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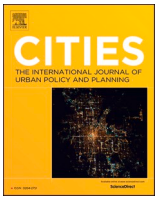

Is proximity enough? A critical analysis of a 15-minute city considering individual perceptions

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ABSTRACT

Urban areas encompass essential social functions that are fundamental for the development and quality of life. This research explores why the concept of the 15-minute city, while commendable in its aspirations, might fall short in effectively mitigating urban inequalities, especially within densely populated and segregated developing cities. Using Bogotá (Colombia) as a case study, this paper advocates and develops a standardized index based on the availability of essential urban functions within a 15-minute walking distance. This index also integrates individual preferences, geographical attributes, and the quality of pedestrian infrastructure. Doing so provides a more comprehensive understanding of the factors influencing proximity, accommodating the diverse needs of various social identities. Considering individual preferences towards proximity is critical to comprehend the determinants of accessibility, encompassing the relevance of sociodemographic characteristics. Although several urban areas worldwide may meet the broad interpretation of the 15-minute city concept, our research reveals significant disparities among population segments regarding access to urban services and their prioritization. Our case study found that grocery stores and healthcare facilities hold paramount importance across all population segments. Furthermore, wealthy segments exhibit a heightened preference for retail shops and commercial services. In contrast, the low-income population has a considerably greater preference for healthcare facilities. This study aims to cast light upon structural disparities inherent in urban areas, thereby unveiling inequalities in the 15-minute city concept's capacity to diagnose and mitigate urban inequalities. The promotion of a more all-encompassing and inclusive measurement approach is posited as a contribution to the advancement of our comprehension and the effective implementation of the 15-minute city concept across heterogeneous urban landscapes.

1. Introduction

Density and mixed land-use patterns are widely acknowledged factors that contribute to developing sustainable urban environments (Choi et al., 2019; Güneralp et al., 2020; Guzman et al., 2020; Stojanovski, 2018). These principles underpin the now-renowned notion of "15-minute cities." The central premise of this concept revolves around the idea that diminishing travel distances render active travel (walking and cycling) more appealing compared to other transport modes, as evidenced by a large body of previous research (Cervero et al., 2009; Frank et al., 2007).

Despite its appeal, it must be recognized that the 15-minute, and often even the related notion of a 30-minute threshold, may not always be the most suitable objective, particularly when considering different urban structures. Considering its origins in the Global North, where dense and walkable cities are more frequent, the concept departs from a position where a substantial portion of the population can conveniently access numerous urban services on foot (Papadopoulos et al., 2023; Staricco, 2022). However, the concept's considerable potential is more difficult to achieve in urban contexts where spatial segregation and social exclusion are inextricable features of daily life, such as in developing cities. In such areas, proximity and accessibility to essential urban services are low, and proper evaluations should consider the diversity of these services, easiness of access, and the population's needs. Therefore, using the concept of 15-minute cities for evaluation and planning requires incorporating local preferences, diversity, and the quality of

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pedestrian infrastructure.

This study explores why the notion of a 15-minute city, while commendable in its aspirations, may fall short of effectively ameliorating urban inequalities (Pozoukidou & Angelidou, 2022), particularly in rapidly growing cities in the Global South. Using the case study of Bogotá, Colombia's capital city, we employ spatial analysis and propose the development of a standardized index based on contour accessibility measures. This index quantifies the number of essential urban functions accessible within a 15-minute walking radius. The paper acknowledges and operationalizes key determinants of the 15-minute city into an index contingent upon geographical attributes, including walking travel time, walkability service performance, and housing location at the block level. Additionally, it incorporates considerations of individual preferences regarding proximity to essential urban services. This represents a crucial stride towards comprehending the determinants of proximity, encompassing the influence of sociodemographic characteristics.

The index proposed in our paper represents an important contribution to the current debates about the notable challenges the realization of the 15-minute city concept faces. First, current applications often neglect the critical role of active transport infrastructure as a precondition for achieving the utopia of proximity. Without significant improvements in walkability and cycling amenities, coupled with measures to enhance safety, the vision of the 15-minute city risks perpetuating existing inequalities (Pozoukidou & Angelidou, 2022; Vale et al., 2015). Second, the 15-minute city's ambitions are hindered by a lack of standardized theoretical and methodological approaches for implementation and assessment. A comprehensive framework must encompass a broad spectrum of essential social functions—enjoyment, care, provision, education, labor, and habitation—and must be adaptable to the diverse needs of various social identities, including public transport as a key factor for mitigating urban segregation and fostering social inclusion (Appleyard et al., 2014; Fraser, 1998; Kwan, 1998; Levy, 2015; Oviedo et al., 2022). The heterogeneity of individual preferences and perceptions further complicates the implementation of the 15-minute city. Differing priorities, whether for healthcare, education, employment, or cultural and recreational amenities, must be accommodated within the urban planning process to ensure a truly inclusive urban environment.

This paper introduces a new index for evaluating the 15-minute city concept, addressing the aforementioned limitations by accounting for a wider array of opportunities and the varied needs of populations with diverse social identities. This novel measurement framework not only facilitates the identification of structural disparities across urban spaces but also advances our understanding of urban accessibility and diversity, laying the groundwork for a more equitable realization of the 15-minute city ideal. In the following sections, we unpack some of the core debates about diversity, density, and proximity as critical dimensions of a 15-minute city and outline our contributions to academic debates. Section 3 introduces the case study of Bogotá from this optic, followed by our methods and proposal for an indicator. Section 5 outlines the empirical evidence stemming from our analysis and the discussion of its implications and conclusions in Sections 6 and 7.

2. Diversity, density and proximity as a 15-minute city concept

The 15-minute city concept, advocating for urban environments where all residents can meet their essential needs within a quarter-hour walk or bike ride from their homes, has gained traction as a blueprint for sustainable urban planning. The appeal of this, and other proximity-based urban and territorial models is that it operates on three interconnected levels -city, neighborhood, and individual scale- allowing practitioners to develop integrated urban development strategies underpinned by overarching aims of enhancing community health, liveability, and well-being, and accelerate climate positive actions. As such, the 15-minute city model and its many variations, such as the 30-minute territory, are holistic approaches that generate systemic impacts at both neighborhood and city scales (Allam, Nieuwenhuijsen, et al., 2022; Moreno et al., 2021). Key elements of urban and territorial proximities include developing polycentric cities or territories with multiple "complete neighborhoods" to reduce daily commutes and enable individuals to work near their homes. Thriving cities that adapt to people's needs and engage them in urban decision-making processes through participatory mechanisms are essential.

The 15-minute city concept (Knap et al., 2023; Logan et al., 2022; Lu & Diab, 2023) advocates for proximity-based planning to develop polycentric cities or territories with complete neighborhoods in which destinations of interest are accessible by walking and/or other active travel modes within a specified time threshold to reduce dependency for private motorized transport, encourage decarbonization, and reduce pollution. Its four key dimensions are proximity, density, diversity, and digitalization. These x-minute city concepts ride on the philosophy of chrono-urbanism, which asserts that the quality of life is inversely proportionate to the time and money spent on transport (Moreno et al., 2021). Staricco (2022) notes that these concepts are not novel; Moreno et al. (2021) reinterpret ideas such as Ebenezer Howard's Garden City (Howard, 2003), Clarence Perry's neighborhood unit (Perry, 2020), Walter Christaller's Central Place Theory (Parr & Denike, 1970), Jane Jacob's approaches to urban vitality (Jacobs, 1961), Peter Calthorpe's New Urbanism (Calthorpe & Fulton, 2001), Torsten Hägerstrand's time geography (Hägerstrand, 1976), and Christopher Alexander's and Jan Gehl's human-scale in urban design (Gehl, 2010).

While not exactly novel, the x-minute city provides an effective vehicle to epitomize the idea of accessibility by proximity to groceries, healthcare, education, and services, offering a clear and straightforward vision for healthier, sustainable, and more resilient urban living for the post-pandemic future (Allam, Nieuwenhuijsen, et al., 2022). Its value for setting planning goals from the short to the medium term and its emphasis on the creation of decentralized production and consumption hubs within urban territories, the notion of x-minute cities have also become relevant instruments in the net-zero agenda (Allam, Bibri, et al., 2022).

Early critiques of the 15-minute city occurred within academic and policy circles. First, the concept lacks analytical rigor when it comes to addressing the pre-existing structural forces that drive urban inequality and unequal access to essential services in the first place (Di Marino et al., 2023). Of particular interest is the lack of recognition that the broader ideas of diversity and digitalization are often at odds with the more specific and quantifiable measures of accessibility (Willberg et al., 2023). Furthermore, its ever-increasing popularity makes the concept susceptible to being treated as a place branding slogan, as recognized by Pozoukidou and Chatziyiannaki (2021). In other words, the popularity of x-minute city glosses over the complexity of the influence of the built environment on travel behavior (Guzman et al., 2020; Guzman & Gomez Cardona, 2021; Wang & Zhou, 2017) and how it depends strongly on the local planning and land use context (De Vos, 2015; Guzman et al., 2017; Vecchio et al., 2020).

The above is surrounded by added complexity brought about by discourses in social and popular media. In early 2023, the concept attracted media attention, notably in the UK, when it was misconstrued as a conspiratorial goal to limit individual freedom by reducing car dependency (Nurse et al., 2023). The unexpected media attention on the 15-minute city concept shed light on the institutional and technical challenges in adapting and operationalizing the concept to ensure that it remains a meaningful driver of equitable transformation and not another technocratic quick fix to the socio-temporal configurations of urban territories.

From a conceptual perspective, Lu and Diab (2023) argue that although accessibility is central to the 15-minute city concept, it is poorly defined, measured inconsistently, and in some instances, misunderstood in their study of existing planning documents in North American and Australian cities. Similarly, Gower and Grodach (2022), in their global survey, note that the concept is found primarily in strategic planning guidance that lacks statutory weight. They suggest the

incorporation of the 15-minute city concept into policy documents is motivated by place branding concerns rather than a serious exercise of local democracy to address inter-city spatial inequality at the neighborhood scale. Knap et al. (2023) further argue that there is scarce research on measuring the concept using accessibility metrics, and how it varies across sociodemographic groups at the neighborhood level within the city. The 15-minute city concept has been associated exclusively with proximity, even though there is consensus in the transport and urban planning literature that accessibility is also a function of perceptions, diversity of services, and transport conditions (Geurs & van Wee, 2004; Guzman, Cantillo-Garcia, Oviedo, & Arellana, 2023).

