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SOCIAL SCIENCE

Combining walking accessiblity measures to map spatial inequalities

Aldo Arranz-López [a], Luis M. Mejía-Macias[b] and Julio A. Soria-Lara [b,c]

[a]Department of Human Geography, Goethe University Frankfurt/Main, Frankfurt am Main, Germany; [b]Transport Research Centre-TRANSyT-, Universidad Politécnica de Madrid, Madrid, Spain; [c]Instituto de Economía, Geografía y Demografía. Consejo Superior de Investigaciones Científicas -CSIC-, Madrid, Spain

ABSTRACT

Evaluating spatial inequalities using a single walking accessibility measure is quite challenging. In response, the paper proposes combining two accessibility measures (real and potential) to provide additional insights into the identification and mapping of spatial inequalities. The municipality of Getafe in the Madrid Metropolitan Area, Spain serves as a case study. A questionnaire, administered via face-to-face interviews, recorded the resident's walking preferences for reaching in-store retail. A gravity-based model was used to calculate real and potential accessibilities, which were combined to map four accessibility places that originate spatial inequalities: advantageous, moderately advantageous, moderately disadvantageous, and disadvantageous. The results suggest that potential accessibility values are higher than real accessibility values, and the final map shows the city centre residents (mostly seniors) benefit from the advantageous accessibility places. Disadvantageous places are mainly found in the city's periphery, where younger people live.

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Social exclusion; travel time; pedestrian; retail; active mobility

1. Introduction

Incorporating equity principles in land use and transport planning is becoming a pressing priority (Boisjoly & Yengoh, 2017; Lucas & Jones, 2012). The accessibility-planning paradigm is a promising approach (Lucas, 2019; Pereira et al., 2017), as the social function of transport largely lies in providing people with minimum levels of accessibility to major destinations, such as workplaces, healthcare facilities, green areas, retail locations (Banister, 2018; Bantis & Haworth, 2020). Since walking is economically accessible for everyone, it is seen as the most universal transport mode. Therefore, planning for accessibility should involve the design of places where destinations are easily reachable on foot (Handy, 2020). This conceptualisation puts walking accessibility at the top of the transport hierarchy to analyse accessibility-based inequalities to reach destinations (Banister, 2005; Tight, 2016).

Gravity-based models are utilised regularly to measure walking accessibility (Vale et al., 2015). Their operationalisation relies on three main components: (1) the geographical distribution of destinations within a reasonable walking travel time (Foth et al., 2013); (2) the existence of a walking network, rather than isolated fragments of walking infrastructure (Bertolini, 2017; Lundberg & Weber, 2014); and (3) the existence of a distance-decay effect that shows how accessibility levels tend to decrease as walking travel time increases. While the first two components of gravity-based models tend to remain constant during static accessibility calculations (e.g. for a specific place and time), it is known that the distance-decay effect strongly vary according to users needs, individual preferences, cultural norms, and socio-economic issues (Ariza-Álvarez, Arranz-López, & Soria-Lara, 2021; Lucas et al., 2016; Páez et al., 2012, 2020). Distance-decay effects are translated into usable functions for gravity-based models through two main approaches: the actual walking time needed to reach destinations, i.e. real accessibility measures (Papa & Coppola, 2012); and the maximum walking time that individuals are willing to spend to reach destinations, i.e. potential accessibility measures (Arranz-López, Soria-Lara, & Pueyo-Campos, 2019a; Sarker et al., 2019).

