that the technological development and initial implementation of this technology has been carried out in cities in the United States, Europe and Asia, there are still no in-depth studies that can support recommendations grounded in the Latin American reality. For this reason, and based on the literature review and the data collected from the Monterrey case study, in this section we include some reflections on the opportunities and risks of AVs based on the assessment of two prospective scenarios. As mentioned at the beginning of this article, this evaluation will be based on 5 aspects: a) accessibility, b) transport modal split, c) regulatory policy, d) multi-sector alliances and e) urban form.

4.1. Scenario 1: business model in favor of AVs for private use

One possibility is that technological deployment will occur only with private-use vehicles: households will replace their car with a driverless car that will remain parked when not in use and its use will remain exclusive to the owner's household. Let us evaluate the performance of this hypothetical scenario on the five selected variables.

4.1.1. Accessibility

The level of accessibility would improve, but only for the adopters of this technology; due to its high cost, higher income households - who generally do not live in the urban periphery - would be the ones who would see gains in their accessibility and mobility in the initial stages of adoption. These households would see an improvement in the flexibility that an AV would give them; they could consider more distant or infrequent travel alternatives to their routines with chauffeur-driven vehicles. However, this business model would not bring an accessibility benefit for lower-income households living on the urban periphery and with limited access to public transportation. Accessibility levels for these households remain unchanged.

4.1.2. Modal split

For the city of Monterrey, we can anticipate an inertial scenario in the modal split, that is, in favor of private vehicles and to the detriment of public transportation. We know that public transport infrastructure does not have the territorial coverage to satisfy the travel needs of households in the urban periphery and, in a scenario of private vehicles, we can forecast a higher rate of motorization in the metropolitan area in general. Middle and lower income households will continue to be forced to purchase a private vehicle to meet their daily mobility

needs. AVs would not be the cause of the decline in the use of public transport, but would reinforce this trend that has been observed for the last two decades in the city. Public transport would continue its downward spiral of precariousness, reduction of trips and feeder routes in the medium and long term.

4.1.3. Regulatory policy

Regulatory policy concerns the private use of vehicles, in a similar way to what happens today with the formalities for a private vehicle to circulate on the streets. The most important regulations in this adoption model have to do with the adaptation of traffic regulations to settle civil and criminal liability in case of accidents involving AVs, a liability that includes the company that produces the vehicle and whoever has ownership rights over it.
Multi-sector alliances

In the case of the adoption of vehicles for private use, levels of coordination are expected between the vehicle distribution companies and the authorities that regulate urban space. This is due to the number of adjustments to intersections, traffic lights and roads that must be carried out to ensure that the technological deployment is safe in its initial phases.

4.1.4. Urban form

This scenario has strong territorial expansion pressures on the urban form. In AVs for private use, the marginal cost for an additional kilometer of travel is reduced because the capital investment in the vehicle has already been made and because the valuation of travel time occurs. By being able to perform another activity in the vehicle while traveling, such as reading or writing, users of this technology may be more willing to travel longer trip distances than they consider when having to drive themselves. Overall, there would be incentives to travel greater distances from home to work, increasing pressures on the territorial growth of the city and its expansion over the urban boundary.

4.2. Scenario 2: business model in favor of on-demand shared autonomous vehicles (SAVs)

As we have seen in the literature review, Milakis et al. (2020) state that one possibility for implementation is to offer an on-demand or mobility-as-a-service scheme. This would occur in a similar way to private transportation applications such as Uber, Lyft or Didi but with driverless vehicles circulating 24 hours per day in service fleets. In this scenario, on-demand SAVs are expected to be the predominant model in the city with private use of AVs playing a marginal role.

Let us assess the performance of this scenario on the five variables.

4.2.1. Accessibility

AVs have the potential to improve accessibility to transportation and opportunities for a wide swath of the population living in the urban periphery; an area of the city that concentrates lower-income households and young households, where mobility needs are not met and where the urban environment is not friendly to its residents. It is in these contexts where the adoption

of a mobility-as-a-service or on-demand business model would have a positive impact. The data we analyzed in this research show that lower-income households in the urban periphery are forced to purchase a private vehicle or face long and costly commutes. A shared fleet feeding into public mass transit would improve accessibility to employment, education and leisure for the most socially disadvantaged households, increasing spatial justice in the city. In a shared service model, higher income households living in the central areas of Monterrey would also see improvements in their accessibility levels by being able to count on an on-demand service that meets their mobility needs.