To address the above limitations, Birkenfeld et al. (2023) assert that planners and policymakers must accommodate for variability in actual travel behavior, which is influenced by age, gender, physical ability, class, and built environment (De Vos, 2022; Kim et al., 2018; Sarmiento et al., 2021; van Wee et al., 2019), to ensure that the 15-minute city concept does not get reduced to an arbitrary planning constraint. Papadopoulos et al. (2023) propose for the time thresholds to be adjusted to specific land-use characteristics of urban territories as x-minute city concepts are rooted in Euro-centric perspectives of planning. In a similar vein, Logan et al. (2022) note that the acceptable travel times vary depending on the destination and trip purpose, suggesting that x-minute city concepts are most valuable when the x is left as a variable.

The aforementioned works align well with the aims and contributions of this paper, which intends to provide methodological and empirical elements nuanced by the complexities of rapidly growing cities to better operationalize the concept. In this vein, Marchigiani and Bonfantini (2022) characterize the 15-minute city concept losing its conceptual nuance as 'proximity syndrome', where planners and policymakers take accessibility by proximity as a standalone solution and ignore the knowledge on accessibility and urban livability in established literature, such as Cervero and Kockelman's (1997) 3Ds -density, diversity, and distance- which is now expanded to 7Ds to include destination accessibility, distance to public transport, demand management, and demographic (Ewing & Cervero, 2010). Moreover, broader reflections on the idea of (hyper)proximity beyond the Euro-centric imaginaries of geographical, political, cultural, and socioeconomic specificities found within the city are much needed to push forward practical ideas on implementing and financing the 15-minute city concept in the Global South (Allam, Bibri, et al., 2022; Guzman, Arellana, et al., 2021; Urrutia-Mosquera et al., 2023).

The academic literature addressing the notion of 15-minute cities and similar models of proximity-based urban development suggest that its principles are grounded in decades of research (Allen & Farber, 2020; Páez et al., 2012; Tsou et al., 2005) and provide academics and practitioners with an easily communicable and operationalizable alternative for rethinking urban development trajectories and reformulating local policy for the improvement of accessibility. However, previous research has pointed to its limitations in addressing critical structural factors such as entrenched spatial inequalities and fragmented urban structures, and their associated spatial and social inequalities, which tend to be pervasive in rapidly growing cities in the Global South such as those in Latin America (Oviedo, 2021).

This means that appropriate evaluations for proximity cities require the development of spatially disaggregated evaluation measures that incorporate the differential effects of urban services through the notion of diversity, as well as the preferences of the population, and suitable active transport infrastructure. If these elements are not incorporated into the discussion, the framework might fall short of solving social inequalities related to proximity and accessibility. In this line, proof-of-concept is required to validate these methods and their usability. Thus, this study contends, building on some of the more critical studies examining the notion of 15-minute cities, that although physical proximity to opportunities plays a relevant role in enabling equality of opportunity (Pereira et al., 2017), in achieving more just distributions of accessibility, it is important to consider individual social positions and the priorities of different individuals according to their roles within their households and social structures (Verlinghieri & Schwanen, 2020).

It is in light of these critiques that our paper makes its most relevant contributions to the literature. First, by recognizing active transport as a core tenet of an x-minute city we consider dimensions such as walkability (i.e., the level of service provided by pedestrian infrastructure), investments in active transport infrastructure and social dynamics, such as enhancing crime and (in)security when assessing the 15-minute city's objectives. Another challenge the paper responds to is consolidating diverse theoretical and methodological approaches for the implementation, assessment, and comparison across different locales, which still needs to be solved. According to the existing literature on inclusive, sustainable, liveable, and equitable urban areas, there are essential social functions, that enable individuals and communities to live a full life of enjoyment, care, provision, education, labor, and habitation. We propose expanding these categories to accommodate the myriad of opportunities available and the varying needs of populations representing diverse social identities (Fraser, 1998; Kwan, 1998; Levy, 2015). For instance, this expansion includes public transport as an indispensable service. This is very important to mitigate urban segregation and increase social inclusion.

Furthermore, as argued by previous research, it is imperative to acknowledge that individuals do not share uniform desires, nor do they perceive the built environment identically. Our framing acknowledges that certain demographic groups may prioritize the proximity of hospitals or educational institutions, while others may prioritize proximity to their workplaces, while others may emphasize the availability of cultural and recreational amenities close to their residences. The role of these preferences and perceptions in the context of the 15-minute city concept has yet to be disentangled.

The application of this measurement framework enables the identification of structural disparities among distinct urban areas, facilitating the elucidation of gaps in the 15-minute city concept. This approach provides a more holistic representation of urban accessibility and diversity in essential opportunities while accounting for the varying needs of populations with diverse social identities. By advocating for a more inclusive and representative measurement approach, this study contributes to advancing our understanding and implementing the 15-minute city concept.

3. Could Bogotá be a 15-minute city?

Walking is the most used daily transport mode in Bogotá (Guzman et al., 2022). Of the nearly 13.6 million trips made during a typical day in the city, 25 % are walking (longer than 15 min). The average walking time as the principal transport mode is 23 min. A person walking in Bogotá moves at an average speed of about 3.2 km per hour (Guzman et al., 2020), i.e., approximately covering 800 m in 15 min.

To fulfill the concept of a 15-minute city, the facilities that provide the essential needs and jobs required by a Bogotan household must be located within 800 m of each home. That is, theoretically, within a buffer of 800 m radius, thus an area of 200 ha. Nevertheless, considering the pattern of Bogotá's streets and the network walking distance, access of 15 min is reduced to a polygon of about 100 ha (see Fig. 2), which suggests that households would only need 0.27 % of the urban territory to live.

At first, needing so little space may seem unrealistic. However, we will see that the population of Bogotá already has this choice. Fig. 1 shows that the vast majority of Bogotanos are close (up to a 15-minute walk) to the bare essential opportunities (enjoyment, care, provision, education, labor, and habitation), with notable exceptions such as higher education services, hospitals, sporting venues, cultural activities, and mass public transport. Despite this, from a proximity perspective, it could be argued that Bogotá is close to being a 15-minute city. However, beyond proximity, a 15-minute city implies a balanced territory with

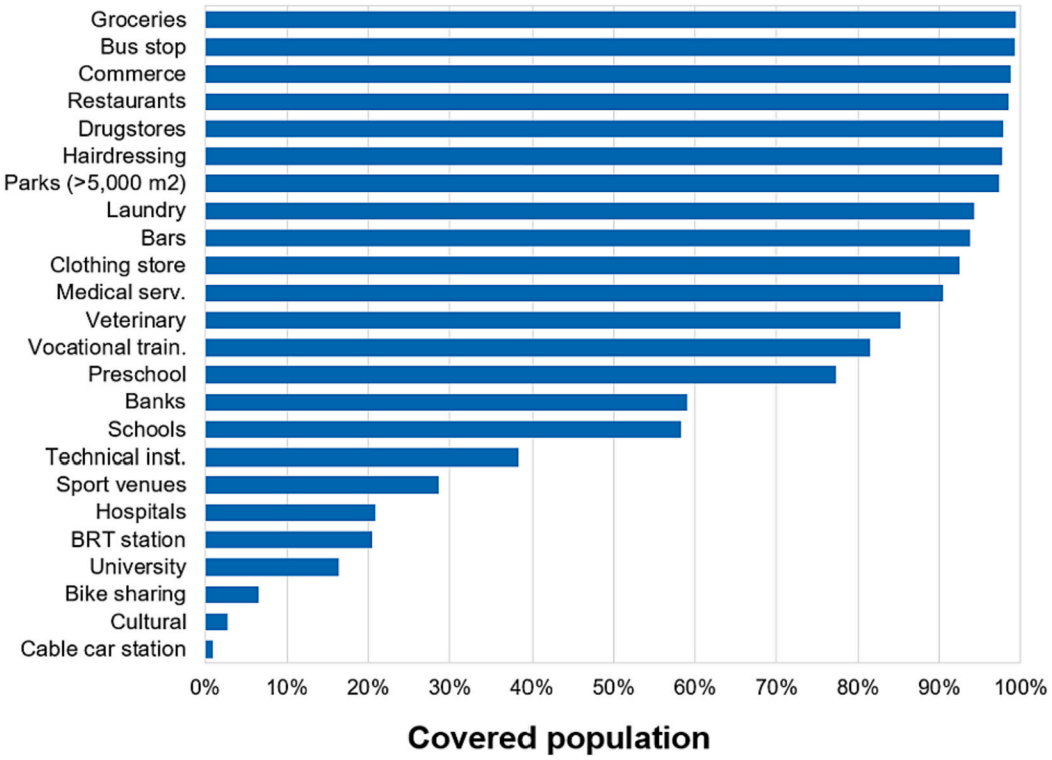

Fig. 1. Covered population by type of establishment (15-minute walking). Source: Census of economic establishments in Bogotá 2017 and own elaboration.

priority to essential opportunities, which in some areas of the city remains to be achieved.

As shown, when assessed purely from the perspective of physical proximity, a model of urban development with local provision of opportunities is not revolutionary for Bogotá. Several essential establishments such as grocery stores, local shops, restaurants, drugstores, schools, and other services are accessible within a 15-minute walk from nearly 80 % of the population. The high average density of Bogotá (19,000 inhab/km^2) and the high mix of land uses allow this diversity and proximity. However, the situation is different depending on the zone of the city, where zoning regulations and urban conditions may influence the creation of primary essential establishments in neighborhoods.

Several studies have shown that Bogotá has an unbalanced territory and is a segregated and unequal city (Guzman & Bocarejo, 2017; Peña et al., 2022), particularly in terms of accessibility to work and study (Guzman et al., 2017), personal exposure to air pollutants (Guzman, Morales, Beltran, & Sarmiento, 2023), or affordability of public transport (Guzman & Oviedo, 2018). Also, there is a high prevalence of low walkability levels across the city (Guzman et al., 2022), where most of the street space is devoted to motorized traffic (Attard et al., 2023; Guzman, Oviedo, et al., 2021). In summary, the high concentration of formal employment on the eastern edge of the city, in addition to higher education and health care services (Guzman, Arellana, et al., 2021), has significant adverse effects in terms of travel time and cost, particularly for the lower-income population (Peña et al., 2022). Then, while groceries, commerce, entertainment, and recreation are already widely available in <15 min of walking in Bogotá, the same is not true of jobs. While many jobs are available within <5 km distance, especially in high-income zones, many citizens prefer to get to work by car.

The evidence presented in this section suggests that the spatial distribution of opportunities in Bogotá enables what many researchers have identified as a proximity model of urban development that holds the potential to be developed as a 15-minute city. However, the structural inequalities that become evident from examining the socioeconomic and functional structure of the city cast doubts about the fairness in the distribution of the quality of such opportunities, the ability of residents to access them, and their contributions to the overall quality of life and well-being. These will be further interrogated in the remainder of the paper.