Higher levels for potential accessibility than for real accessibility would indicate that people are willing to walk more time to reach in-store when comparing to the actual time they spend. For example, two population groups (e.g. adults and seniors) living in the same neighbourhood, where all in-store locations are within 20 min on foot. Adults are willing to walk 25 min to reach in-stores, while seniors are only willing 15 min. Adults would reach all retail locations within their neighbourhood and other retail outside the

CONTACT Aldo Arranz-López arranz-lopez@geo.uni-frankfurt.de Goethe-Universitat Frankfurt am Main, Insitute für Humangeographie, Theodor-W.-Adorno-Platz, Frankfurt am Main, 60325, Germany
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neighbourhood's limits. However, the retail locations further away from 15 min will not be reachable by seniors. This would result in an advantaged situation for adults since they could reach retail even outside of their neighbourhood. From this perspective, the joint analysis of real and potential accessibility may inform transport planners and policymakers about the potentiality of specific places to improve their accessibility levels according to people willingness to reach major locations on foot. Accordingly, using mixed approaches that combine potential and real accessibility would contribute to address accessibility-based inequalities, especially affecting the most vulnerable population groups.

Real accessibility has dominated the evaluation of accessibility-based inequalities (Hahm et al., 2019; Kang, 2016; Millward et al., 2013). However, as accessibility can be measured in several ways, the use of a single approach could result in difficulties for analysing spatial inequalities (Allen & Farber, 2020). The main problem is that actual travel time does not include key accessibility determinants, such as personal characteristics (e.g. age, income), individual preferences, needs, and cultural norms (Dixit & Sivakumar, 2020). In fact, actual walking time might be substantially different from the walking time seen as optimal, resulting in different levels of real and potential accessibility to reach destinations (Van Wee, 2016). An alternative approach that combines real and potential accessibility measures would provide a more comprehensive understanding of accessibility-based inequalities for the following reasons. First, the likely differences between real and potential accessibility may lead to inaccuracies in measuring accessibility when a single approach is used (Bocarejo & Oviedo, 2012; Handy, 2005). Second, potential accessibility can better capture some accessibility determinants, since such potential measures can incorporate individual preferences and social circumstances more easily (Cheng et al., 2019; Martínez & Viegas, 2013). Furthermore, potential accessibility may capture other subjective inequality-generating factors, such as user's travel satisfaction, that real accessibility cannot (Givoni & Rietveld, 2007).

To explore this approach, the paper examines the following research question: *How can real and potential accessibility measures be combined to identify and map spatial inequalities to major destinations?* The empirical analysis is based on a face-to-face questionnaire with 267 residents of Getafe (Metropolitan Area of Madrid, Spain). A gravity-based model is used to calculate both real and potential walking accessibility to in-store retail, one of the urban destinations that generate a higher number of daily travels on foot. Then, the mean value of both real and potential accessibility served as the threshold to combine these two accessibility measures, presented as four accessibility location types: advantageous, moderately advantageous, moderately disadvantageous, and disadvantageous. Finally, the ratio between real and potential accessibility served to map the intensity of the distribution of spatial inequalities across the study area.

The remainder of the paper is structured as follows: Section 2 provides a review of the current state of play of the academic literature on this topic. Section 3 describes the study area, while Section 4 outlines the research design. Section 5 presents the main results, including the final map. Finally, Section 6 closes with a summary of the findings and a few concluding remarks and future research suggestions.

2. Accessibility-based inequalities: a review of approaches and findings

Most previous studies use either real or potential accessibility measures to analyse whether accessibility-related disadvantages exist in different spatial settings. Within the real accessibility approach, Allen and Farber (2020) analyse the link of being socially excluded and real accessibility levels by transit. They use 'dissemination area' (an administrative geographical area of 400–700 inhabitants) as the reference unit to map spatial inequalities originated by accessibility. The research indicated that low-income and zero-car households located outside of major transit corridors show lower accessibility levels by public transport. Delmelle and Casas (2012) evaluate the accessibility disparities by Bus Rapid Transit (BRT) to reach both hospitals and recreational facilities. Real accessibility indicators, mapped at neighbourhood level, revealed accessibility-based inequalities for hospitals but not for recreational facilities. Another example comes from Helbich et al. (2017), who evaluate inequalities in walking accessibility to food supermarkets. Proximity measures, reflecting the actual distance from each origin to the closest supermarket, were deployed on a grid of 100 m cells. The results suggest that no evidence of accessibility-based inequalities exist. The studies using real accessibility had an important limitation due to the lack of specific measurements of the maximum range of reachable places according to individual preferences and social circumstances. This 'potential accessibility' is seen as key for identifying accessibility-related inequalities (Pereira et al., 2017).

