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Designing the city of the future: comprehensive and gender-inclusive strategies for sustainable urban mobility in the Buenos Aires Metropolitan Area

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Introduction: This study analyzed gender disparities in daily mobility patterns in the Buenos Aires Metropolitan Area, with a focus on the impacts of built environment factors and considering the socioeconomic characteristics of the individuals.

Methods: Using data from the 2018 Household Mobility Survey and multilevel regression models, the gender gap in mobility was analyzed with a particular emphasis on work commutes and accompanying trips. The inclusion in the analysis of gender interactions, in particular with transportation and land use factors, is a novel contribution to the field, as it allowed us to analyze in depth the extent to which these factors differentially affect the urban mobility of men and women and could, therefore, contribute to widening or narrowing the gender mobility gap.

Results and discussion: Our findings demonstrated that public transport availability and land-use characteristics primarily affect travel time and distance, with gender-differentiated impacts. Women benefited more from improved public transport coverage and diversity, while higher population density, greater self-containment, and higher density of street intersections reduced travel distances and travel times in general, although they affected women's mobility less. This study underscores the need of integrating gender perspectives into sustainable urban mobility strategies to ensure equitable access to goods and services. However, urban and transport policies alone would be insufficient to reduce the mobility gap, because the results showed that individual socioeconomic characteristics also significantly influence mobility, with women facing greater constraints due to domestic responsibilities or limited access to private vehicles. A comprehensive approach incorporating social measures addressed to mitigate the restrictions that women face is essential to achieving a gender-inclusive mobility.

KEYWORDS

sustainable urban mobility, gender gap in mobility, gender inclusive strategies, land use, transport policy, Buenos Aires Metropolitan Area, multilevel modeling

1 Introduction

Sustainable mobility has emerged as a critical challenge in urban life over the course of recent decades. Initial solutions focused on improving transport systems in environmentally friendly ways, but it became evident that limiting the need to travel was also necessary. Consequently, public policies began to be designed to organize cities from the dual perspective of mobility demand and transport supply, but their scope was limited to linear commuting to work and private motor vehicles. They often ignored non-work mobility and how daily activities connect to form complex travel patterns that vary by gender. They also tended to assume that women's travel needs were the same as men's. Contemporary urban planning and transportation policies are not neutral. They often prioritize male-oriented scenarios, while lacking the land use organization and public transportation coverage necessary for multifaceted daily tasks, thus further harming women (Loukaitou-Sideris, 2016). Considering gender perspectives in urban and transportation planning involves prioritizing the activities of daily living in all spheres, while expanding the analysis to encompass 24-h and 7-day patterns (Ortiz Escalante et al., 2021). Ignoring the specific mobility needs of women limits the ability of policy makers to intervene effectively to reduce existing gaps.

This study sought to detect gender disparities in mobility in the Buenos Aires Metropolitan Area (AMBA). We therefore analyzed the relationship between some mobility aspects, such as trip generation, distance and time, and built environment factors, while also considering travelers' socioeconomic characteristics, which, according to previous research, can affect mobility decisions. The main and most novel objective of this analysis is to examine the reasons for the differences in mobility between men and women and to try to measure to what extent both built environment and socioeconomic factors could contribute to explain this gender gap. A better understanding of the origins of gendered mobility patterns could inform urban and public transport policies that promote equal access to goods and services for women and men.

Our main data source on mobility for the AMBA is the ENMODO-2018 Household Mobility Survey, which identifies the municipality in which respondents reside. It is expected to find similarities in the mobility of individuals within the same municipality and it would be interesting to control for such local effects, which may come from the characteristics of the built environment of each municipality. Multilevel models can recognize and handle such nested data structures while considering both individual and geographical influences. They are therefore increasingly used in the social sciences in a number of fields, such as education (Goldstein, 2003), health (Diez-Roux, 2000), housing (Pérez-Molina, 2022), and mobility (Schwanen et al., 2004; Antipova et al., 2011; Olivieri and Fageda, 2021). Our econometric approach was based on multilevel regression models to consider explanatory variables at two levels, individual and household socioeconomic factors, and the characteristics of the built environment at the municipal level.

There is growing interest in the topic of gender and mobility. A literature review reveals that most studies have focused on high-income countries, while fewer have examined developing countries, which face unique mobility challenges such as greater social disparity and limited public transport. However, some studies have explored this issue in countries like Uganda (Tanzarn, 2008), India (Mahadevia and Advani, 2016), Pakistan (Adeel et al., 2017), Bangladesh (Nasrin and Chowdhury, 2024), Iran (Arman et al., 2018), China (Srinivasan, 2008), and South American metropolitan areas like São Paulo (Silveira et al., 2015), Santiago de Chile (Gauvin et al., 2020), Montevideo (Olivieri and Fageda, 2021), and Mexico city (Mejia-Dorantes, 2018).

Empirical studies on the identification of differences in travel patterns between men and women generally follow two methodological approaches. Some of them include the female variable in the model as a category (Kim and Wang, 2015; Fan, 2017; Gauvin et al., 2020), while others analyze the behavior of women and men separately (Zolnik, 2010; Wang and Akar, 2019; Havet et al., 2021). The results indicate that, in both developed and developing countries, women have more varied purposes for trips and make more non-work trips compared to men. These trips often occur outside peak hours and involve more stops, while men typically follow more direct home-to-work routes (Rosenbloom and Plessis-Fraissard, 2009; Machado et al., 2020). Consequently, women travel shorter distances, particularly to work, tend to be confined to more restricted geographic areas (Schwanen et al., 2002; Scheiner, 2010). The findings are mixed regarding the time spent on daily mobility. Some studies show that women spend less time traveling (Machado et al., 2020), while others indicate that women take the same amount of time as men to cover shorter distances.

A more detailed analysis of mobility and gender involves exploring the source of the differences observed in the mobility patterns of men and women. Most empirical studies have focused on socioeconomic characteristics (e.g., Cristaldi, 2005; Lehmann, 2020), while others have also considered the role of culture or ethnicity (Boarnet and Hsu, 2015; Adeel et al., 2017; Fan, 2017). Age is one of the socioeconomic characteristics that has received more attention in the literature. Some studies have focused on analyzing mobility characteristics for a specific age range—either young people (Tilley and Houston, 2016; Bernheim, 2023) or the elderly (Rosenbloom, 2004; Mitra et al., 2021)—while others have analyzed how mobility evolves over the life span (Mercado and Páez, 2009; Miralles-Guasch et al., 2015; Scheiner, 2020). The results not only show that travel behavior differs across age groups, but that the effect of age on mobility is different for men and women (Craig and van Tienoven, 2019; Havet et al., 2021; Silveira et al., 2015).

Other authors have argued that gender-based mobility gaps may stem from differences in household composition and the corresponding household-related activities (e.g., Boarnet and Hsu, 2015; Silveira et al., 2015; Gauvin et al., 2020; Olivieri and Fageda, 2021). In this line, the household responsibility hypothesis suggests that the differences in the division of labor in a household between men and women may explain mobility differentials. Women tend to take on greater responsibility for childcare and household chores; they must balance these tasks with their paid employment (Johnston-Anumonwo, 1992). Due to constraints in space and time, competing demands lead to limit mobility for women (Crane, 2007; Fan, 2017), especially in commuting to work (Gimenez-Nadal and Molina, 2015; Wang et al., 2023). Another reason for the gender gap in mobility could be women's limited access to private vehicles; women may either lack car ownership or have lower priority for vehicle use in households with few cars. This restriction can hinder women's travel, further exacerbating the mobility gap and restricting their access to job opportunities and services (e.g., Hjorthol, 2000; Rosenbloom, 2006; Scheiner, 2010; Quirós et al., 2014).

The mobility patterns of men and women are also related to the characteristics of the built environment (transportation systems and land use), which can sometimes impose stronger restrictive factors on women, thus conditioning their travel behavior (Rosenbloom, 2006; Handy, 2007; Loukaitou-Sideris, 2016; Olivieri and Fageda, 2021). Women's mobility relies more on public transport, which is more affordable but less efficient (Lecompte and Bocarejo, 2017; Ng and Acker, 2018; Liu et al., 2022; Casado-Díaz et al., 2023). This reliance makes women particularly vulnerable in peripheral areas with limited service (UN Habitat, 2018). When public transport is inadequate, women often have to walk, which significantly restricts their mobility, while men tend to be more likely to use the car (Hjorthol, 2000). The complexity of women's mobility patterns also increases their dependence on circumferential routes, which often receive lower priority from operators compared to radial commuter lines that connect directly to urban centers (UN Habitat, 2018). Land use factors such as urban sprawl, geographical segregation, and inadequate infrastructure lead to increased distances, especially for care-related trips predominantly undertaken by women (Gauvin et al., 2020; Lehmann, 2020). Insecurity in public spaces and transportation also significantly restricts women's mobility (Handy, 2007; Lecompte and Bocarejo, 2017; Priya Uteng, 2021).