4.2.2. Modal split

The mass transit system does not have sufficient coverage to provide service to the most socially vulnerable areas of the urban periphery. In Monterrey, the mass transit system is underutilized due to the lack of feeder routes from the periphery. As a result, public transport loses passengers, to which corresponds a cutback of routes and units, thus worsening the situation and forcing more people to switch to private vehicles as their preferred mode of travel. AVs on demand could offer an affordable service in residential areas of the urban periphery without public transport coverage in shared units that feed the mass transit services of the subway and BRT. This would generate a positive effect, as demand would increase and the proportion of trips by public transport would increase. In this way, an increase in the modal split of public transport could be anticipated.

4.2.3. Regulatory policy

The state government has the authority to regulate public transport and the feeder routes of mass transit are concessioned to private companies, including fares. The state government has also regulated the operating permits of on-demand services such as Uber or Didi, charging fees to the platforms or their drivers in the form of licenses. Under an on-demand SAVs model, it is foreseeable that this regulatory framework will be adapted in order to concession feeder routes with autonomous vehicles to private companies. There are at least two models that would be an extension of the current situation: concessions to transportation companies that provide the service, or regulation to a technological platform whose drivers cover routes on demand and independently.

4.2.4. Multi-sector alliances

The government of the federal entity that regulates Monterrey does not have the financial capacity to provide on-demand service as a public service. Historically, mass transit feeder routes have been concessioned to private individuals due to the lack of financial capacity of the state coffers. It is foreseeable that the government will need public-private partnerships to provide a shared public vehicle model. There are already several partnership models that will need to be considered and evaluated; residents will need to be actively involved in building transportation solutions. There will be cases where residential density (demand for transportation) is not sufficient to cover the operating costs of a shared service. However, in these cases, the feasibility of a public subsidy should be analyzed, justifiable by the improved accessibility conditions it would provide to residents of the urban periphery.

4.2.5. Urban form

Increased use of public transportation and less reliance on private vehicles can help to reduce miles traveled and slow expansionary pressures on the territory. In addition, the provision of better connectivity and improved levels of accessibility in the periphery can help the consolidation of new employment and service sub-centers in these areas, thus favoring densification and the transition to a polycentric city that reduces road congestion in the central area by new trips along corridors in the urban periphery. In an on-demand model with a charge per kilometer traveled, economic incentives would be generated to travel shorter distances and encourage this densification.

Table 5. Future scenarios and performance on five variables

Variables	Scenario 1: Private Use	Scenario 2: On-demand SAVs
Accessibility	Middle- to higher-income households - and those generally living in the best-connected area - would see gains in accessibility and mobility. Accessibility levels for lower-income households remain unchanged.	A shared fleet that feeds mass transit would improve accessibility to employment, education and leisure for the most socially disadvantaged households, increasing spatial justice in the city.
Modal split	Lower-middle and low-income households will continue to be forced to purchase a private vehicle to meet their daily mobility needs.	On-demand AVs could provide an affordable service in residential areas on the urban periphery without public transport coverage in shared units that feed into the metro and BRT mass transit services.
Regulatory policy	The most important regulations in this adoption model have to do with the adaptation of traffic regulations to address civil and criminal liability in case of accidents involving AVs.	The adaptation of the transportation regulatory framework in order to concession feeder routes with autonomous vehicles to private companies is foreseen.
Multi-sector alliances	Levels of coordination between vehicle distribution companies and the authorities are anticipated in order to solve intersection, traffic light and roadway adjustments.	It is foreseeable that the government will need public-private partnerships to provide a shared public vehicle model; in addition, residents will have to actively participate in the construction of transportation solutions.
Urban form	There would be incentives to travel longer distances from home to work, increasing pressures on the territorial growth of the city and its expansion over the urban boundary.	With a per kilometer charge, economic incentives would be generated to travel shorter distances and encourage densification.

Source: prepared by the authors.

In summary, and as can be seen in the comparison in Table 5, the social benefits are greater under a scheme that prioritizes shared fleets over AVs for private use. However, a rigorous financial and business analysis is still needed to compare the adoption of both service models. In this sense, the role of the government is key so that the search for greater spatial equity favors means of transportation for lower-income households. A detailed analysis of this model would be a pending subject for future research. At this time, information about the possible fares or cost of vehicles is still incipient to build on this variable in both scenarios. Finally, the following section addresses the issue of road safety, which is independent of the adoption scenario and applies to both types of ownership models.