4. Methods

The proposed methodology aims to identify a standard measure for 15-minute accessibility at the block level associated with the walking level of service considering Bogotá's 42,656 urban blocks, including proximity preferences according to population segments. It also aims to develop a comparable measure representative of the opportunities, proximity, and diversity available in a city.

4.1. Data and information

We use several quantitative and spatial databases in this study. One is the census of economic establishments in Bogotá conducted in 2017 by the Urban Planning Office of Bogotá. This information identifies and geo-references all the city's economic establishments at the block level by commercial, industrial, service, and agricultural sectors. This large statistical operation identified all visible economic units in the urban area by doing a block-by-block census sweep. The census was conducted in 42,656 city blocks where at least one economic establishment was found in 73 % (31,139 blocks). 37,523 economic establishments were identified, of which nearly 11 % were unoccupied. The results show that the largest proportion of economic units (or establishments) corresponds to commerce, wholesale and retail (48 %, 146,435 establishments), followed by accommodation and food services (hotels, grocery and convenience stores, and restaurants), with 45,821 establishments (15 %). The third place is the establishments dedicated to the manufacturing industry, with a share close to 12 % and about 35,434 establishments. In total, 306,462 establishments were counted in the city and classified into different categories as described in Section 4.2.

In addition, we have data on the city's system of parks and public

sports venues, the location of all stops and stations of the public transport system (Bus Rapid Transit -BRT-, regular buses, and cable cars), and a walkability index at the street segment level (Guzman et al., 2022). We use the latter information to measure the suitability of the current pedestrian network conditions. We also use the 2022 database of the cadastral blocks of the entire city, which includes the population by block and the socioeconomic strata (SES). Bogotá (and Colombia) has a particular system for classifying residential real estate into six categories as an approximation of the economic capacity of its residents. SES is a classification of residential properties, where SES 1 corresponds with lower-income residents and poorer urban conditions, and SES 6 is the wealthiest (Cantillo-García et al., 2019). This classification is used to charge for residential public utilities differentially and allows the allocation of subsidies.

Finally, we rely on survey information collected specifically for this research during 2023 to model heterogeneity in the preferences towards the proximity to the different types of establishments using discrete choice modeling techniques. This data was complemented by a large household mobility survey collected in 2019. The representativeness of this household mobility survey allows us to use the models estimated and expand the results according to the spatial distribution of socio-demographic attributes of the population.

4.2. Definition of basic essential opportunities nearby

As seen, the essential urban social functions needed in all cities are enjoying, caring, supplying, learning, working, and living, in such a way that these basic essential opportunities are located within a 15-minute walk (Moreno et al., 2021). This concept envisions that within that 15-minute radius walking everyone must have easy access to shops, schools, parks, health services, leisure, cultural events, and of course, jobs. Based on this, in this study, we propose the following basic needs that would ideally be available within a 15-minute city include:

- Grocery stores and markets (1): Fresh food is essential for good health. Non-specialized retail establishments of food products (groceries in general) and beverages. The so-called supermarkets, shops, and grocery and convenience stores usually carry out this type of activity in Bogotá. The sale of prepared meals in restaurants and cafeterias is excluded.
- Healthcare facilities (2): Access to health facilities, such as hospitals, clinics, and medical services. This is critical for maintaining good health and responding to emergencies.
- Schools and educational facilities (3): Education is crucial to personal and societal development. The education needs vary according to the level (kindergarten, primary school, secondary school, and university), and the number of facilities required.
- Recreation and entertainment (4). Access to green spaces (larger than 5000 m^2) and sporting venues promotes physical and mental well-being (Bertram & Rehdanz, 2015; Sharifi et al., 2021) and should be incorporated into the urban landscape. Also, community centers and cultural institutions (cinemas, musical or plastic arts centers, theaters, libraries, and museums) provide opportunities for socializing. All these facilities should be located within easy reach.
- Services and general commerce (5). People need nearby shops for clothing, footwear, appliances, hardware, bookstores, sporting goods, etc. In addition to buying simple things, people also need some services that have become basic nowadays, such as banks, laundries, hairdressers, veterinarians, and drugstores. And also, life is not just about work and shopping. Enjoying and leisure time are often related to pleasure or personal satisfaction (Mouratidis, 2018). Therefore we include restaurants, nightclubs, and bars here.
- Public transport (6): Efficient and reliable public transport systems should be available to connect people to other parts of the city beyond the 15-minute walk. This category includes BRT, regular buses, cable car stations, and bike-sharing docks.

Following the above, Table 1 summarizes the types of essential establishments, grouped by category that will be used in this study.

Based on available information and the proposed theoretical framework, the six essential urban social categories should be close to each residence (a maximum of 15 min of walking). To calculate the proposed index, it is necessary to count the number of opportunities (establishments per category) each block, in this case, has in its zone of influence of 15 min of walking. This will be done by calculating a measure of accessibility and its importance (preference) for each of the previously described categories as explained in the following sections.

4.2.1. Measuring accessibility

The accessibility measure used in this study is a contour measure that counts the number of opportunities (in this case, the establishment types according to Table 1) that can be reached within a 15-minute walk from each block in the study area. This indicator builds upon traditional contour measures, which count the number of establishments reached within a given average travel time, in this case, 15 min of walking considering the street network. This measure is also known as an isochronic measure, cumulative opportunities, or proximity count (Geurs & van Wee, 2004; Guzman et al., 2018). The accessibility of a block is estimated as the total number of establishments per category that can reached from a residence location (block) within the previously defined walking time threshold. Eq. (1) is a binary threshold indicating the block i's walking-based accessibility to opportunities by type (Acc_{ie}).

$$Acc_{ie} = \sum_{1}^{e} Establishment_{ie} \bullet T_h \quad (1)$$

where i indicates a residential block in the study area ($i = 1, \ldots, 42{,}656$), and e indicates the total number of essential urban opportunities per category k measured as the number of corresponding establishments (per) around the block i. T_h will be 1 if the walking travel time threshold is a maximum of 15 min walking; 0 otherwise. Therefore, this accessibility indicator counts the number of establishments[1] per category k that can be reached within 15 min of walking as shown in Fig. 2. The

Table 1
Basic essential opportunities nearby.

Categories k	Establishments e
Groceries	Grocery and convenience stores & markets
Healthcare	Hospitals
	Medical services
Education	Preschool
	Primary school and high school
	Technical institutes
	Vocational training
	Universities
Recreation	Parks and green areas
	Sport venues
	Cultural
Services	Bank
	Drugstore
	Local shops
	Clothing store
	Laundry
	Hairdresser
	Bar
	Restaurants
	Veterinary
Public transport	Bus stops
	BRT stations
	Cable car stations
	Bike sharing docks

k [1, 6]; e [1, 24].

[1] Due to data availability limitations, it is not possible to include the scale (size) of each establishment.

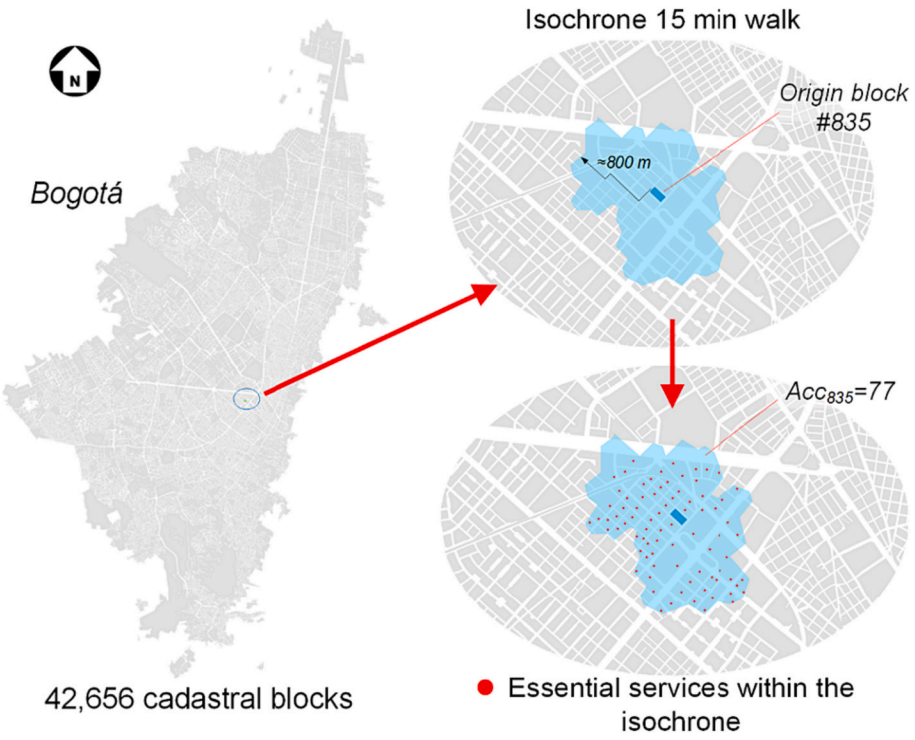

Fig. 2. Example of calculation of cumulative opportunities at the block level.

proposed 15-minute index also accounts for overlaps in walk isochrones, e.g., two or more blocks may share and hospital and a school. In this case, the combined accessibility contour measure to health and educational services are 'double counted' which recognizes that these areas have a higher diversity. The higher the indicator, the better the accessibility.

In this accessibility indicator, all categories k and types of establishments e have different quantities, implying that large numbers have much more power than smaller ones. To avoid this, it is necessary to normalize this indicator and make the accessibility per category move in a comparable range. Therefore, the accessibility indicator from Eq. (1) has been adjusted so that its distribution is on a scale from 0 to 1, assigning a minimum and a maximum value. In this case, a minimum (we define the 5th percentile or at least 1 establishment) and a maximum value (context-dependent: we define the 95th percentile value) per establishment type of the distribution was selected from the information, according to Table 2. On average, the whole city has a high number of restaurants, hairdressers, pharmacies, local shops, and grocery stores (mostly convenience stores). Also, note that the standard deviation is very high for several types of establishments. This implies a significant imbalance in access to these opportunities, compared to the others. Conversely, there are low opportunities for health services such

Table 2
Descriptive statistics of accessibility values.