An alternative approach to real accessibility is to measure potential accessibility. Several alternative approaches seek how to measure potential accessibility. Martínez and Viegas (2013) suggest assessing decay functions according to what individuals consider 'closer' or 'farther'. Furthermore, other authors propose assessing decay functions according to the maximum walking time-willingness to reach the desired destinations, rather than the actual travel time (Sarker et al., 2019). For example, Ariza-Álvarez et al. (2021) used potential accessibility measures (rectangular grid of 100 m cells) to examine walking accessibility variations between different groups of older adults, finding no significant differences in walking levels to groceries between the groups. The common limitation of the reviewed studies is that they use a single approach (real or potential) to identify and map spatial inequalities originated by variations in accessibility levels. To overcome this issue, this research proposes the combination of two accessibility measures: real and potential accessibility.

3. Study area

With 183,374 inhabitants, Getafe is one of the largest municipalities in the Madrid Metropolitan Area (Figure 1). Over the last ten years, local authorities have introduced significant changes, guided by the clear goal to encourage walking accessibility to major destinations, including daily and non-daily in-store retail.[1] Notable examples include the pedestrianisation of much of the historical centre; the widening of sidewalks; and the creation of walking routes that link major destinations (PMUS, 2008). Spurred on by the notable successes – walking became the dominant transport mode for shopping trips (56%) – local authorities are seeking to further incentivise walking by activating various retail-oriented initiatives (e.g. discount campaigns, public funds supporting loyalty campaigns, renovating small shops, etc.).

4. Research design

4.1. Data gathering and sample characteristics

The data gathering process consisted of a face-to-face questionnaire and a spatial database. The questionnaire was administered from December 2019 to February 2020 with a total of 267 respondents. The first part documents socio-economic and demographic characteristics (age, gender, employment status, educational level, monthly household income, and car availability). The second records the respondents' actual walking time (in minutes) to daily and non-daily retail destinations (real accessibility) as well as their walking time-willingness (potential accessibility). Table 1 shows a summary of the main data obtained from the questionnaire. The research team continually encouraged participants that they quantify both their actual time and their willingness to reach in-store retail. Based on this information, distance-decay functions to in-store retail were obtained and processed into indicators for real and potential accessibility, according to a gravity-based model (Section 4.2).