4.3. Road safety and public policies to ensure it: prioritization of pedestrians and non-motorized means of transport

Regardless of the service model with which the technology is adopted (shared vehicles on demand or with private vehicles), there is still a need to generate a safe and comfortable urban environment in the periphery for pedestrians and non-motorized mobility schemes. The latter will not be achieved by the market alone; the intervention of the public entity is required to regulate and carry it out. Let us remember that the 2020 Autonomous Vehicle Adaptation Index, created by the consulting firm KMPG, places Mexico in 28th place out of 30 countries, just behind Chile in 27th place and two places ahead of Brazil in the 30th place; these are the only three Latin American countries ranked. Of the four categories taken into account - Consumer Acceptance, Infrastructure, Technology and Innovation, and Legislation Policies - Mexico's low scores stand out in three categories: Infrastructure, Policies and Legislation, and Technology and Innovation. This assessment is reflected in the indicator "Industrial and political agreements with new technologies", in which Mexico received 0.0 points given the low adaptation of government entities to cutting-edge technologies. This means that our country will have to adapt much of its legislation and infrastructure for AVs.

The literature indicates that, in the first place, the implementation requires a series of regulations and adaptations of the urban environment to make it safe in terms of road safety and to avoid accidents resulting from automation. These updates and adaptations should focus not only on solving the needs of the new technology, but also on taking advantage of the opportunity to generate more equitable urban environments in the urban periphery. For example, they represent the possibility of building sidewalks, improving the equipment of public spaces or enabling safe crosswalks, i.e., they can serve to improve existing and deficient environments due to the rapid urbanization process that has occurred in the periphery. However, these adaptations will not be solved by the market; the regulation and intervention of the public entity is required to incorporate a social and spatial justice agenda when dealing with the changes in the urban environment derived from the adoption of AVs.

5. Conclusion

This research work has addressed the issue of AVs in the case study of Monterrey, an unequal city with declining public transportation and high dependence on private vehicles. Monterrey presents a pattern of socio-spatial segregation that can be found in other Latin American cities: a concentration of lower income households - with a majority of young households - in the periphery that face difficulties in mobility and access to services. In addition, the State has shown limitations in the provision of transportation and territorial management of the urban periphery, which is the area of greatest demographic growth, to ensure spatial equity and social welfare. In this context of urbanization, the technological deployment of AVs can either deepen these conditions of inequality or have a positive impact on lower income communities. The technology itself does not imply a social or ethical dilemma, but rather the business and regulatory model with which it is adopted and whether it will maximize its benefits and mitigate its challenges.

As documented in the literature review and in the case study of Monterrey, the ethical dilemmas that have to do with the changes that AVs would promote in urban form and design and their relationship with social elements have not yet been furthered (Harb et al., 2021), but we know that changes in urban design and form are generated with every technological change. With the advent of AVs, some questions remain: How will they transform the way people live in the city? How will these changes affect its physical form? and How will the results allow us to achieve values of social equity and the right to the city?

The market by itself will not necessarily help close the spatial and territorial justice gap because, in a city like Monterrey, the first adopters of AVs will be the residents of the most affluent areas. These early adopters will influence the business model to be established, and their communities will be the first to adapt their street and road infrastructure for this type of technology to circulate. For this reason, the State and citizen participation are very important so that the market and the AVs business model turn to look at the urban periphery to allow this technology to make an improvement in socially disadvantaged communities.

Based on what has been presented in this article, two aspects of the technology can be identified as having transformative potential to achieve a more equitable territorial development in the city: 1) adopting the scenario of on-demand SAVs, and 2) taking advantage of the changes in infrastructure that the new vehicles will require to improve the environments in the urban periphery. Regarding the former, an on-demand model can generate favorable conditions for leveraging existing public mass transit and optimizing accessibility for households in the periphery; this would occur by employing fleets of mass transit feeder AVs from residential areas to public transit stations. Regarding the latter, if AVs will require adjustments to the urban environment for their safe circulation, these future interventions should be used to generate more friendly environments for pedestrians and the vulnerable population in the periphery and not only to make adjustments to the existing environment for a new type of vehicle. To the extent that these two elements are met, AVs will have the potential to generate fairer cities. In addition, we must not forget that the right to the city and citizen participation are indispensable elements to materialize this opportunity offered by AVs. If this is not taken into account, we anticipate greater social disparity and spatial inequality increased by the differentiated access

to opportunities given not only by the place of residence, but also by the type of vehicle and mode of transportation.