Despite the significance of these issues, empirical research measuring whether and to what extent changes in the characteristics of the built environment affect the mobility of men and women in different ways remains scarce. Descriptive studies have found that gender differences in mobility are more pronounced in small or dispersed cities (Olmo and Maeso, 2014) and rural areas (Miralles-Guasch et al., 2015). Additionally, women, who are the primary users of public transport, have lower trip generation (González-Alvo and Czytajlo, 2022). From an econometric point of view, Boarnet and Hsu (2015) have empirically demonstrated that compact land use development and improved transit service can reduce the intra-household gender gap in non-work travel, particularly in chauffeuring trips. Gauvin et al. (2020) examined gender disparities in the mobility patterns of Santiago residents and identified sociodemographic factors and transportation availability that were linked to mobility inequalities. Larger gaps were correlated with lower income and insufficient public and private transportation options. Havet et al. (2021) disaggregated mobility by gender to determine how socioeconomic factors and variables associated with access to transport modes (e.g., having a driver's license, a private car available in the household, or a seasonal pass for public transport) affect men and women differently. Casado-Díaz et al. (2023) demonstrated that one of the reasons for women taking shorter trips to work comes from the mode of transport they use, which tends to be public transport. However, the multifaceted relationship between gender, mobility, and the characteristics of the built environment remains an area that warrants deeper exploration to provide policymakers with empirical information on which to base effective transport and urban policies to reduce the gender mobility gap.

This article contributes in several ways to reduce the gaps in the literature on the gender differences in mobility. First, this study analyzed not only the existence of the gender gap, but also its origins by conducting an in-depth analysis of how built environment and socioeconomic factors interact with gender. This stands in contrast to previous research, which has focused primarily on individual characteristics. Second, while most previous studies have focused on a single aspect of urban mobility, this analysis considered multiple dimensions, such as trip generation, complexity, distance, and time, thus providing a holistic view. Third, our analysis examined total mobility, while also delving into the two trip purposes with the most marked gender differences—commuting to work and accompanying—to detect whether the origin of the gender gap varies by trip purpose. Fourth, the study is conducted in the context of the AMBA, Argentina's largest metropolitan area, characterized by a strong social disparity, which may affect the magnitude of these differences. To our knowledge, quantitative research on the relationship between mobility and the built environment and socioeconomic characteristics of the AMBA is scarce, thus potentially providing new insights into this issue in developing countries.

The rest of the article is organized as follows. Section 2 describes the study area and data sources, as well as explaining the methodological framework. The results of our study are briefly presented in Section 3, while the discussion and practical implications are compiled in Section 4. Finally, Section 5 provides some concluding remarks, including the limitations of this study and directions for future research.

2 Data and methods

This section is devoted to the presentation of the study area and the main data sources used, and to the development of the methodology applied—that is, the target variables selected; the socioeconomic, transport, and land use factors that may determine their behavior; and the econometric models used to perform the analysis.

2.1 Study area and data

This study focused on the AMBA, which is one of the 20 most populous metropolitan areas in the world and the third most populous in Latin America, after São Paulo and Mexico City. Covering less than 1% of Argentina's total area, the AMBA holds about 35% of the population (approximately 16.5 million people) and 45% of the country's economic activity. Since it began to form between 1870 and 1930, its boundaries have been moving in a radial and monocentric structure around the Autonomous City of Buenos Aires (CABA), the country's capital, which has added new municipalities to the Buenos Aires conurbation. Urban growth has been expansive and unregulated. This has resulted in a segregated and fragmented region with well-developed and precarious areas in close proximity (Abba, 2011). Population distribution is also uneven, with densities ranging from over 30,000 in habitants/km^2 in some capital communes to 11 inhabitants/km^{2}in suburban areas.

Historically, AMBA's development followed the railway lines, with buses later facilitating mobility in interstitial spaces. The area was once a leader in guided transport systems, but since the mid-1970s, investment has shifted towards motorways, which has reduced public transport spending and weakened mass mobility infrastructure (Abba, 2011; Rascovan, 2017). As a result, the AMBA currently has an extensive public transport system (more than 300 bus lines, 7 railway lines, 6 underground lines, and a tramway), but with deficient infrastructure, especially in terms of railways, and uneven deployment in the territory, with a concentration of radial routes that converge in CABA (Rascovan, 2017).

Our main data source is the Household Mobility Survey ENMODO-2018, which was developed by the Metropolitan Transport Agency and provides data on the mobility patterns and individual and household attributes for 16,667 households and 42,971 people in the AMBA. This is the third survey conducted after those in 2008 and 2014. The AMBA is a continuously growing entity, so its geographical scope has changed over time. In ENMODO-2018, the AMBA is composed of the 15 communes of the CABA and the 43 municipalities of the province of Buenos Aires that surround it, including 16 more municipalities than ENMODO-2014 (see Figure 1). For the sake of simplicity, the term municipality is applied in this study to both the municipalities of the province of Buenos Aires and the communes of the CABA, yielding a total of 58 municipalities. The information needed at municipality level, such as population density and variables related to urban layout and transport, were obtained from additional sources such as National Population, Household, and Housing Census 2010 (INDEC/Instituto Nacional de Estadística y Censos de la República Argentina, 2010) and Open Street Maps.

The report of the ENMODO-2018 results (OMSV/Observatorio de Movilidad y Seguridad Vial de la Ciudad de Buenos Aires, 2023) provides a glimpse of mobility patterns in the AMBA, revealing important differences by gender. The main reasons for commuting in the AMBA are work (29.4%) and study (24.9%), followed by accompanying other people (14.2%) and shopping (10.1%). These data hide important gender differences. Trips related to shopping, housework, and accompanying people account for 52% of women's daily mobility, compared to 33% of men's trips. Gender differences are mainly concentrated in trips to work (36.3% of men's trips compared to 21.1% of women's trips) and in accompanying people (8% for men compared to 18.4% for women), particularly for accompanying a member of the household to school (6.5% for men compared to 17.3% for women). These inequalities also reflect gender differences in employment status, as only 36.7% of women are workers compared to 51% of men, while 15.3% of women are homemakers compared to 0.5% of men. The sharing of domestic responsibilities is unequal according to gender, with women taking on more care activities and household-related tasks.

There is not much information in ENMODO to analyze the complexity of mobility, given that 91% of trips are single-stage trips. However, it is worth noting that trips of two or more stages, generally multimodal with changes of line or combinations of different modes of transport, have a slightly higher weight in women's mobility (9.3%) than in men's (8.7%).

Women's mobility in the AMBA tends to be more sustainable, as they tend to opt primarily for public transport (43% of trips), followed by walking (28.3%), and private vehicles (20.6%), whereas men typically favor private vehicles (38.5% of trips), with public transport as the next choice (33.7%) and walking as the third (20.4%). Gender disparities in transport options can affect travel distances and time. Over 70% of journeys under 1 km are made on foot, and single-stage public transport is predominant for 1–10 km trips, while multi-stage public transport and cars become more common for 11–60 km and >30 km trips, respectively (OMSV/Observatorio de Movilidad y Seguridad Vial de la Ciudad de Buenos Aires, 2023). Finally, the survey shows that women's access to private cars is limited: only 23%

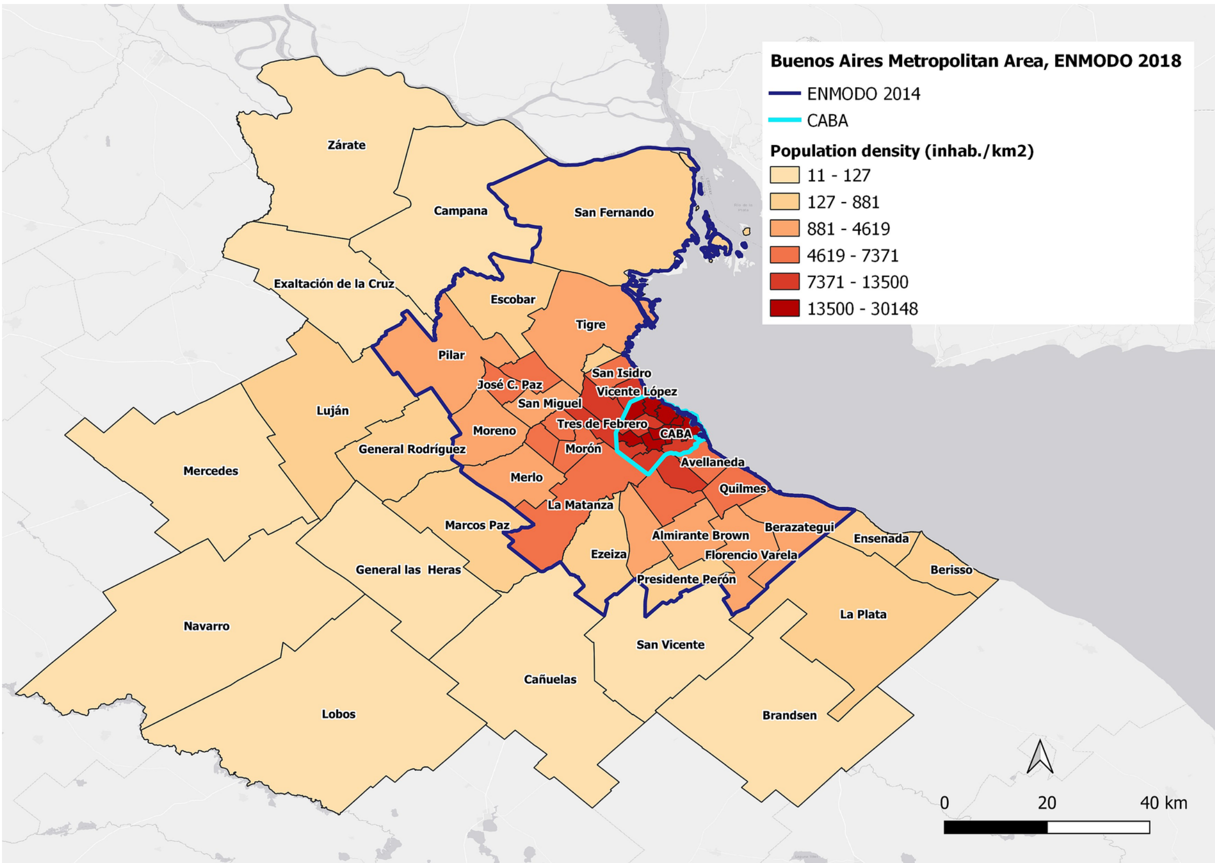

FIGURE 1
Study area.

of women possess a driver's license compared to 54.3% of men, and women use private cars for 20.6% of their trips, while men use them for 38.5% of their journeys.