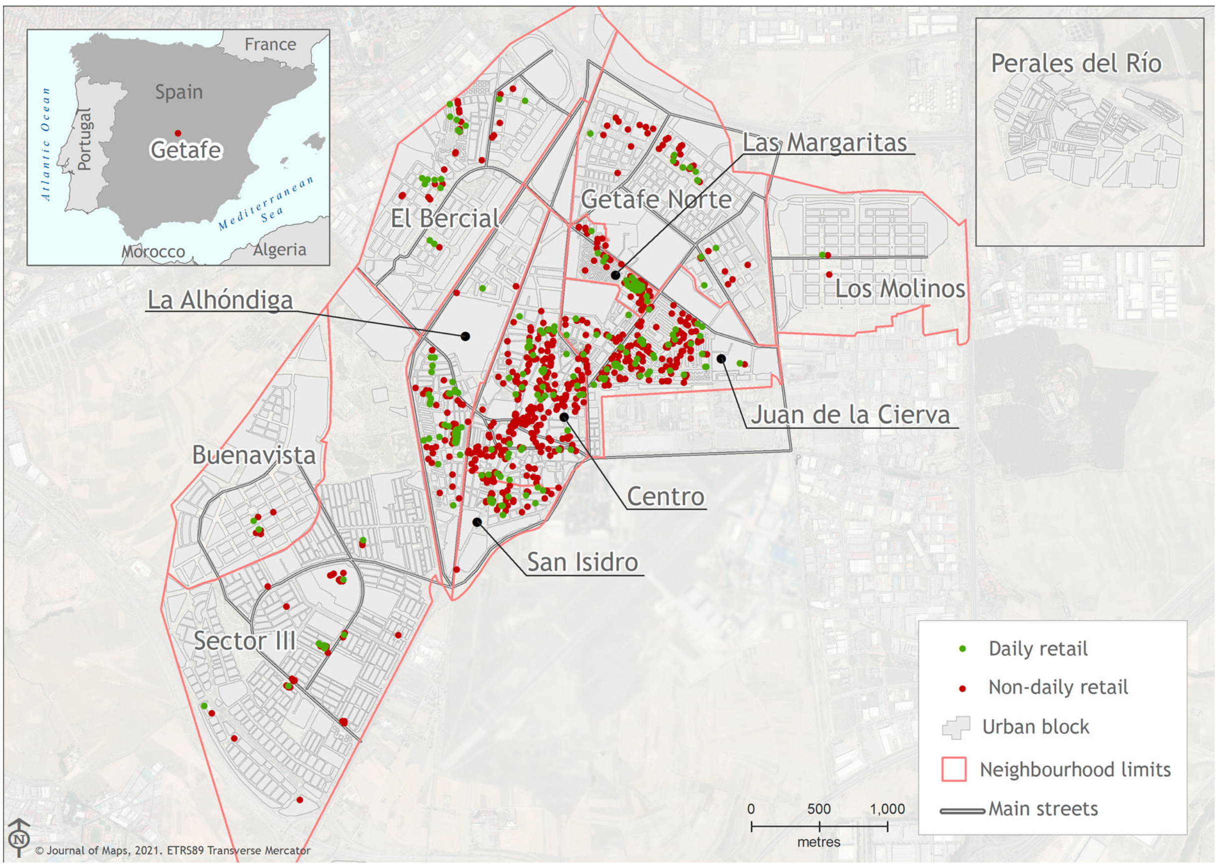

Figure 1. In-store retail location across Getafe's neighbourhoods.

Table 1. Sample's descriptive statistics.

	N	%	Mean
Socio-economic characteristics			
Age			33.34
Gender (female)	133	49.81	
Employment status			
Employee	180	67.42	
Unemployed	79	29.58	
Retired	8	3.00	
Educational level			
Primary school	7	2.62	
High school	132	49.44	
University degree and higher	128	47.94	
Monthly household income (€)			
Less than 1,000	60	25.42	
1,000–1,999	88	37.29	
2,000–2,999	59	25.00	
3,000–5,000	25	10.59	
More than 5,000	4	1.69	
Car availability			
Yes	165	61.80	
No	102	38.20	
Walking travel times (minutes)			
Walking time to daily retail			
Actual walking time			7.97
Walking time-willingness			15.06
Walking time to non-daily retail			
Actual walking time			36.04
Walking time-willingness			22.67

The spatial databases included a street network, retail locations, and a hexagonal grid. The street network, sourced from the Spanish National Centre of Geographic Information, was used to operationalise real and potential walking accessibility calculations. Retail locations were digitised from a 2016 retail directory developed by the Getafe's Local Development Agency, cross-checked with information from retail corporate websites, and classified according to two types: daily retail and non-daily retail. Finally, a hexagonal grid with 892 cells (each representing 75 metres) was built in ArcMap to integrate all the information. Different hexagon sizes were previously tested, including 25, 50, 75, and 100 metres. It was seen that a 75 metres size was the most suitable hexagon to show accessibility patterns in the case study, as a right balance was obtained between geographical resolution and variations in walking travel time declared by participants.