In conclusion, it is worth noting that future research is needed to define a regulatory framework for the adoption of AVs, analyze the implications for street design, conduct studies on the willingness of citizens to use this mode of transportation and further explore their needs, verifying that the proposed business model addresses their concerns. All of this in order to carry out simulations to determine the feasibility of the proposed solution and, finally, to establish cost schemes, public subsidies and investment plans. Perhaps the implementation will actually consist of a mix of the models, and a combination of elements of both forms will be discerned.

6. References

Abe, R. (2019). Introducing autonomous buses and taxis: Quantifying the potential benefits in Japanese transportation systems. Transportation Research Part A: Policy and Practice, 126, 94–113. https://doi.org/10.1016/j.tra.2019.06.003

Adey, P. (2006). If Mobility is Everything Then it is Nothing: Towards a Relational Politics of (Im) mobilities. Mobilities, 1(1), 75–94.

Mayor's Office of Bogotá. (2016). Coeficiente de Gini para Bogotá y la Región (2011 y 2014). [Gini Coefficient for Bogota and the Region (2011 and 2014).] Mayor's Office of Bogotá. http://www.sdp.gov.co/sites/default/files/8._coeficiente_de_gini_para_bogota_y_region.pdf

Almandoz, A. (2008). Despegues sin madurez: Urbanización, industrialización y desarrollo en la Latinoamérica del siglo XX. [Launches without maturity: Urbanization, industrialization and development in 20th century Latin America.] EURE. Latin American Journal of Regional Urban Studies (Santiago), 34(102). Available at: https://www.researchgate.net/publication/250371515_Despegues_sin_madurez_Urbanizacion_industrializacion_y_desarrollo_en_la_Latinoamerica_del_siglo_XX

World Bank (2021). Population living in slums (% of urban population). [Gini.] World Bank, https://data.worldbank.org/indicator/EN.POP.SLUM.UR.ZS

World Bank (2021). Índice de Gini. [Gini Index.] World Bank, https://datos.bancomundial.org/indicador/SI.POV.GINI

World Bank (2021). Urban population (% of total). [Gini.] World Bank, https://datos.bancomundial.org/indicator/SP.URB.TOTL.IN.ZS

Bærenholdt, J. O. (2013). Governmobility: The Powers of Mobility. Mobilities, 8(1): 20–34.

Bissell, D., Birtchnell, T., Elliott, A., & Hsu, E. (2018). Autonomous automobilities: The social impacts of driverless vehicles. Current Sociology, 68(1): 116–134. https://doi.org/10.1177/0011392118816743

Boeing, G. (2017). OSMnx: New methods for acquiring, constructing, analyzing, and visualizing complex street networks. Computers, Environment and Urban Systems, 65, 126-139.

Borja, J., & Muxí, Z. (2003). Public space: city and citizenship. [Gini.] Editorial Electa.

Brown, A., D. Taylor, B. 2018. Chapter 6 —Bridging the Gap between Mobility Haves and Have Nots. In Three Revolutions : Steering Automated, Shared, and Electric Vehicles to a Better Future. Washington, DC: Island Press.

Catalayud, A., Benítez, C., Leaño, J. M., Agosta, R., Blas, F., Goytia, C., Guilera, S., Riobó Patiño, A., Nevas Duk, C., Freytes, C., & Rodriguez Tourón, F. (2020, Julio). Autonomous vehicles. Results of the Delphi survey on their impact and adoption in Latin America and the Caribbean. [Gini.] Inter-American Development Bank. Available at: https://publications.iadb.org/publications/spanish/document/Vehiculos-Autonomos-Resultados-de-la-encuesta-Delphi-sobre-su-impacto-y-adopcion-en-ciudades-de-America-Latina-y-el-Caribe.pdf

Bujedo Esteban, M. (2019). Vehículos autónomos. [Autonomous vehicles.] University of Valladolid. Available at: https://core.ac.uk/download/pdf/228073967.pdf

Childress, S., Nichols, B., Charlton, B., & Coe, S. (2015). Using an Activity-Based Model to Explore the Potential Impacts of Automated Vehicles. Transportation Research Record: Journal of the Transportation Research Board, 2493(1), 99–106. Available at: https://www.researchgate.net/publication/295244756_Using_an_Activity-Based_Model_to_Explore_the_Potential_Impacts_of_Automated_Vehicles

Claypool H, Bin-Nun A and Gerlach J (2017) Self-Driving Cars: The Impact on People with Disabilities. Boston: Ruderman Foundation.