Category	Basic essential opportunities (establishments)	Accessibility (mean)	DevSt	Max (95th percentile)	Min (5th percentile)*
Groceries	Groceries	187.5	125.2	409	16
Healthcare	Hospitals	0.4	0.9	2	1
	Medical services	10.3	11.6	32	1
Education	Preschool	3.3	3.6	11	1
	Schools	1.2	1.5	4	1
	University	0.7	3.2	2	1
	Technical institute	1.1	2.5	5	1
	Vocational training	4.6	5.5	15	1
Recreation	Cultural	0.6	1.5	3	1
	Sport venues	0.1	0.4	1	1
	Parks (>5000 m^2)	4.9	3.0	10	1
Services	Restaurants	90.3	80.8	231	5
	Bars	18.4	16.5	49	1
	Commerce (local shops)	107.1	113.8	277	6
	Banks	3.0	5.5	14	1
	Laundry	6.7	5.1	16	1
	Hairdressing	45.3	31.4	103	2
	Veterinary	3.4	3.2	10	1
	Clothing store	44.3	95.1	152	1
	Drugstores	24.7	18.5	58	1
Public transport	BRT station	0.4	0.9	2	1
	Bus stop	28.9	13.6	53	7
	Cable car stations	There are four cable car stations in the whole city			
	Bike sharing	0.8	3.2	8	1

* Or at least one establishment per type.

as hospitals, and education such as universities. We also tested 20 and 30 min as other thresholds, finding similar trends to what was observed when applying the 15-minute threshold.

With the normalized accessibility indicator, we can compare the accessibility levels of all the blocks in the study area. For instance, in the case of education services, if a residential block is close to the maximum of 4 schools (row 6 of Table 2), it will have a value of 1 (best context-related accessibility). In contrast, if a block has nothing, it will have a value of 0 (worst accessibility). This indicator moves on a scale from 0 to 1, so that it is easier to compare the 15-minute accessibility of each block. Note that this method is context-related. An empirical normalization has been done since the minimum and maximum values of available information were used to normalize the accessibility indicator. A theoretical normalization could also have been used, but this implies that we must have a concrete reason based on theoretical assumptions to justify the minimum and maximum values of essential establishments. We should have concrete evidence of how many facilities are sufficient per category, which can be very complex and vary according to the study area.

4.2.2. Are all essential establishments equally important?

The accessibility indicator in the previous section gives equal importance to all establishments. Assuming a standardized significance between 0 and 1 means that each category is worth 0.167 in the final 15-minute city index calculation. However, we acknowledge that the proximity to some types of facilities is more important than others and therefore, should have greater importance, that is, a higher preference or weight. In addition, population segments might value each type of establishment differently, so there is heterogeneity in the preferences and a subjective valuation that must be considered in the index. For example, older adults might want to be closer to medical services, or a family with young children might be more interested in being close to a kindergarten.

To include these perceptions in the proposed 15-minute index, a ranking survey ($N = 334$) was collected between April and July 2023 to unveil the prioritization and valuation of the proposed categories for Bogotans once the accessibility indicator is normalized. The purpose of this ranking survey is to estimate the relative importance or weight of each establishment e on the 15-minute city index and therefore, understand the levels of acceptance of the selected essential services for residents according to socioeconomic and demographic characteristics. The survey was divided into three sections. In the first section, respondents must rank each defined essential services category (1st column in Table 1) according to preferences about which are the more important to have close to their home. Similarly, the second section asks to rank the importance of each of the 24 types of establishments defined in Table 1 (2nd column) by category. Then, in the third section, the survey asked about socioeconomic conditions and housing location. The survey results are then modeled considering the ranking nature of the data collected. The rank survey was conducted online, considering different question types, rating scales, and drag-and-drop interfaces (in Spanish: https://new.maptionnaire.com/q/4bx7ish3wxb3).

Table 3 shows a description of the rank survey sample. Gender, age, SES, and occupation categorized participants. The distribution of the variables age and occupation are very similar by gender. There is only a small difference regarding SES, as females with SES lower than 3 (7.5 %) have a higher participation than males (2.0 %). Therefore, it is possible to assume that differences in modeling parameters can be attributed to heterogeneity in preferences rather than differences in the distribution of attributes. Around 13.8 % of the sample answered survey Sections 1 and 2 but declined to report sociodemographic characteristics in Section 3. Even though these observations do not allow for modeling heterogeneity in the preferences by attributes, the data was included in modeling stages assuming homogeneity in preferences for this group of observations.

To assess and understand the preferences for the categories of essential services we estimate discrete choice models using the ranking data collected. This formulation allows us to estimate the probability of each type of establishment being the preferred alternative by the survey participants, considering heterogeneity in the preferences by the characteristics of participants.

Table 3
Rank survey sample summary.

Attribute	Sample
Gender (%)	
Female	42.5 %
Male	42.8 %
I prefer not to answer	14.7 %
Age (%)	
18–29	28.4 %
30–45	31.7 %
46–59	16.8 %
60–70	6.9 %
Over 70	2.4 %
I prefer not to answer	13.8 %
Socioeconomic strata SES (%)	
SES 1	3.3 %
SES 2	6.6 %
SES 3	15.6 %
SES 4	22.5 %
SES 5	20.1 %
SES 6	18.3 %
I prefer not to answer	13.8 %
Occupation (%)	
Student	6.0 %
Working (employee)	50.3 %
Working (self-employed)	19.5 %
Unemployed	6.0 %
Retired	4.5 %
I prefer not to answer	13.8 %
Sample size	**334**

As the data is in rank format, we implement a rank explosion in which the first position in the rank (denoted by R_1) is the choice where alternatives included in the rank are available, then, the second position (R_2) is the choice when R_1 is not available, and the third position (R_3) is chosen when the R_1 and R_2 are not available. This process can be repeated iteratively until obtaining $e–1$ choice situations, in which case e refers to the total number of alternatives included in the rank (the number of establishments from Table 1). Then, the probability of observing the rank (R_{zj}) for participant z and position j is given by Eq. (2) (Hess & de Palma, 2019), where V is the utility function associated.

$$P_z = \prod_{j=1}^{e-1} \frac{exp\left(V_{R_{zj}}\right)}{\sum_{1}^{e} exp\left(V_{R_{zj}}\right)} \tag{2}$$

Eq. (2) allows us to estimate the probability of choosing each category or establishment as the preferred type, considering the utility perceived by participants according to their characteristics. We included systematic taste variations in the utility by sex, age, occupation, and SES. In total 7 models are estimated, one to assess preferences towards the six main categories k (first column in Table 1), and six models to evaluate the establishment preferences inside each category (second column in Table 1). Instead of using a single model to estimate the proximity preferences towards the 24 types of establishments, we rely on this approach to reduce the fatigue and burden in the rank survey and reduce the associated biases.

In the survey, we first asked participants to rank the six main categories, and then the establishments inside each category were asked to be ranked. Because of the structure of this information, we do not estimate a single model comparing all establishments but rather follow the two-stage process in which preferences towards the six main categories are evaluated first, and then the establishments belonging to each of these categories are assessed. Several specifications for the utility were tested, and the final models utilized for the analysis were selected based

on the criteria of model fit, congruency, and statistical significance of parameters.

The final probability for the 24 establishment types to be used as weights for our analysis is calculated by multiplying the corresponding probability of the six main categories by the probability of the establishment inside the nest of the correspondent category. Note that these probabilities are predicted through the models estimated with the rank data collected in 2023. This information allows to capture of heterogeneity in the preferences by sociodemographic attributes. However, this dataset does not represent the spatial distribution of sociodemographic attributes of the whole population. Then, given that we are interested in capturing spatial heterogeneity in the preferences, to predict the probabilities we rely on a large sample ($n = 25{,}863$) from the 2019 household mobility survey that is representative of the distribution of population in Bogotá, disaggregated spatially. Using this complementary dataset, we can average the probabilities following the distribution of population within each zone and at the city level, obtaining the weights that represent the relative importance of each category and establishment type that influences the 15-minute city index. Overall, this proposal is a powerful tool for analyzing ordinal response variables and provides a flexible and interpretable approach to understanding the relationships between categories and personal preferences.

4.3. Definition of a 15-minute city composite index

Besides results from individual preferences, two dimensions are utilized to calculate the average 15-minute index, as well as for specific population segments: an approach grounded in walkability, and secondly, a balanced diversity of essential opportunities in proximity. First, we define and justify the proposed 15-minute index. Secondly, we measured the average suitability and attractiveness of a 15-minute walking isochrone from every residential block through a walkability index. Finally, to quantify balanced diversity, a composite of accessibility indicators is employed for each establishment outlined in Table 1. It is important to note that the proposed methodology is generic and, thereby applicable to districts and urban areas of diverse contexts.

4.3.1. The 15-minute city index

The 15-minute city index aims to create a measure of 'walkable proximity' for each city block which is representative of the diversity of the essential services. Also includes the easiness of walking that each 15-minute walk isochrone would have. Therefore, a combined measure of the diversity of essential services (D_i) and walkability (WI_i) by each block i was then computed using the following:

$$\mathrm{P}_{15i} = \sum_k D_{ik} \bullet WI_i \tag{3}$$

$$\mathrm{P}_{15} = \frac{\sum_i D_i \bullet WI_i}{\sum_i i} \tag{4}$$

where P_{15i} is the 15-minute index for each block i, D_i is the diversity indicator by block i (see Eq. 6) and WI_i is the average walkability indicator by block 15-minute walk isochrone i (see Eq. 5). If city blocks are covered by walk isochrones to the six categories k and also have a high average walkability indicator, the 15-minute city index will be higher. On the contrary, if a particular block has a large and balanced number of establishments (high accessibility and diversity), but a low walkability indicator, the 15-minute index will be low because even though the block has a large diversity of opportunities nearby, they are not as easy to reach on foot. In summary, Fig. 3 shows the diagram of how the 15-minute index is composed. In addition, Annex 1 provides a step-by-step summary of how the proposed index is constructed, including its application.

Note that to have a perfect 15-minute index (equal to 1) urban conditions should be ideal. In other words, to have a balanced diversity and a perfect level of walkability. If the index is to be estimated at the city scale, Eq. (4) should be used. The result will be an average of the individual indicators of all blocks. This formulation also allows for aggregations at the level of neighborhood, zone, or any other desired spatial scale.

4.3.2. Walkability: easiness of reaching the destination

A zone of the city, or a neighborhood, can have a great diversity of opportunities nearby, as in Bogotá (see Fig. 1). However, despite having many cumulative and diverse establishments, walking towards them may not be easy or pleasant. Therefore, streets that encourage safe and attractive walking trips are necessary to reach the 15-minute city concept. The walkability index used in this research was previously developed and is a weighted additive function that estimates the walkability level by street segment considering socioeconomic characteristics of pedestrians (Guzman et al., 2022). This indicator is composed of non-observable factors and their corresponding observable attributes as shown in Table 4.