2.2 Econometric approach

This study focused exclusively on adult trips (15 years or older) that occur with a frequency of at least once a week, thus excluding occasional trips. Our research analyzed three dimensions of travel behavior as target variables: trip generation, trip distance, and trip time, where trip generation considers both the number of trips and their complexity.

i) Trip count is defined as the number of trips made by an individual during the week. Off-peak trips, usually made by women on household-related tasks, are analyzed separately.
ii) The trip complexity indicator measures the amount of heterogeneity in the distribution of trip time by activity. Five activities are considered: work, studies, shopping/private errands, accompanying, and leisure. It is calculated using Shannon's entropy (Scheiner and Holz-Rau, 2017) as $-\sum(p_i * \ln p_i)$, where p_i indicates the share of time spent on trips associated with one activity in the week, weighted by the number of intermediate stops and the modes of transport needed. Zero entropy means that a person's trips are related to only one type of activity over the week.
iii) Trip time quantifies, in minutes, the total time spent on these trips over a week.
iv) Trip distance covers the total number of kilometers usually traveled in a week.

Trip count, time, and distance were analyzed, both in total and for commuting to work and accompanying trips separately. These two purposes for travel represent more than 43% of all the trips in the AMBA and exhibit different patterns of behavior between men and women, as illustrated in the descriptive analysis in Table 1. Generally, women's travel behavior appears to be slightly more complex, with more trips, shorter distances, and less time spent in mobility compared to men. Disparities in distance and time are pronounced: women travel 27 kilometers less on average and spend one hour less on their trips per week than men. However, the overall results hide some gender inequalities. For instance, while the total trip count difference is minor, women have significantly fewer commuting trips but more accompanying trips than men. Furthermore, men's commuting distance is double that of women, while the opposite is true for accompanying trips. Women also dedicate almost two hours less to commuting for work but three times as much time as men on accompanying trips.

The factors used to explain mobility were selected based on previous research and data availability and are nested at two levels (see Table 2). The first level includes individual and household attributes:

i) Gender: women and men, the only two categories considered by the ENMODO survey.
ii) Age: individuals aged 15 and over are classified into youth (16–29), young adults (30–44), adults (45–59), and seniors (60 and over) (Rodríguez Vignoli, 2022).
iii) Household type: classified into four categories according to the number of adults and children in the household. Some studies (e.g., Boarnet and Sarmiento, 1998) have used the number of persons in the household as an explanatory variable. The advantage of having information on family composition (adults and minors), as in this study, is that it makes it possible to explore the effects on mobility of family situations that, even with the same number of members, may be very different.
iv) Accessibility to the private vehicle through two indicators: holding a driver's license and the number of cars per adult;
v) Control variables: education level, employment, socio-urban status, and number of potential dependents (inactive seniors and disabled people). Socio-urban status reflects housing quality and

TABLE 1 Average weekly mobility indicators among adults by gender and trip purpose.

Variable	All		Women (W)		Men (M)		Gender gap	
	Mean	SD	Mean	SD	Mean	SD	(W-M)	p-value
Trip count	9.53	(5.22)	9.62	(5.77)	9.43	(4.51)	0.19	0.0253
Commuting	4.44	(5.19)	3.27	(4.74)	5.76	(5.34)	−2.49	0.0000
Accompanying	2.09	(5.69)	3.06	(6.76)	0.99	(3.90)	2.07	0.0000
Off-peak trips	4.23	(3.97)	4.25	(4.08)	4.20	(3.83)	0.05	0.4797
Trip complexity	0.05	(0.17)	0.05	(0.17)	0.04	(0.16)	0.01	0.0007
Trip distance (km)	54.77	(85.84)	41.81	(67.10)	69.40	(100.99)	−27.59	0.0000
Commuting	39.32	(82.52)	24.14	(58.87)	56.45	(100.15)	−32.31	0.0000
Accompanying	4.40	(21.43)	6.03	(24.79)	2.56	(16.67)	3.47	0.0000
Trip time (min)	318.65	(316.36)	291.44	(294.01)	349.35	(337.21)	−57.91	0.0000
Commuting	200.83	(323.01)	147.72	(281.68)	260.75	(354.65)	−113.03	0.0000
Accompanying	38.38	(127.91)	56.89	(156.19)	17.49	(80.48)	39.4	0.0000
Number of observations	15,403		8,165		7,238			

TABLE 2 Explanatory variables.

Area	Variable	Mean/ proportion	SD	Min.	Max.
Level 1: Age and socio-economic attributes					
Gender	Female	0.5301	-	0	1
Age	Age 16–29 (ref.)	0.2844	-	0	1
	Age 30–44	0.2941	-	0	1
	Age 45–59	0.2276	-	0	1
	Age 60+	0.1938	-	0	1
Education level	Primary education (ref.)	0.3560	-	0	1
	Secondary education	0.4637 0.1803	-	0	1
	Higher education		-	0	1
Employment status	Employer	0.1745	-	0	1
	Employee (ref)	0.4174	-	0	1
	Unpaid family worker	0.0031	-	0	1
	Domestic employee	0.0159	-	0	1
	Self-employed	0.0040	-	0	1
	Not working	0.3850	-	0	1
Driver's license	Driver's license holder	0.3769	-	0	1
Level 1: Household characteristics					
Car availability	Number of cars per adult	0.2493	0.3502	0	4
Care demand	Number of inactive seniors (65+)	0.2457	0.5391	0	3
	Number of disabled people	0.2266	0.6022	0	7
Household type	Single (ref.)	0.1487	-	0	1
	Single parent	0.0636	-	0	1
	2 or more adults	0.4301	-	0	1
	2 or more adults + minors (<16)	0.3576	-	0	1
Socio-urban status	High status	0.0056	-	0	1
	Medium status	0.9585	-	0	1
	Low status (ref.)	0.03580	-	0	1
Level 2: Availability of public transport					
Public transport offer	Public transport coverage	0.5399	0.3219	0.0106	1
	Public transport diversity	2.1355	0.4114	1	4
	Public transport density	8.9520	15.1650	0.0043	81.7413
Level 2: Land use characteristics					
Density[(a)]	Gross population density	6543.60	6191.57	11.1359	30147.6
Diversity	Self-containment capacity	0.6755	0.1579	0.3535	1
Urban design[(b)]	Street Intersection density	311.909	246.935	2.6682	1004.12
	Street density	13.6059	6.2882	0.5966	24.7111

Source: ENMODO (2018) and (a) National Population, Household and Housing Census for 2010 (INDEC) and (b) Estimations made using the geographical information software QGIS and OpenStreetMaps.

neighborhood characteristics, and it is included as a proxy for income. High status corresponds to a house or flat in the "country" or gated community; medium status to a house or flat in any other neighborhood; and low status to substandard housing.

The second level includes variables related to the characteristics of the built environment with the aim of analyzing whether public transport availability and the land use characteristics of the municipality of residence facilitate or hinder mobility in a gender-differentiated way. The variables related to the availability of public transport are:

i) Public transport coverage: the ratio of the area covered by public transport to the total area of the municipality, with a 1-km radius around stops;

ii) Public transport diversity: the number of different modes of public transport offered (bus, train, metro, and tram); and
iii) Public transport density: the number of public transport stops (bus, train, metro, and tram) per km^2.

Improving public transport is expected to increase the trip numbers by enhancing accessibility and convenience, especially for non-work activities. It also expands the radius of accessibility, replacing shorter trips with longer ones, but its impact on total travel time depends on transport efficiency and urban conditions (Krasic and Novacko, 2015; Olivieri and Fageda, 2021).

The land use characteristics at place of residence included in the model are the so-called "3D" land use factors (Cervero and Kockelman, 1997):

i) Population density: thousands of inhabitants per km^2.
ii) Diversity is usually factored in by using functional mix indicators such as the job/resident ratio. Due to the lack of employment data at the locality level for the AMBA in 2018, the commuting self-containment capacity has been used as an alternative (Travisi et al., 2010; Mendiola and González, 2018). It is calculated as the ratio of trips within the municipality to total trips in the municipality. High scores may indicate locations with a mix of functions.
iii) Urban design is measured by street intersection density (number of intersections per km^2) and street density (length of roads per km^2) (Ewing and Cervero, 2010). Street intersection density is a measure of network connectivity, while street density measures network availability. Both variables are calculated including all types of thoroughfares (e.g., motorways, pathways, primary, secondary, tertiary, residential, footways, among others).