Regional Service Center for Latin America and the Caribbean, Regional Bureau for Latin America and the Caribbean, United Nations Development Program. (PNUD) (2013). Informe regional de desarrollo humano 2013-2014. [Regional Human Development Report 2013-2014.] United Nations Development Program. Available at: https://www.latinamerica.undp.org/content/rblac/es/home/library/human_development/informe-regionalde-desarrollo-humano2013-2014-.html

Clewlow, R.R., & Mishra, G.S., 2017. Disruptive Transportation: The Adoption, Utilization, and Impacts of Ride-Hailing in the United States. Institute of Transportation, UC Davis, Davis, California.

Cómo Vamos Nuevo León (2018). Así vamos Nuevo León. [The way we are going, Nuevo León.] Retrieved June 25, 2021 from: http://comovamosnl.org/alcalde-como-vamos/

CONEVAL. (2020). Informe de Pobreza y Evaluación 2020. [Poverty Report and Assessment 2020.] National Council for the Evaluation of Social Development Policy. https://www.coneval.org.mx/coordinacion/entidades/Documents/Informes_de_pobreza_y_evaluacion_2020_Documentos/Informe_Nuevo_Leon_2020.pdf

Coppola, P., & Silvestri, F. (2019). Autonomous vehicles and future mobility solutions. Elsevier Inc. Available at: https://www.sciencedirect.com/science/article/pii/B9780128176962000019?via%3Dihub

Coppola, P., & Silvestri, F. (2019). Future mobility and land use scenarios: impact assessment with an urban case study. Transportation Research Procedia, Modeling and Assessing Future Mobility Scenarios Selected. In Proceedings of the 46th European Transport Conference 2018, Dublin, Ireland, 10–12 October 2018. Transportation Research Procedia, 42, 53–63. https://doi.org/10.1016/j.trpro.2019.12.006

Collarte, N. (2012). The Woonerf Concept. Rethinking a Residential Street in Somerville.

Cordts, P., Cotten, S. R., Qu, T., and Bush, T. (2021). Mobility Challenges and Perceptions of Autonomous Vehicles for Individuals with Physical Disabilities. Disability and Health Journal, p. 101131. Available at: https://doi.org/10.1016/j.dhjo.2021.101131

Creger, H., Espino, J., & Sánchez, A. (2019, Enero). Autonomous vehicle heaven or hell? The Geenlining Institute. Available at: http://greenlining.org/wp-content/uploads/2019/01/R4_AutonomousVehiclesReportSingle_2019_2.pdf

Cremata, I. (2016). "Inteligencia Artificial: La necesidad de resolver el vacío legal en la regulación de vehículos autónomos." [Artificial Intelligence: The need to solve the legal vacuum in the regulation of autonomous vehicles.] UADE, Faculty of Law and Social Sciences.

Dianin,A., Ravazzoli,E., & Hauger, G. "Implications of Autonomous Vehicles for Accessibility and Transport Equity: A Framework Based on Literature". Sustainability 2021, 13, 4448. https:// doi.org/10.3390/su13084448

Derr, V., Chawla, L., Mintzer, M., Cushing, D., & van Vliet, W. (2013). A City for All Citizens: Integrating Children and Youth from Marginalized Populations into City Planning. Buildings, 3(3), 482–505.

Demographia. (2021).World Urban Areas,17th edition. Demographia. Available at: http://www.demographia.com/db-worldua.pdf

Fagnant, D. J., & Kockelman, K. M. (2014). The travel and environmental implications of shared autonomous vehicles, using agent-based model scenarios. Transportation Research Part C: Emerging Technologies, 40, 1–13.