This walkability indicator for Bogotá includes variables relative to the quality of pedestrian infrastructure, security, and traffic. Also includes characteristics of the built environment (density, diversity, and

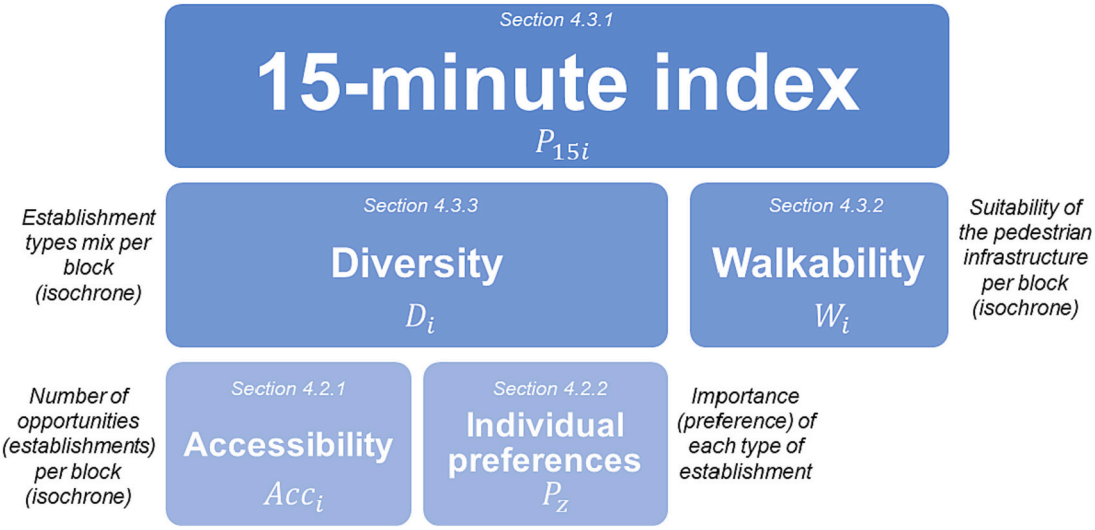

Fig. 3. 15-minute index composition

Table 4
Factors and components selected for the formulation of the walkability index.

Non-observable factors	Observable components (scale)				
Pedestrian infrastructure robustness	Presence of sidewalk (segment)	Sidewalk width (segment)	Quality of sidewalk pavement (segment)	Presence of ramps (segment)	Obstacles on sidewalk (segment)
Road safety	Motorized traffic speed (segment)	Motorized traffic flow (segment)	Presence of traffic control devices (segment)	Traffic accident records (segment)	Street cross-time (segment)
Personal security	Presence of security cameras (segment)	Presence of police stations (500 m buffer)	Pedestrian flow (zone)	Crime records (zone)	Quality of lighting (segment)
Destination access	Commercial density (zone)	Institutional density (zone)	Residential density (zone)	Access to public transport (segment)	Park or green areas density (zone)
Comfort	Presence of trees (segment)	Quality of the urban environment (zone)	Congestion levels (segment)	Sidewalks slope (segment)	Block length (segment)

design). Based on the hierarchy of the walking needs model (Alfonzo, 2005; Arellana et al., 2020), the non-observable factors were grouped. Therefore, using the set of factors and components shown in Table 4, a walkability indicator was constructed at the street segment level for the entire city (https://luisangelguzmang.github.io/walkability/).

This indicator value ranges from 0 to 1, where a value closer to 1 is better for walkability. To measure the walkability indicator by block in this study, we estimated a weighted average walkability value per each 15-minute walk isochrone according to Eq. (5):

$$WI_i = \frac{\left(\sum_{s\in i} WI_{s,i} \bullet L_{s,i}\right)}{\sum_{s} L_{s,i}} \tag{5}$$

where WI_i is the average walkability value for the 15-minute isochrone of block i. $WI_{s,i}$ is the walkability value of the street segment s inside the isochrone of block i. L_s is the length of each segment s in the 15-minute isochrone area of block i. This formulation allows us to have an average WI weighted by the length of the pedestrian network and its corresponding walkability value for each block i.

An attractive 15-minute city environment must encourage walking. The main results from the Bogotá walkability index show that the most important factor in almost all cases is related to security. I.e., desirable streets in Bogotá are characterized mainly by road safety and personal security. More details about the walkability index at street level in Bogotá can be found in Guzman et al. (2022).

4.3.3. Diversity: a balanced mix of opportunities

After having the accessibility indicators normalized and the importance (preference) of each establishment e from the ranking survey, it is necessary to combine the accessibility indicators and corresponding weights in a diversity indicator. The proposed diversity indicator includes the proportion of dissimilar establishment types aggregating the accessibility indicators using the geometric mean. We deliberately decided to use the geometric mean, as this intentionally penalizes low values, so that if a block has a very low accessibility value of any category, it will be penalized in its final value. In addition, when using the geometric mean, the blocks with a high diversity index are those with the least numerical difference between the accessibility values and this translates into a practically imperceptible penalty in the index. On the other hand, blocks with low accessibility values in some categories will be penalized. This approach has the advantage that blocks with high accessibility values and balanced access (similar values) to the basic essential opportunities will have a better score.

According to the above, the diversity indicator was operationalized as the sum of the logarithm of each normalized accessibility indicator (Acc_{ie}) multiplied by its weighting from the ranking survey (w_e).

$$D_{ik} = \frac{exp\left(\sum_{e\in k} log(Acc_{ie}) \bullet w_e\right)}{\sum_{e\in k}(w_e)} \tag{6}$$

where D_{ik} in this case, is the diversity indicator for block i aggregated per category k, Acc_{ie} is the normalized accessibility indicator of each category k (aggregating the corresponding establishments, see Table 1) by block i, and w_e is the importance (weight) of each establishment type e per category k from Eq. (2).

5. Results

First, we estimated seven Multinomial Logit (MNL) models using survey data to assess preferences towards establishments. The outcomes of the first MNL model assessing the primary six categories k of essential opportunities are presented in Table 5. This model includes interactions by SES, age group, gender, and occupation. The models also include a random error component to account for the panel effect of the repeated observations by individuals. Results on the preference for having bike-sharing docks nearby are not included, since all participants ranked it as the least preferred alternative. This is because this is a relatively new system (<1-year-old) and is only available in a small part of the city.

According to the results, alternative specific constants (ASC) suggest that healthcare and grocery categories are the most preferred types of essential categories, while the recreational category is the least important. Low SES participants prefer to be closer to healthcare facilities in comparison to other SES groups, while younger adults of <30 years old, prefer to be close to services and commerce, recreational, and public transport. Regarding occupation, participants not working or studying prefer to be close to educational facilities and services/commerce. Men and women have no significant differences regarding preferences in these six main categories. However, differences in preferences between men and women are important in all establishment types except for parks, laundries, and bus stops (see Tables A1 to A6 in Annex 2).

The detailed outcomes of the remaining six discrete choice models (i.e., a model for each category k) employed for assessing preferences are provided in Annex 2 (Tables A1 to A6). These models also encompass systematic variations in tastes by age, occupation, SES, and gender. This approach facilitates the capture of heterogeneity in individual preferences, recognizing that distinct population segments value the facilities and their categories differently.

The models then estimated the probability of each establishment being the preferred alternative within specific population segments, which were then used as weights. Ranging from 0 to 1, these weights can be interpreted as standardized values, ensuring that all weights for a given population segment are summated equal to 1. A higher weight signifies a stronger preference towards a particular establishment and its

Table 5
MNL estimates for the six main categories of basic essential opportunities.

Parameter	Coef.	*t*-test	*p*-value
ASC Education	−2.57	−4.38	3.5E-05***
ASC Services	−2.45	−3.97	1.8E-04***
ASC Recreation	−3.23	−4.65	1.1E-05***
ASC Public transport	−1.51	−4.42	2.9E-05***
Education: SES 1 and 2	−0.89	−1.60	1.1E-01
Education: Age 18–29	1.72	2.79	8.5E-03***
Education: Age 30–45	1.60	2.70	1.1E-02**
Education: Age 46–59	1.89	2.85	7.1E-03***
Education: Non-occupied	1.19	2.31	2.8E-02**
Groceries: SES 1 and 2	−2.87	−4.40	3.2E-05***
Groceries: Age 18–29	1.84	5.16	1.1E-06***
Groceries: Age 30–45	1.25	3.96	1.8E-04***
Groceries: Age 46–59	0.92	2.28	3.0E-02**
Services/commerce: SES 1 and 2	−3.19	−4.59	1.4E-05***
Services/commerce: SES 3 and 2	−1.02	−2.49	1.8E-02**
Services/commerce: SES 4	−0.61	−1.77	8.4E-02*
Services/commerce: Age 18–29	2.13	3.17	2.8E-03***
Services/commerce: Age 30–45	1.71	2.73	9.9E-03***
Services/commerce: Age 46–59	1.62	2.45	2.0E-02**
Services/commerce: Non-occupied	0.98	1.86	7.1E-02*
Recreation: SES 1 and 2	−3.17	−4.41	3.1E-05***
Recreation: SES 3	−1.06	−2.59	1.4E-02**
Recreation: SES 4	−0.58	−1.67	9.9E-02*
Recreation: Age 18–29	2.21	3.14	3.1E-03***
Recreation: Age 30–45	2.36	3.45	1.1E-03***
Recreation: Age 46–59	2.27	3.12	3.2E-03***
Recreation: Non-occupied	1.12	1.98	5.7E-02*
Public transport: SES 1 and 2	−3.09	−4.60	1.4E-05***
Public transport: Age 18–29	2.32	4.95	2.8E-06***
Public transport: Age 30–45	1.75	3.90	2.3E-04***
Public transport: Age 46–59	1.25	2.47	1.9E-02**
Panel effect (standard deviation)	−1.31	−5.11	1.4E-06***
Loglikelihood	−1924.45		
N	334		

Significance level: ***p < 0.001 **p < 0.01 *p < 0.05, p < 0.1.

corresponding category.

Table 6 summarizes the weight (i.e., choice probabilities) of six categories of basic essential opportunities *k* obtained from the rank perception survey by age range, SES, and gender. The estimated weights of these six categories indicate that the most important categories are groceries and healthcare services, constituting an average of 65.5 % of the total weight. High and medium-SES individuals are more inclined towards grocery stores, services, recreation, and public transport. This preference can be attributed to a higher willingness to pay for goods and services. Young adults tend to prefer residing in proximity to grocery stores, a predilection that may be linked to a greater frequency of shopping trips. Low SES individuals and older adults manifest higher preferences for proximity to healthcare facilities, a propensity potentially stemming from an elevated susceptibility to health risks. Furthermore, it is noteworthy that females are more inclined to favor educational and recreational facilities than their male counterparts.