Compact urban developments—which are linked to higher population density, mixed land uses, dense street intersections, and more streets—improve accessibility and mobility, thus facilitating a greater number of daily trips. Although they tend to reduce distances and travel time, they can also cause congestion (e.g., Handy, 2005; Ewing and Cervero, 2010; Litman and Steele, 2024).

Finally, given that the main objective of this study was to analyze in depth the reasons that generate the gender gap in mobility, we included interactions between gender and some factors of interest in the model: (i) age, to reflect mobility evolution over the life cycle; (ii) household type, to detect differences due to domestic responsibilities; (iii) access to private vehicles; and (iv) availability of public transportation and land use factors at residence, to determine if specific transport and urban policies would be useful to improve women mobility.

2.3 Multilevel regression models

The data collected in this study on gender and mobility have a hierarchical structure: individuals are nested within geographical areas (i.e., municipalities). There are likely to be unobserved similarities and connections between individuals in the same municipality in part because some public policies may be designed at the municipal level. In this framework, the assumption of the independence of the observations basic to traditional regression analysis is not satisfied. As a consequence, the standard errors of regression coefficients are likely to be underestimated, thus leading to an overstatement of statistical significance (Snijders and Bosker, 2011). Multilevel regression modeling was proposed to handle the nesting of data by allowing for residual components at each level in the hierarchy data (Goldstein, 2003)—in our case, the individual level and the municipality level. A multilevel model partitions the residual variance into a between-municipalities component (the variance of municipality-level residuals) and within-municipalities component (the variance of individual-level residuals). The basic two-level regression model is written as follows:

$$Y_{ij} = \beta_{0j} + \beta_{1j}\, X_{1ij} + \beta_{2j}\, X_{2ij} + \ldots + \beta_{kj}\, X_{kij} + e_{ij}$$

where Y_{ij} is the continuous dependent variable (distance and time, for instance) for individual i in municipality j, (X_1, …, X_k) is a set of k explanatory variables at the individual level (first level), e_{ij} is the residual capturing the random variation among individuals, and β_{0j} is a random intercept that captures the variation between municipalities and is modeled as a function of a set of m level-2 explanatory variables Z and a municipality residual u_{0j}.

$$\beta_{0j} = \gamma_{00} + \gamma_{01}\, Z_{1j} + \gamma_{02}\, Z_{2j} + \ldots + \gamma_{0m}\, Z_{mj} + u_{0j} \quad (1)$$

We assume that the error terms e and u follow normal distributions with zero mean and variances given by σ_e^2 and σ_u^2, respectively, and they are uncorrelated. Given this, the proportion of the variance explained at the municipality level is:

$$\rho = \frac{\sigma_u^2}{\sigma_e^2 + \sigma_u^2}$$

Multilevel modeling has been extended to analyze other type of dependent variables. In the case of regressions with count dependent variables (number of trips, for instance), Poisson regression and the negative binomial are two commonly used approaches. However, Poisson regression requires the assumption of equidispersion (the equality of the mean and the variance), while count data are often heteroskedastic, which means the variance increases with the mean (overdispersion). This overdispersion can also generate an underestimation of standard errors. The negative binomial model was therefore preferred in our case, because it accommodates the possibility of overdispersion by introducing an additional parameter in the conditional mean. This parameter also controls for the unobserved heterogeneity of the dependent variable. The multilevel negative binomial model is specified as follows:

$$Y \sim Poisson(\mu)$$

$$\mu = \exp\left(\beta_{0j} + \beta_{1j}X_{1ij} + \beta_{2j}X_{2ij} + \ldots + \beta_{kj}X_{kij} + \nu\right)$$
$$V(Y) = \mu + \alpha\mu^2.$$

where the random intercept β_{0j} is modeled according to Equation 1. The random variable of unobserved heterogeneity ν follows a Gamma distribution $(1,\alpha)$, where the parameter α is the dispersion parameter. If α is equal to zero, the negative binomial regression model is equivalent to the Poisson regression model.

Tobit regression multilevel models are applied in the case of censored variables, because it allowed us to handle corner solution problems, resulting from a significant fraction of zero observations (distance and time for commuting and accompanying, for instance). The censored dependent variable Y is modeled as follows:

$$Y = \begin{cases} Y^*, Y > 0 \\ 0, otherwise \end{cases}$$

$$Y_{ij}^* = \beta_{0j} + \beta_{1j}\, X_{1ij} + \beta_{2j}\, X_{2ij} + \ldots + \beta_{kj}\, X_{kij} + e_{ij}$$

where the random intercept β_{0j} is modeled according to Equation 1.

3 Results

The results of applying multilevel regression models to the analysis of mobility in the AMBA are shown in Tables 3, 4 for trip generation, and in Tables 5, 6 for trip distance and time, respectively. The tables show the estimated coefficients along with their robust standard errors, the intraclass correlation coefficient (ICC), and the likelihood-ratio test (LR) results. The reference group in all models are young men (16–29) with primary education, working as employees, and living alone in precarious housing with no driver's license and cars.

Several conclusions can be drawn from the overall analysis of the results in the AMBA: (i) socioeconomic factors influence mobility more than built characteristics, especially for trip generation; (ii) commuting to work and accompanying trips exhibit distinct mobility patterns that warrant further investigation; and (iii) the gender mobility gap is related to the characteristics of the built environment, even when controlling for socioeconomic factors. The analysis of the reasons for the mobility gap is the main objective of this paper, so it is the focus of the presentation of the results.

3.1 Trip generation

The number of trips generally decreases with age, and this decrease is more marked for women. The only exception is young women (30–44), who make more trips per week than young men do and many more off-peak trips, likely due to dual responsibilities of family and work. Women make more accompanying trips than men throughout all life stages, but the gender gap appears to narrow with age. Gender differences in the number of trips to work are only significant in the 45–59 age group, where women's trips to work increase more than those of men. This result may be due to the fact that family responsibilities may have decreased, so women start or resume work.

Family composition is related to the number of trips, with significant differences between men and women. A multi-person household is associated with higher mobility per person, even for off-peak trips, compared to a single person household, but the results are quite different depending on the composition of the household. If there are only adults, the estimated increase in mobility is smaller for women than for men, while if there are children in the household, women's mobility increases almost twice as much as men's. We also found some differences in the results depending on trip purpose. The presence of children is associated with a significant reduction in the number of trips to work and increases the number of accompanying trips for single-parent families, particularly when the head of the household is a woman. In multi-adult households, the increase in mobility to work and in accompanying trips is higher for women than for men if there are no children. However, in households with several adults and children, men's mobility increases for both types of trips, while women tend to travel less to work in exchange for an increase in the number of accompanying trips.

Access to private vehicles, indicated by having a driver's license and the number of cars is linked to an increment in the number of trips for everyone, with men benefiting more from additional household cars, which may indicate that car access for women may be a lower priority in the family.

The influence of the availability of public transport on trip generation appears to be limited, and we did not observe any differences by trip purpose. Public transport density is associated with an increment in both the total number of trips and the off-peak trips and with a greater mobility complexity. Off-peaks trips also benefit from greater public transport diversity, but only for women as they use public transport more frequently.

Some land use characteristics seem to influence trip generation, but this depends on the trip purpose. While self-containment is only related to accompanying trips by increasing their volume, intersection density is associated with commuting and accompanying trips but in an opposite way: it benefits accompanying trips but reduces trips to work. We only detected gender differences in the relationship between street intersection density and commuting, with a negative effect for men and virtually no effect for women.

The results obtained on the factors that could determine trip complexity are scarce. This may be due to the fact that most of the trips in the sample are single-stage, single-purpose, single-mode trips, which implies a low variability in the complexity index used. Access to private vehicles is one of the few individual factors that significantly influence mobility complexity in the AMBA: greater access to private vehicles is associated with increased mobility complexity for both men and women. The results on type of household only show that being a single parent is associated with a greater trip complexity. The limited information presented in the sample does not allow us to isolate gender disparities within specific household types. However, a joint test of gender's interactions related to household type indicates the presence of a gender gap in how household type influences complexity. Given that the reference is people who live alone and that all interactions show a positive sign, we might conclude that as the size of the household grows, especially when including minors, the complexity increases, and it does so more for women than for men. Finally, the influence of the variables of access to public transport and urban characteristics boils down to the fact that higher public transport density correlates with mobility that is more complex.

3.2 Trip distance

The distance traveled varies according to age and gender: women travel shorter distances than men over the course of their lives,

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TABLE 3 Estimated coefficients for trip generation, level 1.