4.2. Calculation of real and potential walking accessibilities to retail

A gravity-based model was used to calculate real and potential walking accessibility. The equation is formulated as follows:

$$A_i = \Sigma_{j\neq i} E_j e^{-\beta X_{ij}}$$

where A_i is the accessibility for zone i; E_j is the number of stores at destination j; X_{ij} is the distance between origins and destinations, along the street network; and β is a parameter of the equation derived from the distance-decay function. The distance (X_{ij}) was calculated from each origin (the centroid of each hexagonal cell) to all other destinations in the study area.

Distance-decay functions were empirically based on the walking travel times declared by respondents (Table 1). Such functions adopted the negative exponential form shown in Figure 2 (Arranz-López et al., 2021; Iacono et al., 2008; Papa & Coppola, 2012). For real accessibility, β parameter was based on actual walking time declared (Table 1), while β parameter for potential accessibility relied on walking time willingness (Table 1). Four β parameters were obtained based on distance-decay functions equations, including one β value for each type of accessibility (real and potential) (Table 2).

Four accessibility maps were produced: two for real accessibility to daily and non-daily retail, and for potential accessibility. The two maps for each accessibility were summed to provide the total accessibility value for each type. The resulting maps provide the basis for identifying and analysing walking accessibility places (Section 4.3).

4.3. Identification of walking accessibility places

The mean values of total real accessibility and the total potential accessibility were used as thresholds to identify different walking environments (Figure 3) (Arranz-

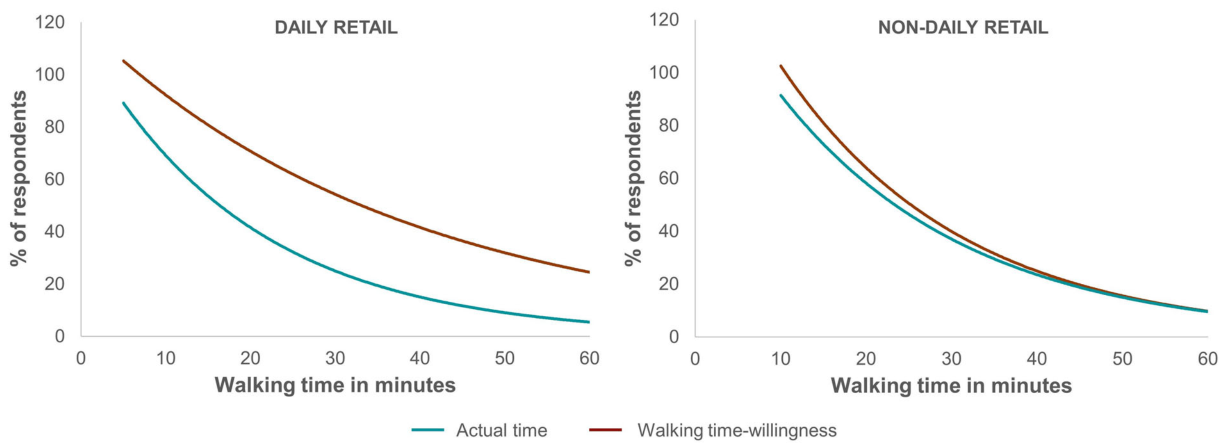

Figure 2. Distance-decay functions for real and potential accessibility.

Table 2. β values for each accessibility and retail type.

	Daily retail	Non-daily retail
Real accessibility	−0.051	−0.027
Potential accessibility	−0.045	−0.047

López, Soria-Lara, Witlox, & Páez, 2019b; Guzman et al., 2017). The rationale underlying this conceptual figure is that values above the mean for both real and potential accessibility result in an advantageous accessibility place. This is mainly due to they are places accessible on foot, and people would be willing to reach them even if they were further from the origin. In the case of intermediate situations i.e. the moderate accessibility places, having a potential accessibility above the mean is considered as the most advantageous position, since people's willingness to reach retail on foot would be higher than the time they have currently to walk. On this basis, four walking accessibility places were identified (see Figure 3).