Females aged from 30 to 59, particularly those from low-SES segments, display a more pronounced inclination towards being close to preschools. This inclination can be attributed to their roles as parents of young children, potential considerations regarding travel expenses, and the prevalent involvement of women in caregiving responsibilities within Colombia. In addition, low-SES segments indicate a preference for being near technical institutes and schools compared to other educational services. In contrast, the group of young adults demonstrates a significant preference for being close to universities, comprising the primary demographic that engages with such educational services. The estimated weights assigned to each category and establishment across the population segments are presented in Table A7, located in Annex 2. It is noteworthy that this still represents a generalization of preferences for specific opportunities. Further information is required to understand more specific preferences and limitations linked with, for example, health restrictions, and specific nutrition requirements, which considerably limit their real supply of opportunities.

It is worth noting that certain establishments, such as bars and nightclubs, are considered the least preferred options among the general population. This preference likely arises due to their association with noise and disorder, reducing the appeal of coexisting with such venues. The heightened inclination of the younger population towards proximity to public transport is of particular significance, highlighting their firm reliance on this transport mode. In contrast, low-SES individuals tend to exhibit a reduced preference for proximity to public transport. This trend could be attributed to their increased willingness to cover longer distances on foot (Bocarejo & Oviedo, 2012; Guzman et al., 2020) and the increase in residential land prices near the BRT (Guzman, Enríquez, & Hessel, 2021), coupled with the relatively limited affordability of public transport (Guzman & Oviedo, 2018). However, it is important to recognize that populations with lower socioeconomic statuses do indicate a more pronounced preference for the proximity of cable car stations. This observation confirms an ongoing pattern within the city, where such infrastructure has notably improved accessibility and built environment perceptions in low-income neighborhoods (Guzman, Cantillo-Garcia, Arellana, & Sarmiento, 2023).

Out of the 306,462 establishments encompassing the six categories studied, it has been discerned that the overwhelmingly predominant proportion is dedicated to the sphere of retail, with their distribution spanning across almost the entire expanse of the city (constituting 73 % of the urban blocks). Upon a thorough analysis of these statistics and the information presented in Fig. 1, an initial assertion might arise, suggesting that Bogotá functions as a 15-minute city. Nevertheless, this assumption necessitates a more nuanced consideration, as significant gaps in terms of mobility and accessibility persist, disproportionately impacting low-income households due to the city's urban configuration (Guzman et al., 2017; Guzman, Arellana, et al., 2021; Oviedo Hernandez & Titheridge, 2016).

Moreover, as shown in Tables 2 and 6, a large imbalance emerges in the distribution of basic opportunities throughout the urban landscape. This is confirmed due to the large variability observed in the estimated accessibility values. The average values of these estimates exhibit a range spanning from 60 % to 250 %, depending on the type of establishment. Should we confine our evaluation solely to the aggregate count of establishments and their respective location, it becomes apparent that grocery (convenience) stores, local retail shops, and drugstores

Table 6
Accessibility indicators and preferences by sociodemographics.

Categories *k*	Avg. acc. (DevSt)	Preferences (weights)								
		Average value	Age range			SES			Gender	
			18–29	30–59	≥ 60	Low	Medium	High	Female	Male
Groceries	0.428 (0.293)	0.300	0.352	0.288	0.267	0.167	0.406	0.371	0.293	0.308
Healthcare	0.179 (0.237)	0.355	0.291	0.334	0.475	0.541	0.213	0.209	0.350	0.359
Education	0.172 (0.187)	0.138	0.123	0.159	0.110	0.181	0.108	0.093	0.148	0.127
Recreation	0.174 (0.230)	0.035	0.027	0.045	0.023	0.023	0.040	0.073	0.038	0.032
Services	0.324 (0.230)	0.047	0.068	0.070	0.060	0.043	0.078	0.137	0.071	0.063
Public transport	0.208 (0.154)	0.124	0.159	0.125	0.083	0.058	0.178	0.157	0.121	0.129

constitute the most prevalent establishment types within the city. These types of establishments are predominantly concentrated in the southern and western areas of the city, which coincide with the residential zones populated by the low-income population.

This situation gives rise to an unequal diversity indicator, as illustrated in Fig. 4. As the maps show, high-SES areas (wealthy population) exhibit more favorable diversity scores (depicted as darker regions along the eastern edge), with certain focal points in the outskirts. Concurrently, these peripheral zones are characterized by a low employment-to-population ratio, indicating that individuals lack the opportunity to engage in their primary activities close to their residences. Regarding walkability, its spatial distribution closely mirrors that of the diversity indicator. In other words, the areas of the city with the wealthiest population also boast the highest quality of pedestrian infrastructure and the built environment (Guzman et al., 2022). The findings depicted in Fig. 4 inherently encompass the preferences obtained from the survey of an average citizen.

The combination of these two indicators culminates in the suggested metric of a 15-minute city. This metric boasts three primary advantages. The first underscores that not all essential services hold equal importance or preference for individuals, even though, in this instance, the outcomes are illustrated for an average citizen. The second advantage involves the combination of both the quantity and diversity of the examined essential services (an equilibrium between nearby essential opportunities heightens the indicator). This approach considers the convenience and attractiveness of walking to these services. Fig. 5 presents the outcome of the proposed 15-minute indicator, which already encompasses the populace's preferences. Drawing from the previously established methodology, it becomes feasible to gauge and chart numerous metrics based on the socio-economic attributes of the population, as shown in Table 6.

In summary, the findings of the 15-minute city index measurement using the methodology described previously state that:

- From the results in Figs. 4 and 5, the average city diversity indicator (D) is 0.273. The average 15-minute city index (P_{15}) is 0.133. Although there is a high mix of land uses in Bogotá, significant imbalances exist between the different categories of essential opportunities. Hence, the diversity indicator demonstrates a low value. It is imperative to remember that the suggested indicator intentionally penalizes low accessibility values. Consequently, if a block exhibits a low accessibility value, its diversity indicator will be substantially impacted. When coupled with reduced levels of walkability, this outcome, when coupled with reduced levels of walkability, culminates in a diminished 15-minute index.
- The categories that have better accessibility throughout the city are groceries (0.428), services (0.324), and public transport facilities (0.208) as shown in Table 6. The relatively high accessibility indicator of the groceries category is due to the large number of grocery and convenience stores in the city, particularly in low-income areas located on the periphery (see Annex 2, Fig. A1).
- The establishments analyzed are valued differently by the population since the proximity to some urban amenities is more important than others. Proximity to groceries, health, and education is the most important to *Bogotanos* (79.3 %). Specifically, proximity to hospitals, medical services, grocery, and convenience stores are the preferred establishments (65.5 %).
- Women prefer to be close to preschool institutions, as well as to hospitals with specialized healthcare. These results might be associated with the fact that in Bogotá, women are still acting as the main caregivers and providers of mobility of care, performing more care activities such as taking kids to school (Montoya-Robledo et al., 2020). Moreover, they have slightly higher preferences towards some services and commerce establishments, especially drugstores, local shops, and banks.
- A low 15-minute index, below the 50th percentile value of the city (0.133), is provided for 3.48 million residents, or almost 50% of the population which almost exclusively resides in the urban periphery of Bogotá. Conversely, just 9.5% of the population enjoy a high 15-minute index (over 0.190, the 90th percentile). This implies a high spatial inequality.

This methodology serves as the foundation for a comprehensive and resilient diagnosis of cities. More importantly, it enables the formulation

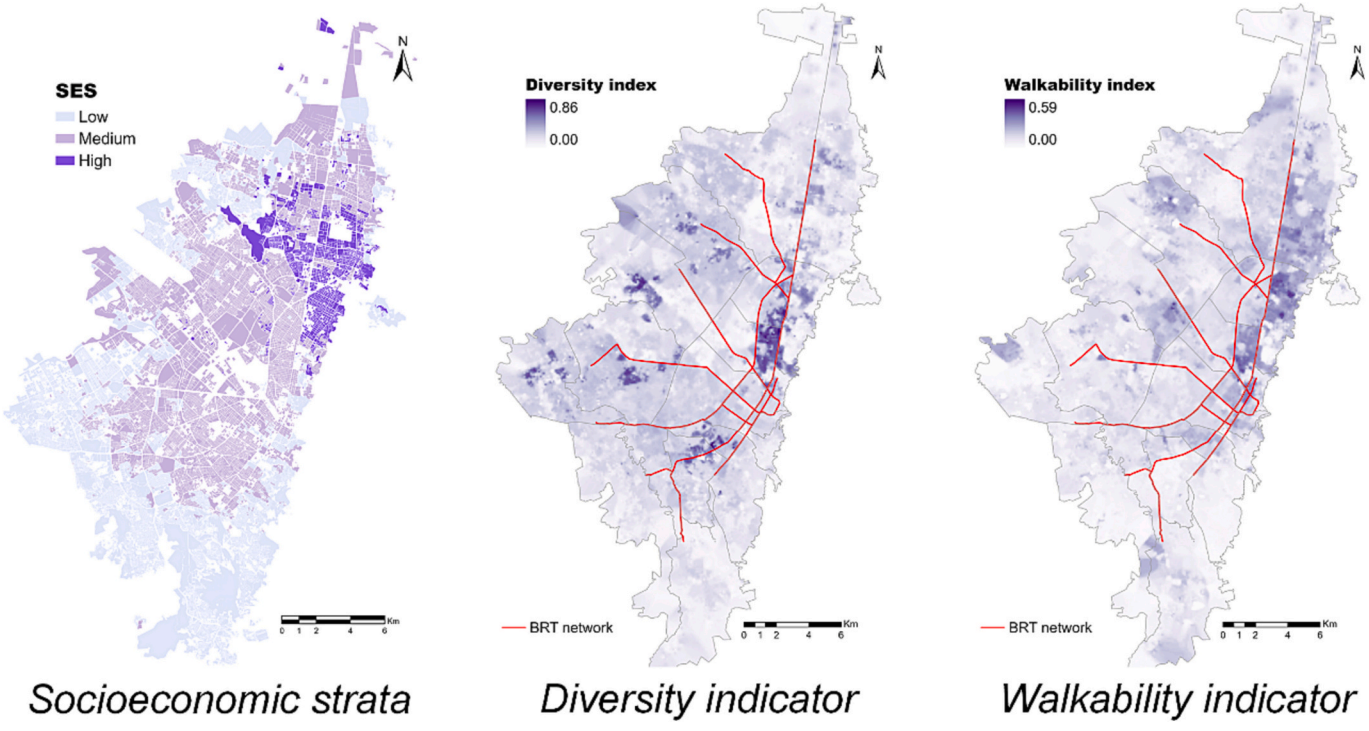

Fig. 4. Diversity and walkability at the block level.