Variable	TRIP count		TRIPS commuting		TRIPS accompanying		Off-peak trips		Complexity	
	Estimate	Robust SD	Estimate	Robust SD	Estimate	Robust SD	Estimate	Robust SD	Estimate	Robust SD
Fixed effects: *Intercept*	2.1575***	0.0973	1.9288***	0.3188	−4.2942***	0.9069	1.5986***	0.1601	−0.0286	0.0307
Level 1: Age and socio-economic attributes										
Female	0.0035	0.0910	0.0635	0.2877	1.9518**	0.8993	−0.2677	0.1636	0.0251	0.0385
Age 30–44	−0.0259	0.0172	0.0925*	0.0539	1.1799***	0.2124	−0.0921***	0.0318	−0.0031	0.0065
Age 30–44 * female	0.0465**	0.0206	0.0627	0.0565	−0.6356***	0.2324	0.1099***	0.0357	0.0036	0.0093
Age 45–59	−0.0300*	0.0173	0.0420	0.0531	1.2746***	0.2229	−0.0818**	0.0364	−0.0034	0.0053
Age 45–59 * female	−0.0674***	0.0228	0.1841***	0.0597	−0.8823***	0.2822	−0.0251	0.0467	−0.0011	0.0054
Age 60+	−0.1652***	0.0216	−0.0043	0.0720	1.0463***	0.2639	−0.2246***	0.0484	0.0002	0.0080
Age 60 + * female	−0.0713***	0.0237	0.0196	0.1129	−1.1821***	0.3623	−0.0216	0.0505	−0.0006	0.0075
Secondary education	−0.0264**	0.0108	0.0793*	0.0456	−0.0288	0.1026	−0.0443*	0.0240	0.0003	0.0038
Higher education	−0.0236*	0.0141	0.1818***	0.0518	−0.1334	0.1109	−0.0530**	0.0217	0.0053	0.0041
Employer	−0.0143	0.0130	−0.3902***	0.0261	0.9690***	0.1305	−0.0423*	0.0231	0.0061	0.0045
Unpaid family worker	0.0673	0.0769	−0.3744*	0.2081	−0.2176	0.3559	−0.0380	0.1532	−0.0108	0.0202
Domestic employee	−0.1310***	0.0388	−0.1792***	0.0635	0.2608	0.2594	−0.2529***	0.0638	0.0281*	0.0155
Self-employed	0.0581	0.0776	0.0492	0.1224	0.0426	0.4211	0.0301	0.1207	0.0457	0.0309
Not working	−0.1172***	0.0173	−3.2459***	0.0905	1.0584***	0.1198	−0.1564***	0.0191	−0.0106***	0.0035
Driver's license holder	0.0344***	0.0114	0.0855**	0.0359	0.4460***	0.1133	0.0443**	0.0232	0.0086*	0.0047
Driver's license holder * female	−0.0226	0.0172	0.0623	0.0738	−0.3646**	0.1804	−0.0103	0.0393	0.0076	0.0073
Level 1: Household characteristics										
Number of cars per adult	0.0953***	0.0144	0.0073	0.0403	0.4139**	0.1886	0.0622*	0.0347	0.0387***	0.0075
Number of cars per adult * female	−0.0475**	0.0199	−0.0633	0.1085	0.0251	0.2057	0.0026	0.0508	−0.0032	0.0103
Number of inactive seniors (65+)	−0.0427***	0.0147	−0.1123***	0.0378	0.0244	0.1374	−0.0413**	0.0214	−0.0010	0.0040
Number of disabled people	0.0119*	0.0065	0.0164	0.0364	−0.1029**	0.0510	0.0102	0.0111	0.0045*	0.0024
Single parent	0.2484***	0.0416	−0.2634***	0.0822	3.6051***	0.3135	0.2907***	0.0620	0.0419**	0.0164
Single parent * female	0.2303***	0.0470	0.0413	0.0865	−0.5298	0.3437	0.1653**	0.0708	0.0179	0.0209
2 adults or more	0.0828***	0.0176	0.1922***	0.0476	0.8033***	0.2740	0.0587**	0.0286	−0.0102	0.0072
2 adults or more * female	−0.0503**	0.0227	0.1088*	0.0651	−1.0770***	0.3410	−0.0509	0.0359	0.0002	0.0083
2 adults or more+ minors	0.1974***	0.0172	0.2193***	0.0517	2.7693***	0.2496	0.2166***	0.0353	0.0060	0.0074
2 adults or more+ minors *female	0.1240***	0.0239	−0.2453***	0.0890	−0.1165	0.2969	0.1240**	0.0482	0.0120	0.0089
High socio-urban status	−0.0671	0.0422	0.0323	0.0673	−1.9123***	0.3603	−0.0593	0.0816	0.0065	0.0197
Medium socio-urban status	−0.0201	0.0251	0.0321	0.0572	−0.4811**	0.1918	−0.0217	0.0452	0.0064	0.0071

Significance is indicated by ***, ** and * for the 1%, 5% and 10% levels (respectively).

TABLE 4 Estimated coefficients for trip generation, level 2.

Variable	Trip count		Trips commuting		Trips accompanying		Off-peak trips		Complexity	
	Estimate	Robust SD	Estimate	Robust SD	Estimate	Robust SD	Estimate	Robust SD	Estimate	Robust SD
Level 2: Availability of public transport										
Public transport coverage	−0.0336	0.0731	0.1554	0.1985	0.6413	0.5916	−0.1140	0.1199	0.0044	0.0215
Public transport coverage *female	0.0365	0.0835	−0.1624	0.2622	−0.9972	0.7044	0.0943	0.1304	−0.0152	0.0159
Public transport diversity	−0.0202	0.0332	0.1288	0.1005	−0.2883	0.2325	−0.0488	0.0475	0.0066	0.0080
Public transport diversity *female	0.0244	0.0319	−0.1169	0.0841	0.1681	0.2653	0.0996**	0.0482	0.0028	0.0116
Public transport density	0.0027**	0.0011	0.0026	0.0049	−0.0044	0.0108	0.0048**	0.0020	0.0013***	0.0004
Public transport density *female	0.0000	0.0013	−0.0020	0.0058	0.0123	0.0130	−0.0015	0.0027	0.0005	0.0005
Level 2: Land use characteristics										
Gross population density	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Gross population density *female	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Self-containment capacity	0.1439	0.1017	−0.3784	0.2964	1.8712**	0.9159	0.0087	0.1608	0.0492	0.0378
Self-containment capacity *female	0.0066	0.1165	−0.1529	0.3216	−0.4097	0.8845	0.0694	0.2158	−0.0194	0.0247
Street Intersection density	−0.0001	0.0001	−0.0009	0.0005	0.0015*	0.0009	−0.0002	0.0002	0.0000	0.0000
Street Intersection density *female	0.0001	0.0001	0.0009*	0.0005	−0.0014	0.0009	−0.0001	0.0002	0.0000	0.0000
Street density	0.0011	0.0040	0.0086**	0.0142	−0.0539	0.0410	0.0012	0.0082	0.0005	0.0014
Street density *female	−0.0062	0.0045	−0.0171	0.0176	0.0640	0.0471	−0.0002	0.0084	0.0000	0.0012
LR test	75.46***		16.05***		49.71***		1.58		89.27***	
ICC									0.0127**	0.0037

Level 1, number of observations: 15403 individuals. Level 2, number of groups: 58 municipalities. Significance is indicated by ***, ** and * for the 1%, 5% and 10% levels (respectively).

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TABLE 5 Estimated coefficients for trip distance.

Variable	Distance		Distance commuting		Distance accompanying	
	Estimate	Robust SD	Estimate	Robust SD	Estimate	Robust SD
Fixed effects: Intercept	133.2010***	31.9523	111.1604***	31.8734	0.2877	7.3250
Level 1: Age and socio-economic attributes						
Female	−11.8190***	11.7615	−21.6985*	12.1203	2.6926	3.8119
Age 30–44	11.3688***	2.9544	16.3627***	2.8317	2.5227***	0.4277
Age 30–44 * female	−18.3315***	3.1837	−14.5659***	2.8624	1.2816	1.0966
Age 45–59	9.0311***	3.3485	13.7943***	3.1693	2.7758***	0.5254
Age 45–59 * female	−19.3339***	4.3642	−11.5271***	4.0455	−1.3428	1.0406
Age 60+	−11.8543***	2.6909	−1.6695	2.4889	1.8293***	0.5619
Age 60 + * female	−4.3812	2.7730	2.5546	2.1693	−1.4725**	0.7258
Secondary education	6.5057***	1.7965	1.1496	1.5854	1.3695***	0.5191
Higher education	8.7033***	2.8819	8.0943**	3.1574	0.2478	0.5478
Employer	−24.1645***	3.0577	−30.5670***	3.1057	2.1927***	0.3335
Unpaid family worker	−34.5092***	9.5022	−49.7084***	7.9053	5.8024	4.4384
Domestic employee	−8.4539*	4.4317	−15.0853***	4.1097	2.2031	1.9183
Self-employed	−6.6153	10.9861	−11.7040	10.1725	7.2196	8.7892
Not working	−41.2527***	3.5656	−59.2990***	3.6430	3.6993***	0.5293
Driver's license holder	7.3686**	2.8611	8.8433***	2.7420	0.7284*	0.4078
Driver's license holder * female	−5.1472*	2.6427	−7.3798***	2.4224	−0.0935	0.9287
Level 1: Household characteristics						
Number of cars per adult	11.0469**	4.6342	5.4838	4.0495	2.1237***	0.5680
Number of cars per adult * female	−12.3835**	4.9166	−10.3323**	4.4774	−0.5582	0.8997
Number of inactive seniors (65+)	−1.3771	1.6280	0.2771	1.3299	−0.6620**	0.2610
Number of disabled people	−1.7733**	0.8854	−1.2961	0.8892	−0.0547	0.2384
Single parent	−12.3910*	6.5656	−24.1988***	6.3577	11.7232***	2.2872
Single parent * female	4.8590	6.9874	12.1706**	5.6704	1.6143	3.1750
2 adults or more	5.5285	3.8986	3.0695	3.5475	1.2135***	0.3341
2 adults or more * female	−2.7464	3.4998	−1.4496	3.3901	−1.2679***	0.4532
2 adults or more+ minors	7.8075*	3.9967	6.5384*	3.8192	4.4971***	0.6337
2 adults or more+ minors *female	−11.3735***	4.2808	−12.0525***	4.4196	4.4848***	0.7473
High socio-urban status	37.3253*	21.3517	34.1190**	15.7637	−4.3700**	2.0731
Medium socio-urban status	5.4286*	2.9744	5.2980**	2.3119	−2.1258	1.7165