Fainstein, S. S. (2014). The just city. International Journal of Urban Sciences, 18(1), 1–18. https://doi.org/10.1080/12265934.2013.834643

Fischer, S., David, D., Crotty, B., Dierks, M., & Safran, C. (2014). Acceptance and use of health information technology by community-dwelling elders. International Journal of Medical Informatics, 83(9), 624–623.

Fuentes, L., Mac-Clure, O., Moya, C., & Olivos, C. (2017) Santiago Chile: city of cities? Social inequalities in local labour market zones. Economic Commission for Latin America and the Caribbean. Available at: https://www.cepal.org/sites/default/files/publication/files/42011/RVI121_Fuentes.pdf

Fuentes, V. (2020). La ONU se lo pone difícil a los coches 'autónomos': una nueva normativa limita el uso del nivel 3 a 60 km/h. [The UN makes it difficult for 'autonomous' cars: a new regulation limits the use of level 3 to 60 km/h.] MotorPasion. Available at: https://www.motorpasion.com/tecnologia/onu-se-pone-dificil-a-coches-autonomos-nueva-normativa-limita-uso-nivel-3-a-60-km-h

Gerrish, S. (2018). How smart machines think. MIT Press.

Greenblatt, J., & Saxena, S. (2015). Autonomous taxis could greatly reduce greenhouse-gas emissions of US light-duty vehicles. Nature Climate Change, 5 (September),860–863.

Gelauff, G., Ossokina, I., & Teulings, C. (2019). Spatial and welfare effects of automated driving: Will cities grow, decline or both? Transportation Research Part A: Policy and Practice, 121, 277–294. Available at: https://doi.org/10.1016/j.tra.2019.01.013

Golbabaei, F., Yigitcanlar, T., & Bunker, J. (2020). The role of shared autonomous vehicle systems in delivering smart urban mobility: A systematic review of the literature. International Journal of Sustainable Transportation.

Gruel, W., & Stanford, J. (2016) Assessing the long-term effects of autonomous vehicles. Transportation Research Procedia 13: 18–29.

Harper, C., Hendrickson, C. T., Mangones, S., & Samaras,C. (2016). Estimating potential increases in travel with autonomous vehicles for the non-driving, elderly and people with travel-restrictive medical conditions. Transportation Research Part C: Emerging Technologies, 72, 1–9.

Harb, M., Stathopoulos, A., Shiftan, Y., & Walker, J. L. (2021). What do we (Not) know about our future with automated vehicles? Transportation Research Part C: Emerging Technologies, 123, 102948. https://doi.org/10.1016/j.trc.2020.102948

Harvey, D. (2012). The right to the city. In The Urban Sociology Reader (pp. 443-446). Routledge.

Holley-Moore, G., & Creighton, H. (2015) The Future of Transport in an Ageing Society. London: Age UK.

Hulse, L. M., Xie, H., & Galea, E. R. (2018). Perceptions of autonomous vehicles: Relationships with road users, risk, gender and age. Safety Science, 102, 1–13. doi:10.1016/j.ssci.2017.10.001

IBGE.(2010). Índice de Gini da Renda Domiciliar per Capita-São Paulo. [Gini Index of Household Income per Capita - São Paulo.] Brazilian Institute of Geography and Statistics -http://tabnet.datasus.gov.br/cgi/ibge/censo/cnv/ginisp.def

INEI. (2018). Evolución de la Pobreza Monetaria 2007-2017. [Evolution of Monetary Poverty 2007-2017.] National Institute of Statistics and Informatics. https://www.inei.gob.pe/media/cifras_de_pobreza/informe_tecnico_pobreza_monetaria_2007-2017.pdf

Irazábal, C., & Jirón, P. (2021). Latin American smart cities: Between worlding infatuation and crawling provincialising. Urban Studies, 58(3), 507-534.

Iveson, K. (2011). Social or spatial justice? Marcuse and Soja on the right to the city. City, 15(2), 250-259.