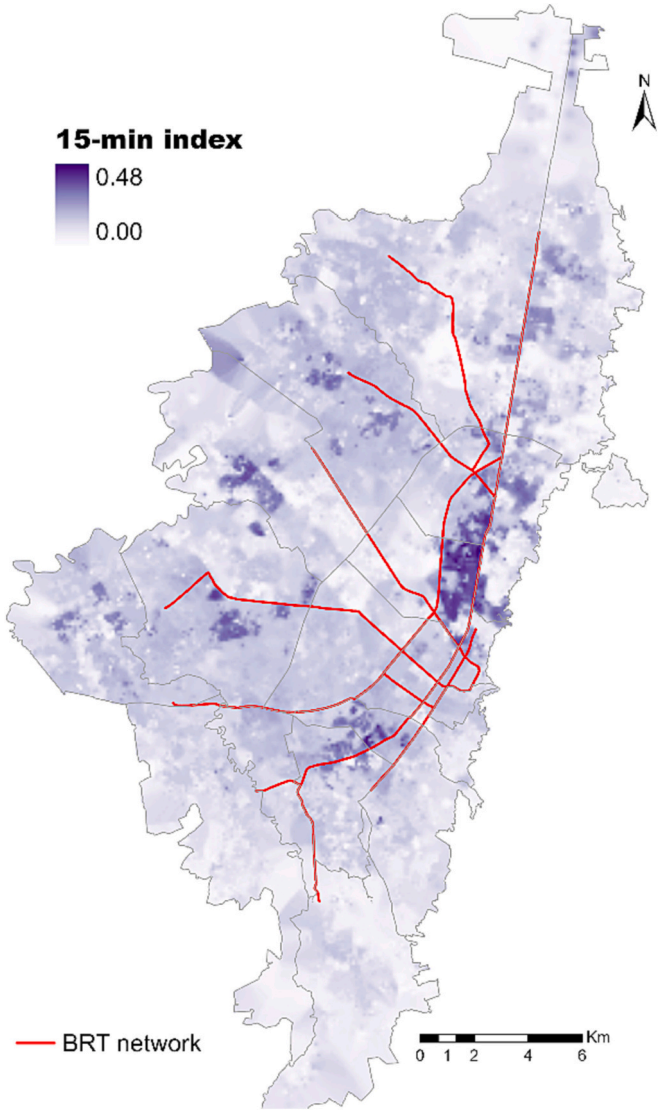

Fig. 5. 15-minute weighted index at the block level.

of policy actions aimed at enhancing and balancing the urban landscape at a micro level. Consequently, it contributes to the improvement of the proposed index's performance. As an illustration, Fig. 6 depicts the key findings in both the wealthiest and the poorest zones of the city. For each zone, the first row outlines the average values of the 15-minute index, while the second and third rows present the indicators of diversity and walkability, respectively.

The overall walkability of each zone is relatively high, surpassing the city average. However, the low diversity values indicate an imbalanced territory due to the omission of essential services. This omission notably affects the 15-minute index. Particularly in low-income zones, a pronounced disparity is observed in the limited availability of healthcare, education, and public transport (BRT) services. This emphasizes the heightened importance of these omitted essential services, revealing the potential for "retrofitting" the existing urban fabric to align with the 15-minute city concept. The absence of a particular essential service implies a restriction on creating a balanced territory that fails to meet the basic needs of its inhabitants. Therefore, strategically locating and offering the omitted service can enhance the performance of the studied zone under the conceptual framework explored here.

In terms of resident population, affluent areas, on average, have 1.5 health facilities per 1000 inhabitants, whereas poorer areas have only 0.2. Regarding education, there are 0.7 establishments per 1000 inhabitants in wealthier areas, compared to a mere 0.1 in the poorest areas. In the realm of grocery services, there are 10.7 establishments and 2.5 per 1000 inhabitants, respectively. Despite these great differences, these low-income zones, characterized by distinct impacts and imbalances, hold substantial potential for transformation into more livable spaces with improved walkability.

Based on the previous analysis, we are interested in determining whether the distribution of the 15-minute index is uniform across the city and its population. Consequently, the outcomes presented in Fig. 7 depict the concentration curve of the 15-minute index categorized by the SES group. This graphical representation illustrates the cumulative percentage of the 15-minute index (y-axis) concerning the cumulative percentage of the population. In instances where each block, irrespective of its SES group, demonstrates an identical value for the proposed index, the concentration curve will manifest as a 45-degree line. The mean concentration value for the entire city, as indicated by the Gini index, stands at 0.333. However, the concentration curves for SES 1 and SES 6 lie notably below the line of parity, underscoring that the most unequal areas are concentrated in the poorest and wealthiest zones. These latter results reinforce the results of Fig. 7, which shows that the poorest and wealthiest areas have the most unbalanced territories.

This implies that if the 15-minute index is construed as a measure of effective proximity to essential urban opportunities, merely 6.7 % of the opportunities provided by the city in these zones are accessible to 50 % of Bogotá's SES 1 population. Correspondingly, in SES 6 zones, only 12.8 % of the opportunities can be reached by half of the population. This phenomenon is mainly attributed to the heightened imbalance among the basic essential categories evaluated in these zones, consequently resulting in a diminished diversity indicator (see Table 7).

These findings are complemented by the information presented in Table 7. Approximately half of the population resides in areas where the 15-minute indicator is below the city's average. Interestingly, the areas exhibiting the lowest values correspond to both the most economically disadvantaged (SES 1, 2) and the most affluent (SES 5–6) zones of the city. While their diversity indices show similarities, the distinguishing factor between these zones is the considerably higher walkability found in the wealthier areas. A lower diversity score in high SES areas is also associated with a higher land value that limits the number of establishments. In contrast, even though lower SES areas are more affordable, they might not be attractive from a commercial point of view. In summary, the low 15-minute scores encompass the entire urban periphery of Bogotá, along with substantial portions of the low-SES areas. In contrast, high and very high 15-minute index scores predominantly cluster around the eastern edge of the city.

As previously stated, the observed low values of the diversity index stem from the methodology employed for its calculation. These values are indicative of significant spatial disparities throughout the urban landscape. This disparity is not solely attributable to variations between areas of distinct SES but also arises from a considerable imbalance in the proximity to various basic essential needs that have been subjected to analysis.

The proposed analysis has substantively identified healthcare, grocery, and education services as key factors for redefining the livable area, representing 79 % of individual preferences. These services serve as crucial benchmarks for the future design and planning of 15-minute zones. The absence of these services in proximity, which are highly significant for people, negatively impacts the 15-minute index. Integrating the preferences of the population towards the evaluated essential needs requires the estimation of discrete choice models to derive valuation weights for different types of establishments. This integration is important as it introduces heterogeneity into the computation of the 15-minute index across distinct population segments. Our investigation revealed that valuation and preferences exhibit variations based on sociodemographic characteristics, particularly in terms of age group, socioeconomic status (SES), and gender.

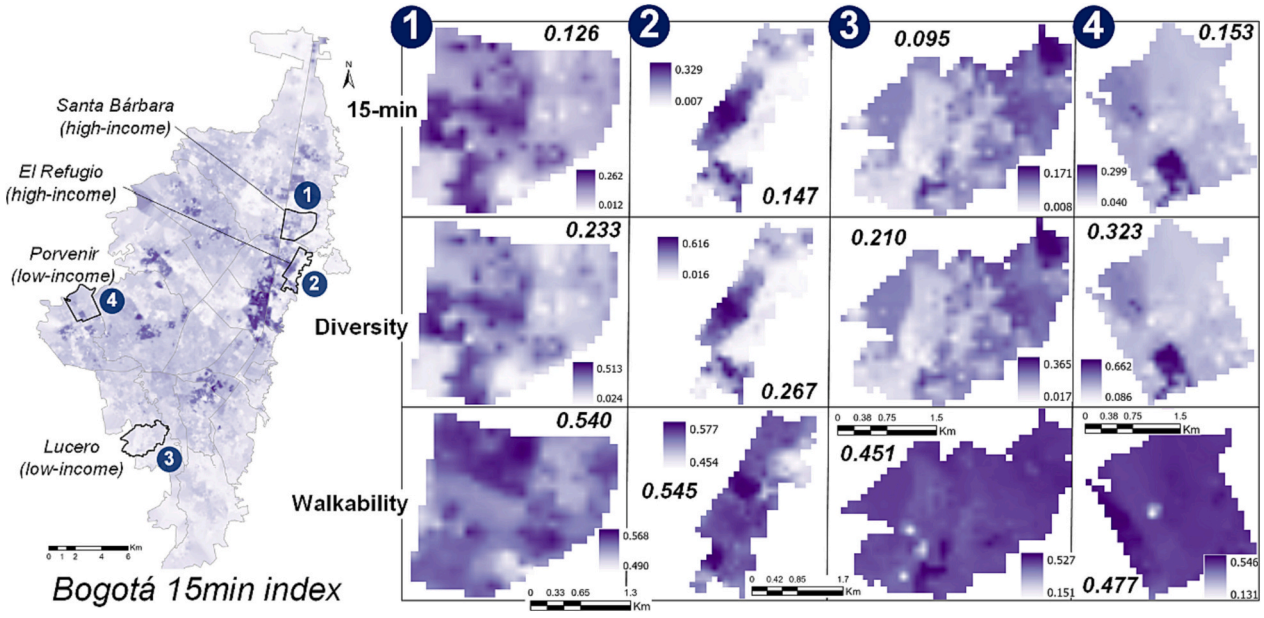

Fig. 6. Analysis by zone.