(Continued)

TABLE 5 (Continued)

Variable	Distance		Distance commuting		Distance accompanying	
	Estimate	Robust SD	Estimate	Robust SD	Estimate	Robust SD
Level 2: Availability of public transport						
Public transport coverage	−22.6152	17.9660	−28.4496*	16.2277	2.0761	1.7415
Public transport coverage *female	12.7732	14.2101	21.6266*	12.5303	−5.5270**	2.8008
Public transport diversity	10.8681	9.4752	9.9349	8.7587	−0.8275	1.6209
Public transport diversity *female	−9.6458**	4.4355	−10.8174*	4.5882	1.1754	0.8979
Public transport density	0.3202	0.2577	0.3077	0.2287	0.0045	0.0332
Public transport density *female	−0.1423	0.1897	−0.2538	0.1948	0.0271	0.0566
Level 2: Urban characteristics at residence						
Gross population density	−0.0025***	0.0006	−0.0021***	0.0006	−0.0001	0.0001
Gross population density *female	0.0008	0.0005	0.0012**	0.0005	−0.0001	0.0001
Self-containment capacity	−90.5457***	28.7906	−80.3413***	26.8895	−0.3860	3.9987
Self-containment capacity *female	32.8132*	16.9803	37.5525**	17.5490	−2.8971	3.9279
Street Intersection density	−0.0915***	0.0336	−0.1029***	0.0332	0.0021	0.0035
Street Intersection density *female	0.0595**	0.0239	0.0629**	0.0250	−0.0008	0.0038
Street density	1.5544	1.3184	2.6523**	1.1885	−0.1653	0.1369
Street density *female	−1.1280	0.9455	−1.4479*	0.8278	0.1480	0.1743
LR test	161.77***		117.26***		1.87*	
ICC	0.0246**	0.0084	0.0184**	0.0062	0.0013**	0.0015

Level 1, number of observations: 15403 individuals. Level 2, number of groups: 58 municipalities. Significance is indicated by ***, ** and * for the 1%, 5% and 10% levels (respectively).

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TABLE 6 Estimated coefficients for trip time.

Variable	Trip time		Time commuting		Time accompanying	
	Estimate	Robust SD	Estimate	Robust SD	Estimate	Robust SD
Fixed effects: Intercept	580.3020***	91.4276	489.7918***	96.1053	−32.8907*	17.8423
Level 1: Age and socio-economic attributes						
Female	−51.5229	52.6472	−86.7745	55.4618	15.3268	19.5650
Age 30–44	0.5241	10.8075	38.0814***	9.8793	20.3912***	2.4764
Age 30–44 * female	−32.0680**	13.7807	−29.5696**	12.9379	14.4744**	5.9621
Age 45–59	−12.2033	15.8631	23.8277*	13.8078	21.5603***	2.6224
Age 45–59 * female	−57.2851***	18.9040	−19.7436	15.6396	−7.2173	5.5293
Age 60+	−72.6583***	9.6239	−8.3880	9.8439	10.5180***	1.9850
Age 60 + * female	−41.1181***	10.1194	1.4834	9.5582	−13.3983***	4.2146
Secondary education	23.8459***	6.4553	8.9588	5.8033	9.3711***	2.2753
Higher education	19.7826**	9.3427	28.7799***	10.9295	2.4511	2.7556
Employer	−108.3504***	10.4462	−154.9499***	11.7073	22.6379***	3.3738
Unpaid family worker	−128.4248**	49.7532	−221.2342***	30.7150	31.3285	27.1209
Domestic employee	−31.7894	19.7383	−58.1463***	18.2653	4.7655	7.6101
Self-employed	−13.4958	45.9681	−17.0231	53.8881	9.5149	17.4770
Not working	−192.5069***	13.5783	−335.4997***	14.1055	38.2768***	3.9256
Driver's license holder	−29.3819***	9.7305	−13.2069	10.0698	7.4360***	2.3775
Driver's license holder * female	1.5900	13.7246	−6.4161	12.6663	−17.4738***	4.5355
Level 1: Household characteristics						
Number of cars per adult	−19.1703	13.5448	−33.3843**	13.3351	5.6089**	2.7578
Number of cars per adult * female	−10.3590	14.7951	−3.6268	15.2635	−2.3849	6.3448
Number of inactive seniors (65+)	−9.8618*	5.3938	0.8490	4.0592	−4.8045***	1.5424
Number of disabled people	−3.7462	3.5422	−2.1482	3.2463	−1.7234	1.2244
Single parent	16.2036	22.1541	−66.0295***	18.3928	98.7205***	13.5040
Single parent * female	5.5829	24.3511	11.2397	18.0722	48.2877***	14.8358
2 adults or more	32.6004***	10.4038	24.5617**	9.7239	7.3860***	1.5383
2 adults or more * female	−21.7879**	10.6522	−13.0393	9.3549	−7.6805***	2.6571
2 adults or more+ minors	51.3628***	9.7460	41.1518***	10.5249	29.8846***	2.7230
2 adults or more+ minors *female	−34.7363***	12.4469	−59.2162***	13.7795	51.7664***	6.5861
High socio-urban status	127.3438***	46.4241	96.4746***	28.7416	−32.3655**	13.5105
Medium socio-urban status	19.7962*	10.3597	11.4328	10.4506	−13.8965**	5.9937

(Continued)

TABLE 6 (Continued)

Variable	Trip time		Time commuting		Time accompanying	
	Estimate	Robust SD	Estimate	Robust SD	Estimate	Robust SD
Level 2: Availability of public transport						
Public transport coverage	−10.8309	59.4631	−38.4631	53.6326	6.9166	9.5561
Public transport coverage *female	6.6405	53.5789	24.4066	46.5294	−8.0137	21.1847
Public transport diversity	50.3117*	29.2367	41.3315	27.7648	1.9153	3.7175
Public transport diversity *female	−34.5886*	19.7757	−41.8757**	20.2199	−2.5557	5.5787
Public transport density	0.8937	1.0183	0.5720	0.9390	0.0881	0.1508
Public transport density *female	−1.3010	1.0804	−0.7156	0.9680	−0.4154	0.2769
Level 2: Urban characteristics at residence						
Gross population density	−0.0078***	0.0027	−0.0056**	0.0026	−0.0004	0.0004
Gross population density *female	0.0060**	0.0030	0.0043	0.0027	0.0015*	0.0008
Self-containment capacity	−366.9773***	92.0581	−314.3065***	87.8100	11.8106	14.1822
Self-containment capacity *female	168.7131**	67.2262	172.2841**	69.1580	10.5209	27.1973
Street Intersection density	−0.4566***	0.1207	−0.4852***	0.1121	0.0149	0.0120
Street Intersection density *female	0.2627***	0.0951	0.3048***	0.0961	−0.0131	0.0205
Street density	10.7450**	4.2180	13.0370***	3.7890	−0.6360	0.5966
Street density *female	−5.9410*	3.5757	−5.8750*	3.2001	−0.1235	1.1049
LM test	131.01***		80.07***		21.92***	
ICC	0.0152**	0.0043	0.0107**	0.0026	0.0032**	0.0013

Level 1, number of observations: 15403 individuals. Level 2, number of groups: 58 municipalities. Significance is indicated by ***, ** and * for the 1%, 5% and 10% levels (respectively).

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especially for commuting to work. On the other hand, women tend to travel longer distances than men on accompanying trips, although this difference narrows after the age of 45.

Household characteristics are significantly correlated to trip distances. Single-parent households are associated with travelling shorter distances, especially for work-related trips, but this is so to a lesser extent in female-headed households. However, accompanying trip distances increase as the single adult assumes more mobility responsibilities generated by children. In households with multiple adults, the presence of minors increases the overall distances traveled by men and considerably reduces those of women. This is because the decrease in the distances traveled by women to go to work is greater than the increase they experience in accompanying trips. However, in households with several adults and no children, women's travel distances for accompanying trips decrease, while men's distances increase.

Access to a driver's license and a car is associated with increases in overall distance travelled. There are differences by gender in the estimated impact of these two variables but of a different kind: having a driver's license reduces the distance gap between men and women, while the number of cars in the household increases this gap, with women travelling even shorter distances. This general behavior reflects what happens in commuting trips, because we do not observe any gender gap related to accompanying trips.