KPMG (2020), 2020 Autonomous Vehicles Readiness Index. Assessing the preparedness of 30 countries and jurisdictions in the race for autonomous vehicles

Lang, N. et al. (2020). Can self-driving cars stop the urban mobility meltdown? BCG; Uni St.Gallen. Available at: https://image-src.bcg.com/Images/BCG-Can-Self-Driving-Cars-Stop-the-Urban-Mobility-Meltdown-Jul-2020_tcm9-252485.pdf

Libertun de Duren, N. (2014). Urbanización rápida y desarrollo: Cumbre de América Latina y China. [Rapid Urbanization and Development: Latin America and China Summit.] InterAmerican Development Bank. Available at: https://publications.iadb.org/es/publicacion/16894/urbanizacion-rapida-y-desarrollo-cumbre-de-america-latina-y-china

Litman, T. (2020). Autonomous Vehicle Implementation Predictions: Implications for Transport Planning. Transportation Research Board Annual Meeting, 42(5 June 2020):1–39.

López Cantú, M. (2021). Pájaros Rompiendo Ventanas. [Birds Breaking Windows.] Cómo Vamos Nuevo León. Available at: http://www.comovamosnl.org/

Lutz C (2014) The US car colossus and the production of inequality. American Ethnologist 41(2): 232–245.

Lungo, M. (2001). Urban Sprawl and Land Regulation in Latin America. Lincoln Institute. Available at: https://www.lincolninst.edu/es/publications/articles/urban-sprawl-land-regulation-latin-america

Macrotrends.(2021). Largest World Cities by Population 2021. Macrotrends, https://www.macrotrends.net/cities/largest-cities-by-population

Marcuse, P. (2009). From critical urban theory to the right to the city. City, 13(2-3), 185-197.

Marcuse P (2009), "Spatial justice: derivative but causal of social injustice" [« La justice spatiale : à la fois résultante et cause de l'injustice sociale », translation: Sonia LehmanFrisch], justice spatiale | spatial justice

McCulloug, C., & Colle. (2016) Regulatory Issues Related to Autonomous Vehicles, Lynne McChristian, Florida University

McGuirk, J. (2016). Ciudades radicales: Un viaje a la arquitectura latinoamericana. [Radical Cities: A Journey into Latin American Architecture.] Turner.

Metz, D. (2018). Developing Policy for Urban Autonomous Vehicles: Impact on Congestion, Centre for Transport Studies, University College London, Gower Street, WC1E 6BT London, UK;

Milakis, D.; van Wee, B. Chapter 4—Implications of vehicle automation for accessibility and social inclusion of people on low income, people with physical and sensory disabilities, and older people. In Demand for Emerging Transportation Systems; Antoniou, C., Efthymiou, D., Chaniotakis, E., Eds.; Elsevier: Amsterdam, The Netherlands, 2020; pp. 61–73.

Milakis, D., van Arem, B., & van Wee, B. (2017). Policy and society related implications of automated driving: A review of literature and directions for future research. Journal of Intelligent Transportation Systems, 21(4), 324–348. https://doi.org/10.1080/15472450.2017.1291351

Millard-Ball, A. (2016). Pedestrians, Autonomous Vehicles, and Cities. Journal of Planning Education and Research, 38(1), 6–12. doi:10.1177/0739456x16675674

Moavenzadeh, J. & Lang, N. S. (2018). Reshaping urban mobility with autonomous vehicles lessons from the city of Boston. World Economic Fourum. Available at: http://www3.weforum.org/docs/WEF_Reshaping_Urban_Mobility_with_Autonomous_Vehicles_2018.pdf

Mumford, L. (1961). The city in history: Its origins, its transformations, and its prospects (Vol. 67). Houghton Mifflin Harcourt.

Myers, J. (2016). How will self-driving cars make life or death decisions? World Economic Forum. Available at: https://www.weforum.org/agenda/2016/08/the-ethics-of-self-driving-cars-what-would-you-do?utm_content=bufferc701b&utm_medium=social&utm_source=facebook.com&utm_campaign=buffer

Nair G. & Bhat C. (2020), "Transportation Research Part C", Sharing the road with autonomous vehicles: Perceived safety and regulatory preferences

National Scientific Council on the Developing Child (2020). Connecting the Brain to the Rest of the Body: Early Childhood Development and Lifelong Health Are Deeply Intertwined Working Paper No. 15. Retrieved from: www.developingchild.harvard.edu.
Navazu M. (2021), Las ciudades al servicio de la vitalidad urbana, [Cities in the Service of Urban Vitality.] Ciudades que caminan, Panorama.

Nieto, A. T. (2019). Metropolitan economic development: the political economy of urbanisation in Mexico. Routledge.