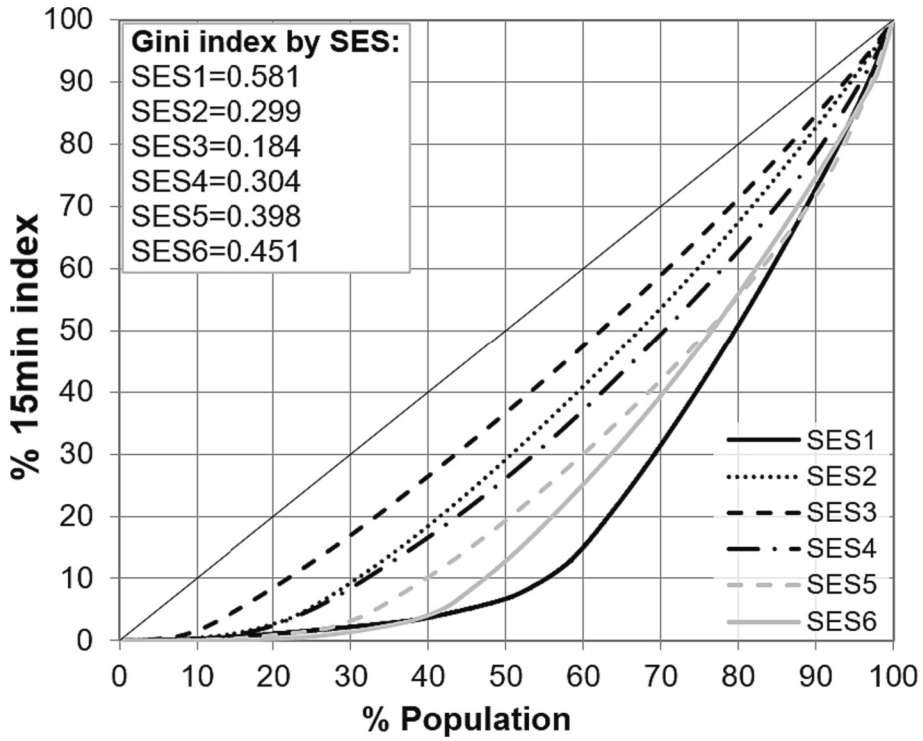

Fig. 7. 15-minute index concentration curve

6. Beyond indicators: livable and inclusive cities

As seen, the 15-minute city concept based on proximity to urban services is not revolutionary for Bogotá. Residents can, for the most part, access essential food shops, drugstores, and basic schools within less than a 15-minute walk from home. The high population density of Bogotá and the absence of zoning that functionally separates activities and land uses allow this proximity. However, our findings invite a reflection on the implicit inequalities of the 15-minute city concept and the pitfalls of its assessment in terms solely of proximity and access to essential services if diversity and population preferences are not considered. Urban and territorial planning should be leveraged to reduce inequalities concerning access to and use of land, public spaces, public services, and urban regeneration. Bogotá's 15-minute inequalities are first highlighted by the distribution of access to different opportunities. First, although most essential services (except jobs) can be accessed, the diversity and quality of such opportunities, which are just as relevant, differ considerably.

The observed configuration of the accessibility environment in Bogotá has been, at least from the perspective of land use, organically developed. Thus it becomes necessary to operationalize accessibility as defined in the New Urban Agenda (UN., 2017), to build upon the

Table 7
Indicators by SES.

SES	% population	Diversity index	Walkability index	15-min index
1	9.5	0.182***	0.456***	0.084***
2	41.1	0.283***	0.470***	0.133***
3	33.8	0.345***	0.500***	0.173***
4	10.1	0.305***	0.521***	0.162***
5	3.4	0.222***	0.528***	0.119***
6	2.1	0.156***	0.531*	0.085***
City	100	0.273	0.483	0.133

Note: Difference in means concerning the SES immediately below using *t*-test for hypothesis testing. SES 1 is compared with SES 2 and so on.
Significance levels: ***p < 0.001 **p < 0.01 *p < 0.05, p < 0.1.

foundations of a proximity-based model for developing a truly equitable and inclusive development. The findings of this paper show that the distribution of a "complete" vs. an "incomplete" 15-minute city cannot be corrected without first incorporating principles of community health, liveability, and well-being into proximity-based urban and territorial models at all scales. In this regard, it is important to recognize that a 15-minute city model may not be applicable equally in cities dealing with consolidated unequal urban structures. This model can become a medium to long-term goal while defining intermediate targets (e.g., 30 min) to be considered in the transition to an inclusive proximity city. This can inform holistic approaches that generate systemic impacts at both neighborhood and city scales.

It is also important to recognize the nuances provided by our findings to academic debates that thus far have concentrated on areas where urban densities and essential infrastructure for efficient and sustainable collective and personal mobility already exist. Although Bogotá boasts high population densities and a mature public transport system, structural inequalities show significant gaps between haves and have-nots, even in an optimistic scenario where the distance to opportunities is one of the main variables of analysis. Insufficient attention has been given to the structural transformations required to apply the concept to peripheral and disadvantaged areas, particularly in cities in the Global South (Guzman, Arellana, et al., 2021). As policymakers, achieving consensus on the type of city that societies require involves complex negotiations of power relationships, resources, and regulations. The vision for a 15-minute city risks remaining a local policy and academic rhetoric unless accompanied by policies addressing the high levels of socio-spatial segregation and inequalities produced by historical patterns of development.

Findings also point to the need for a redistribution of education facilities (mainly higher education) and hospitable within reasonable walkable or cyclable initiatives that mitigate social divides relating to care. This redistribution should prioritize access for lower-income population segments, which prioritize such types of services. Such policies can reduce segregation, promote care-based education, integrate educational policy into community social action, develop critical citizenship, and extend opportunities beyond formal settings. By the same token, the provision of localized urban health care can ensure that primary care and innovative prevention methods are accessible to various urban population groups. Guaranteeing health involves prioritizing water and sanitation, urban planning and design for proximity and equitable access to health services, and promoting active transport in safe and non-polluting conditions.

Understanding that transport is not an end but a derived demand and a facilitator for accessing opportunities, cities are encouraged to adopt transit-oriented development strategies informed by the 7Ds identified in the literature. These strategies should synchronize public transport investments with land-use plans, incorporating various functionalities such as daycare centers, workplaces, shopping areas, and affordable housing around public transport hubs. This cross-sectoral approach can enhance mobility efficiency and offer a chance to address the inequalities inherent in urban spatial structures. Further integrated approaches involve linking development initiatives that enhance healthcare, education, or job training for vulnerable populations with investment in and subsidies for public transport services. The nuanced understanding of these influential services enables us to formulate more targeted and efficient urban development strategies. Within a broader policy framework, these projects can bolster coordination among transport, land-use planning, housing, and other sectors where reducing poverty, inequality, and social exclusion are shared priorities. Addressing imbalances in access to walkable and cyclable infrastructure and public spaces requires enhancing more inclusive approaches to planning within transportation systems.

The findings in this paper show the applicability and operationalizable nature of the 15-minute city concept when approached from a more in-depth consideration of structural conditions and the entrenched inequalities underpinning accessibility. In addition, it demonstrates, through an empirical case study, the relevance of incorporating diversity and perception indicators in the analysis, beyond just proximity. The paper builds on learnings from a wealth of studies on the accessibility topic locally for over ten years to demonstrate its limitations in developing contexts. This is relevant for the international literature insofar as it questions the role of proximity models in urban areas where informality and small-scale economic activities have led to a relatively comprehensive distribution of basic opportunities across the territory. The paper's findings are also replicable using similar available information, on the one hand, using household travel surveys, on the other, although Bogotá has the advantage of the availability of high-quality data, the analysis presented for opportunities can be conducted using open-source information such as that from OpenStreet Maps. The data collected in 2023 for the estimation of weights for preferences of opportunities for different residents can also be replicated and it entails a relatively low-cost method for refining available analyses of accessibility. Overall, the paper's significance stems beyond its specific local relevance, it provides an opportunity to test in practice a popular concept in academic research, using relatively accessible information, and providing insights for many similar cities in a region characterized by segregation and exclusion (Oviedo, 2021).

7. Conclusions

This paper provides a fresh take on the social, economic, and functional realities of Global South cities and their nuances linked with, among other factors, informal employment, and income disparities, in light of a popular concept in the literature such as the 15-minute city. Our paper questions if proximity is enough in contexts where access to quality jobs is highly unequal, the informal sector is ubiquitous and there is irregular income and job insecurity. A first way of addressing such a question is that achieving economic sustainability and equal access to employment opportunities within a 15-minute radius of every resident's home is a formidable challenge in such contexts. Our results suggest that more inclusive analysis requires the incorporation of perceptions and the concept of diversity of services and opportunities into the notion of accessibility and the 15-minute index.

Our methodology takes a critical view of proximity-based models for development that enriches our understanding of the 15-minute concept's core elements. By combining proximity preferences, walking accessibility to basic essential urban services, and pedestrian infrastructure performance, grounded on an in-depth understanding of the entrenched functional and socioeconomic inequalities present in the local context, it is possible to posit more realistic practical and policy implications of the findings. In this regard, although Bogotá meets the 15-minute city objective in its broadest interpretation, we found significant inequalities among different socioeconomic groups in accessing basic urban services, as confirmed by previous works (Guzman et al., 2017; Guzman, Arellana, et al., 2021). However, we go beyond the characterization of opportunities to make reflections on the quality of such opportunities and the implicit inequalities that having more basic

establishments and services, particularly within a model that favors low carbon and active mobility as the main mechanism for accessibility, will have for disadvantaged populations throughout their life.

The paper also enables reflections about the applicability of idealistic visions of development crafted with a present photograph of cities such as European capitals in mind while ignoring the transition pathways they have followed to be in a position to think about a city of proximity. While the 15-minute city concept offers a compelling vision for sustainable and equitable urban development, its application in the Global South faces significant obstacles related to informal settlements, economic disparities, and infrastructure deficits. Recognizing these challenges is essential for policymakers and urban planners as they seek to address urban inequalities in the cities of the Global South. Alternative approaches that consider these cities' unique contexts and needs may be necessary to achieve meaningful and lasting progress towards reducing urban disparities.

This study has limitations that should be considered. First, the methodology is tested only in a specific context. Although the methodology described here is clear and reproducible, it would be interesting to apply it in other contexts and further compare the results. Regarding datasets, the census of establishments dates back to before the pandemic. Indeed, some businesses will have closed or moved locations. Fortunately, this does not affect the proposed methodology or change the essence of the results. As for the results, and although we do not collect information about the parental status, we must be careful with the results of the type that women prefer to be close to preschool institutions. In this case, we argue that this preference of women can be related to the fact that in Bogotá, women are more engaged in caring activities compared to men (Montoya-Robledo et al., 2020). However, the context of these results based on individual preferences can be heavily dependent on other socioeconomic characteristics, which not necessarily would exclusively relate to gender. Despite these limitations, our study also has several strengths. This is the first study in Latin America to critically evaluate the 15-minute concept using individual preferences with a rigorous quantitative design, including individual preferences and walkability. This study used a validated assessment tool to assess the x-minute concept at the block level.

CRediT authorship contribution statement

Luis A. Guzman: Writing – review & editing, Writing – original draft, Supervision, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Daniel Oviedo:** Writing – review & editing, Writing – original draft, Validation. **Victor A. Cantillo-Garcia:** Writing – original draft, Formal analysis, Data curation.

Declaration of competing interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Annex 1. Step-by-step construction of the 15-minute city index
Annex 2. Supplementary material
Supplementary data to this article can be found online at https://doi.org/10.1016/j.cities.2024.104882.

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