The findings of our study indicate that changes in the built environment of the municipality of residence, especially land use factors, are significantly related to travel distances, particularly for work. Moreover, these changes appear to have differentiated effects on men and women. As for the availability of public transport characteristics, diversity is the only variable associated with total distance: greater diversity is related to longer trips for men, but this effect is less pronounced for women and may even shorten the distances for their work commute. The effect of public transport coverage is observed only for the distance of commuting and accompanying trips, with distinct results for each type of trip. For commutes to work, better public transport coverage is linked with shorter travel distances, but this effect is weaker for women. This result may suggest that better coverage brings destinations closer and reduces distances for everyone, but it may make it easier for women to use public transport to travel further to work than they would on foot. Accompanying trip distances are solely affected by public transport coverage, with differing impacts by gender: higher coverage correlates with longer distances for men and shorter distances for women.

In terms of urban characteristics, our results indicate that higher population density, higher self-confinement, and higher street intersections density are associated to shorter travel distances by facilitating greater proximity to destinations, particularly for men. However, it should be noted that land use characteristics appear to exert minimal influence on distances traveled in accompanying trips and mainly affects trips for commuting to work.

3.3 Trip time

Age significantly influences weekly travel time, with variations based on trip purpose and gender. Throughout their lives, women generally spend less time on daily mobility than men. However, the patterns are very different depending on the purpose of the trip. Women typically spend less time commuting than men, but their accompanying trips are often significantly longer, a gap that narrows with age. In fact, women aged 30–44 spend nearly twice as much time as men on accompanying trips, while women aged 60 and over tend to spend less time than their male counterparts, which suggests a shift in domestic responsibilities.

The type of household is also significantly correlated with travel time. Members of multi-adult households spend more time traveling than people in single-person households, especially in the case of men. We observed some interesting differences in mobility patterns by trip purpose. The presence of minors is related to a reduction in the time spent by single-parent households on commuting trips in favor of accompanying trips, especially among women. In multi-adult households with children, women reduce their commuting time compared to men, while increasing the time spent on accompanying trips by a similar magnitude.

Having a driver's license and more household cars is associated with shorter commuting times but longer accompanying trips. It should be noted though that having a driver's license allows for longer accompanying trips for men, but not for women, again suggesting that they have less access to the car/s in the household.

With regard to the characteristics of the built environment within the municipality of residence, the influences of the availability of public transportation and urban characteristics are quite different. Only public transport diversity is related to travel time, with more options leading to longer travel times, particularly for men, as public transport generally takes longer than travel by private vehicle. Regarding commuting time, diverse transport options are associated with shorter commuting times for women, perhaps because it provides them with alternatives to walking.

In contrast, all the land use characteristics considered significantly influenced travel time, while affecting commuting to work trips more than accompanying trips. The differences observed in the relationship of these factors to the mobility of men and women are important. Higher population density, better self-containment, and a greater street intersection density are related to shorter travel times by bringing destinations closer. However, this physical proximity seems to have a lesser effect on women's travel time, likely due to the modes of transport more used by women (walking and public transport). Finally, increased street density is associated with longer travel times but again affecting women less.

4 Discussion and policy implications

Using data from the 2018 Household Mobility Survey and employing multilevel regression models, we found that, in general, socioeconomic conditions significantly influenced all the dimensions of mobility analyzed, while the effect of the characteristics of the built environment is limited to travel time and distance, with a lesser impact on accompanying trips, which are less sensitive to changes in the built environment. This result aligns with the conclusions of Ewing and Cervero (2001), who, after reviewing more than 50 empirical studies, determined that trip frequencies are largely shaped by sociodemographic factors, whereas trip distance is more influenced by the built environment.

Our results also highlighted significant gender-based differences in travel patterns in the AMBA. While the total number of trips is similar for women and men, women's mobility behavior is generally more complex, characterized by more off-peak trips, shorter travel distances, and less time spent on mobility compared to men. These differences are particularly pronounced in commuting to work and accompanying trips. Women make fewer work-related trips, tend to work closer to home, and spend less time commuting than men, while making many more accompanying trips than men. These results reinforce the findings observed in international research, although its extent vary depending on cultural and socioeconomic contexts (Cristaldi, 2005; Crane, 2007; Sandow, 2008; Rosenbloom and Plessis-Fraissard, 2009; Machado et al., 2020).

The observed gender gap in mobility is not simply a matter of individual choices; it is deeply entwined with broader socioeconomic factors, transportation infrastructure, and land use characteristics. In fact, the main conclusions of our study confirm, on the one hand, previous results that found a close relationship between mobility disparities and individual characteristics (age, type of household, and access to a car) and, on the other hand, provide new empirical evidence of the relationship between the mobility gap and the built environment.

4.1 The impact of socioeconomic factors on the gender mobility gap

This study revealed that the socioeconomic characteristics of the individual can partly explain the gender gap in mobility patterns. Everyday activities, such as work and accompanying, cause mobility patterns to change at different stages of life and in different ways for women and men. In the AMBA, the most pronounced mobility gender gap was observed among young adults (ages 30–44). Women in this age group make more trips, often non-work-related and during off-peak hours, while traveling shorter distances and spending less time on mobility compared to men. The purpose of travel also determines these patterns. The need to balance work and childcare appears to lead young women to make more accompanying trips and spend more time on them than men, although there are no significant gender differences in terms of distance travelled. These longer travel times could be because women, particularly in lower income groups, tend to use less time efficient transport (Duchene, 2011; Lecompte and Bocarejo, 2017). Additionally, young women may tend to reduce their commuting distance and time to allocate more time for caregiving. In adulthood (ages 45–59), women continue to make shorter trips in terms of distance and time, primarily for work-related purposes. However, from the age of 60 onwards, the age at which working life usually ends, there is a significant change in accompanying travel patterns, with women reducing both the number of trips and the time spent on them compared to men. This suggests that men may take on more caregiving responsibilities upon retirement, possibly facilitated by greater access to household vehicles. These results align with prior research indicating that women generally travel more than men during life stages requiring them to balance work and personal activities (Olmo and Maeso, 2014; Miralles-Guasch et al., 2015) and for non-work purposes (Vance and Iovanna, 2017), with a shift in accompanying travel trends after the age of 50 (Olmo and Maeso, 2014).

Household composition significantly shapes mobility patterns, especially for women, due to traditional gender roles and family responsibilities. The presence of minors increases the total number of trips, particularly during off-peak hours, with a more pronounced effect on women. However, the effect of minors on travel distance and time varies depending on the number of adults in the household. Thus, in single-parent households, 77.5% of which are headed by women, the presence of minors increases the distance and time spent on accompanying trips, with women spending more time traveling similar distances, which again reflects again the magnitude of immobility women face in their everyday lives (Olmo and Maeso, 2014). In addition, commuting distance and time are reduced, significantly more for women, who tend to relocate their residence or workplace to areas closer to daily activities. In contrast, in multi-adult households, the presence of minors increases travel distance and time for men for every kind of trips, while women reduce commuting to work distance and time in favor of longer accompanying trips (Hjorthol and Vågane, 2014). This supports the Household Responsibility Hypothesis, which posits that women in households with children, particularly in multi-adult households, take on additional caregiving duties that necessitate proximity between work and home (Silveira et al., 2015; Fan, 2017; Olivieri and Fageda, 2021). Along these same lines, research has shown that women are more likely to work from home (Rosenbloom, 2006) or select jobs closer to home (Schwanen et al., 2002; Hanson, 2010; Machado et al., 2020). Our results are also consistent with those of Scheiner and Holz-Rau (2017), who found that having children significantly increases the complexity of women's mobility to a greater extent than that of men.

Our study associates greater access to private vehicles with increased mobility complexity in both men and women in the AMBA. However, on this point, unlike others, there is no consensus in the literature. Kwan and Kotsev (2014), for example, found a negative association between the number of cars and mobility complexity, which suggests that households with more adults, drivers, and vehicles tend to share domestic responsibilities more equally, thereby reducing commuting complexity. Moreover, as Scheiner and Holz-Rau (2017) highlight, the causal relationship between car access and mobility complexity remains unclear: driving may make it easier to combine more varied responsibilities and activities, or conversely, individuals engaged in multiple activities may become more dependent on car use.

Access to a private vehicle is related to possessing a driver's license and having a car, each of which influences mobility in distinct ways in the AMBA. A driver's license increases mobility volume for both men and women by enabling longer-distance and shorter-duration trips. However, having a car at home boosts men's mobility more than women's. Additionally, while men tend to travel greater distances when more cars are available in the household, women's travel distances, particularly for commuting, often decrease. These disparities may stem from the fact that while car access enables potential drivers to become users (Páez et al., 2007), studies suggest that men are often prioritized in car use (Scheiner and Holz-Rau, 2017). In the AMBA, driving remains male-dominated: only 23% of women hold a driver's license compared to 54.3% of men (OMSV/Observatorio de Movilidad y Seguridad Vial de la Ciudad de Buenos Aires, 2023). Additionally, women use private cars for just 20.6% of their trips, whereas men use them for 38.5% of their journeys. This disparity limits women's employment opportunities and overall mobility (Priya Uteng, 2021).