OECD. (2021). Áreas Metropolitanas: PIB 2018 Base 2015, [Metropolitan Areas: GDP 2018 Base 2015.] Organization for Economic Cooperation and Development, https://stats.oecd.org/Index.aspx?DataSetCode=CITIES

Ohnemus, M., Perl, A., 2016. Shared autonomous vehicles: catalyst of new mobility for the last mile? Built Environment 42, (4), 589e602.

Owens, J. M., Clamann, M., Aylor, D., Balk, S. A., Lynott, J., Pindeus, M., Rosepiler, A., Silverstein, L., & Gemperle, F. (2020). Automated Vehicles & Vulnerable Road Users: Representing the Under-Represented. Road Vehicle Automation 7, 97–107. https://doi.org/10.1007/978-3-030-52840-9_10

Perlman, J. (2010). Favela: Four decades of living on the edge in Rio de Janeiro. Oxford University Press.

Riggs, W., Larco, N., Tierney, G., Ruhl, M., Karlin-Resnick, J., & Rodier, C. (2018). Autonomous Vehicles and the Built Environment: Exploring the Impacts on Different Urban Contexts. Road Vehicle Automation 5, 221–232. doi:10.1007/978-3-319-94896-6_19

Sampson, R. J. (2012). Great American city. University of Chicago Press.

SEMARNAT. (2017). Compendio de Estadísticas Ambientales 2017: Coeficiente de Gini. [Compendium of Environmental Statistics 2017: Gini Coefficient.] Ministry of Environment and Natural Resources. https://apps1.semarnat.gob.mx:8443/dgeia/compendio_2017/dgeiawf.semarnat.gob.mx_8080/ibi_apps/WFServletd8df.html

Sivak, M. & Schoettle, B. (2015). Road Safety with Self-Driving Vehicles: General Limitations and Road Sharing with Conventional Vehicles (Ann Arbor, Michigan: The University of Michigan, Transportation Research Center, January 2015).

Soja, E. W. (2013). Seeking spatial justice (Vol. 16). U of Minnesota Press.

Sperling, D. (2018). Three revolutions: Steering automated, shared, and electric vehicles to a better future. Island Press.

Tamez González, S., & Eibenschutz, C. (2008). El seguro popular de salud en México: pieza clave de la inequidad en salud. [Popular health insurance in Mexico: a key factor in health inequity.] Revista de salud pública, 10, 133-145.

Townsend, A. M. (2020). Ghost Road: Beyond the Driverless Car. WW Norton & Company.

Transconsult, S. A. de C.V. (2021). Programa Integral de Movilidad Urbana Sustentable de la Zona Metropolitana de Monterrey. [Comprehensive Program for Sustainable Urban Mobility in the Monterrey Metropolitan Area.] Government of Nuevo León. https://www.nl.gob.mx/publicaciones/documento-ejecutivo-pimus

Valdivia, B. (2018). Del urbanismo androcéntrico a la ciudad cuidadora. [From androcentric urbanism to the caring city.] Hábitat y Sociedad, 28, 65–84. http://dx.doi.org/10.12795/HabitatySociedad.2018.i11.05

von Mörner, M. (2019). 4-Demand-oriented mobility solutions for rural areas using autonomous vehicles. In Autonomous Vehicles and Future Mobility; Coppola, P., Esztergár-Kiss, D., Eds.; Elsevier: Amsterdam, The Netherlands, 2019; pp. 43–56.

Yamaji, M. (2020). Hype cycle for automotive technologies, 2020. Gartner. Available at: https://www.gartner.com/document/3987644?ref=solrAll&refval=291421062&toggle=1

Yin, R. K. (2009). Case study research: Design and methods (Vol. 5). sage.

Zandieh, R., & Acheampong, R. A. (2021). Mobility and healthy ageing in the city: Exploring opportunities and challenges of autonomous vehicles for older adults' outdoor mobility. Cities, 112 (December 2020):103135. https://doi.org/10.1016/j.cities.2021.103135.3

Udell, G., & Potter, T. (1989). Pricing New Technology. Research Technology Management, 32(4), 14-18. Retrieved August 21, 2021, from http://www.jstor.org/stable/24124579

***Disclaimer** The opinions expressed in this publication are those of the authors. They do not purport to reflect the opinions or views of CETyS, CLD or of any other organization involved in the project*