4.2 Built environment characteristics and the mobility gender gap

The characteristics of the built environment also affect travel behavior, but differently for women and men, result that may help to design public policies that mitigate the gender gap in mobility.

4.2.1 Public transport availability

Although the overall impact of public transport availability on mobility is somewhat limited in the AMBA, significant differences were found in the way men and women respond to improvements in public transport. This may be linked to the fact that women in the AMBA mostly use public transportation and walking instead of the private vehicles, while men prefer to use private vehicles, followed by public transportation and walking (OMSV/Observatorio de Movilidad y Seguridad Vial de la Ciudad de Buenos Aires, 2023). The geographic coverage of public transport only affects the distance traveled to work and in accompanying trips. Improved coverage reduces the distance to work, potentially by providing more direct routes, although to a much lesser extent for women, perhaps because it opens up the possibility of accessing employment they would not be able to access if they were walking. It also significantly reduces the distance travelled in accompanying trips, but only for women who are primarily responsible for them. On the other hand, a greater diversity of public transport provides flexibility for users and makes it easier for women to take more off-peak trips. It also makes easier for women to reduce the distance and time they spend commuting to work, but not for accompanying trips, nearly half of which are made on foot in the AMBA. Finally, our findings indicate that a higher transit stop density promotes greater travel complexity and overall mobility, particularly during off-peak hours. In principle, we would expect the effect of this variable to be different for women because, as the literature points out, they have a more complex mobility with more multi-stop trips and visit fewer unique locations (Gauvin et al., 2020). However, it is possible that the low variability of the complexity indicator in our sample did not allow us to detect gender differences.

4.2.2 Land use factors

Land use characteristics influence overall mobility in the AMBA (Schwanen et al., 2004; Limtanakool et al., 2006; Waygood and Susilo, 2011; Boarnet and Hsu, 2015), and their impact varies by trip purpose and gender. Urban characteristics have little influence in trip generation. The variable that has the greatest effect is self-containment capacity, the result of which shows that a greater mix of land uses increases accompanying trips. However, land use factors play a more decisive role in determining travel distance and duration, especially for commuting to work, with a generally different impact by gender. Higher population density and functional mix enable diverse activities to be concentrated in smaller areas, while denser street intersections improve connectivity, allowing for more direct routes (Handy, 2005; Ewing and Cervero, 2010; Litman and Steele, 2024). This generally reduces trip distances and durations, for work commutes in particular, although the effect is less pronounced for women in the AMBA. Higher street density provides more options and better access to destinations, potentially encouraging people to choose work alternatives in more distant locations, thus increasing travel distances and durations. However, this impact is much smaller for women in the study area. It is noteworthy that urban land use factors do not significantly affect the distance and duration of accompanying trips. This may be because the nature of accompanying trips differs from work-related trips, which have fixed origins, destinations, and schedules.

In summary, while urban land use policies are associated to different mobility patterns, especially distances and times for work commutes, their estimated impact remains limited for women. This result may suggest that, regardless of the urban context, women tend to work closer to home than men as a consequence of the limitations they face when deciding their mobility due to the need to balance employment with care responsibilities.

4.3 Recommendations for gender-inclusive public policies

These insights about the contribution of the characteristics of the built environment on the gender gap in mobility can help policymakers in designing gender-sensitive urban planning and transport policies aimed at creating more sustainable and livable cities.

In the AMBA region, women rely more on public transportation than men; however, the current transit system does not adequately address their mobility needs. This study reveals that women tend to make more complex trips, often involving multiple transfers. To better accommodate these travel patterns, public transportation systems should facilitate multi-purpose trips with minimal detours. A more transversal and interconnected transport network—frequently overlooked in favor of direct routes to central areas (UN Habitat, 2018)—could significantly enhance accessibility for women. Public policies should also prioritize transport infrastructure near key destinations for women. Our findings indicate that women in the AMBA undertake more and longer accompanying trips than men, often leading them to work closer to home. Expanding public transport services in proximity to schools, healthcare facilities, and caregiving institutions would make daily travel more accessible and affordable, particularly for women. Furthermore, the study highlights the importance of improving public transport availability to reduce travel distances and facilitate overall mobility, especially during off-peak hours. Given that women in the AMBA travel more frequently throughout the day than men, limited service availability during these times may pose significant challenges (Quirós et al., 2014; Priya Uteng, 2021). Increasing off-peak service frequencies would directly benefit women's mobility.

Our findings regarding land use factors underscore that urban policies are not gender-neutral. Compact, mixed-use urban developments improve connectivity and accessibility, which is associated with less need for long commutes—particularly for work-related travel—though the effects appear less pronounced for women. This suggests that even in compact urban contexts, women's mobility remains constrained by various factors (e.g., caregiving responsibilities, safety concerns), underscoring the need for targeted urban policies that address gender-specific mobility challenges. Notably, land use characteristics have limited influence on accompanying trips, which account for 17.3% of women's travel versus 6.5% for men in AMBA (OMSV/Observatorio de Movilidad y Seguridad Vial de la Ciudad de Buenos Aires, 2023). Future gender-sensitive planning efforts should consider the spatial distribution of employment, education, and healthcare services, and address the balance between "production" (paid labor) and "reproduction" (unpaid domestic and care work) (Priya Uteng, 2021), in order to reduce the need for long commutes and foster more equitable urban environments. The literature further emphasizes that perceived safety is a key determinant of women's transportation choices, destination decisions, and employment opportunities (Loukaitou-Sideris, 2016; Lindkvist, 2024). Urban policies targeting safety-related barriers—such as inadequate lighting, poor sidewalk conditions, social isolation, and neighborhood characteristics—can significantly mitigate the mobility constraints women face (Miralles-Guasch et al., 2015; González-Alvo and Czytajlo, 2022).

Public transport and urban land use are closely linked, which leads to the convenience of integrating both aspects in urban planning policies. In fact, some transport and urban development measures can indirectly benefit women. For example, measures like improving school transport and promoting compact, walkable layouts (Waygood and Susilo, 2011; Boarnet and Hsu, 2015) can enable independent school commutes for children, thus reducing accompanying trips. This would free women's time for work-related travel and access to distant job opportunities.

However, as previously discussed, efforts to reduce mobility disparities through public transport and land use policies, whose impact is more limited for women in the AMBA, do not inherently promote gender equality. Regardless of public transport availability, social factors such as income constraints limit women's mobility (Gauvin et al., 2020), with poorer women relying mainly on walking due to economic constraints that prevent them from accessing a wider range of public transport options (González-Alvo and Czytajlo, 2022). Additionally, deeply rooted gender norms that disproportionately assign domestic and caregiving responsibilities to women also significantly limit the effectiveness of such policies (Craig and van Tienoven, 2019). Improving women's mobility and access to opportunities requires a comprehensive approach that integrates transport and land use policies with social measures like flexible schedules, expanded childcare, and subsidized public transport for low-income women (Craig and van Tienoven, 2019; Machado et al., 2020; Passman et al., 2024). The design of future urban and transport policies should involve women as workers, planners, and decision-makers to ensure that their perspectives are considered.

5 Conclusion

Our findings underline the need for sustainable mobility to incorporate specific interventions in transport policies and urban planning that address the gender mobility gap and promote more accessible and equitable mobility for women—that is, to promote gender-inclusive mobility in the AMBA. Current policies often fail to account for the distinct mobility needs of women, which results in unequal access to goods and services. Recommendations include improving public transportation infrastructure to accommodate the non-linear travel patterns more common among women, as well as implementing land use policies that foster integrated, accessible, and safe urban environments. However, our results suggest that urban and transportation policies alone would be insufficient to effectively address gender-based mobility disparities. The city of the future must adopt a comprehensive and multidisciplinary approach, complementing these policies with context-specific socioeconomic measures that address deeply rooted gender roles, family structures, and social norms, while actively involving women to incorporate their perspectives.

Several limitations of this study should be noted. Public transport variables exclude cost, frequency, and safety, which are key factors in modal choice, especially for women. In terms of land use variables, analyzing urban design characteristics at a sub-municipal scale would offer deeper insights into local mobility impacts.

Future research should refine public transport and land use indicators, explore the origin of the gender differences in the election of sustainable transport modes, and conduct longitudinal studies to track changes in mobility. This would enhance our understanding of gender-based mobility differences and inform more effective and gender-inclusive urban and transport policies. Data limitations have prevented us from analyzing the impact of perceived safety in public spaces and on public transportation on travel patterns, a factor that affects men and women differently. For example, 72% of women in the AMBA reported feeling unsafe on public transport, compared to 58% of men (Pereyra et al., 2018). Future research should directly assess safety perception to understand its impact on travel behavior.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found at: https://data.buenosaires.gob.ar/dataset/encuesta-movilidad-domiciliaria.

Ethics statement

Ethical approval was not required for the study involving humans in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and the institutional requirements. Written informed consent was not obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article because publicly available datasets were analyzed in this study.

Author contributions

LM: Validation, Conceptualization, Methodology, Writing – review & editing, Data curation, Investigation, Writing – original draft, Funding acquisition, Software. PG: Investigation, Writing – original draft, Formal analysis, Funding acquisition, Validation, Data curation, Conceptualization, Methodology, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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