(i) *Advantageous accessibility places*: Characterised by high values for both real and potential accessibilities, these places are usually found in the inner areas of the city, marked by high residential and retail land use mix. Both daily and non-daily retail are present, and walking is a recurrent mode to complete shopping activities.

(ii) *Moderately advantageous accessibility places*: Low values for real accessibility and high values for potential walking accessibility result in areas with moderate daily and non-daily retail opportunities. Despite the considerable time needed to reach shops, most people are willing to visit these locations on foot.

(iii) *Moderately disadvantageous accessibility places*: Characterised by high values for real accessibility and low values for potential walking accessibility, these locations are distinguished by the predominance of single-family real state over buildings with dedicated retail space. This land use presents difficulties to reach in-store retail on foot, and motorised modes dominate shopping activities.

(iv) *Disadvantageous accessibility places:* With low values for both real and potential walking accessibilities, these places mainly host single-family houses. In-store retail is almost non-existent, and walking to shops is not practical or even possible.

The conceptual model showed by Figure 3 might result in a bi-dimensional legend. However, spatial variations with different intensities for each of the above-described accessibility places are expected. With the aim to map such variations, the ratio between real walking accessibility and potential walking accessibility levels for each of them was conducted. Finally, each accessibility place was divided into two categories by using a quantile classification, as this data classification technique adequately shows a balance between geographical resolution and accessibility patterns in the case study. Within this framework, the 2-dimension legend was transformed into a 1-dimension legend to facilitate the visualisation of variations in internal intensity.

5. Results

This section shows the spatial distribution of real and potential walking accessibility (Figure 4a and Figure

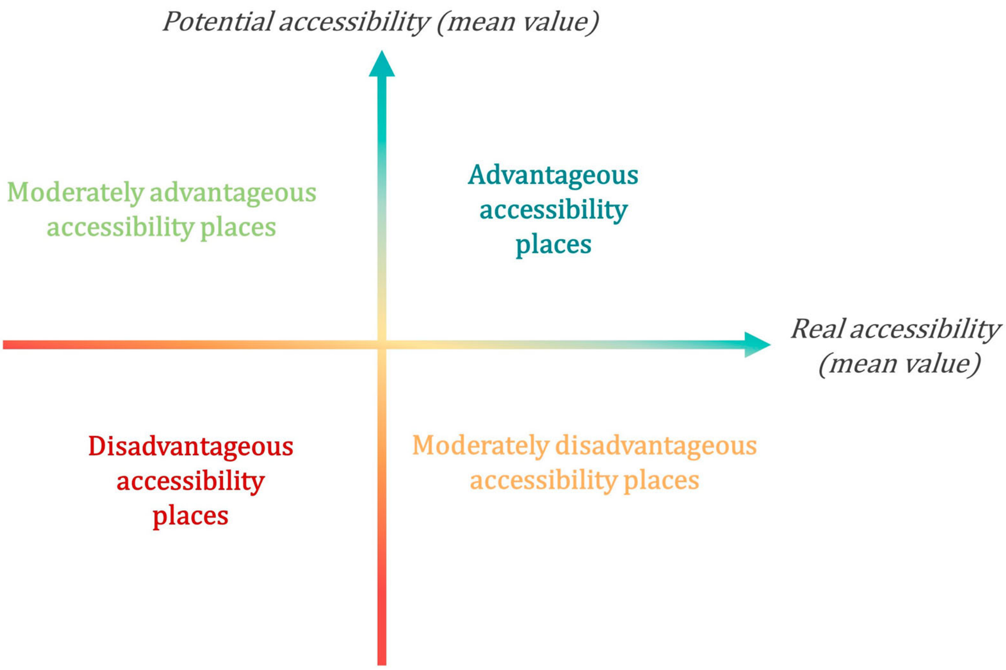

Figure 3. Conceptual representation of the four walking accessibility places.

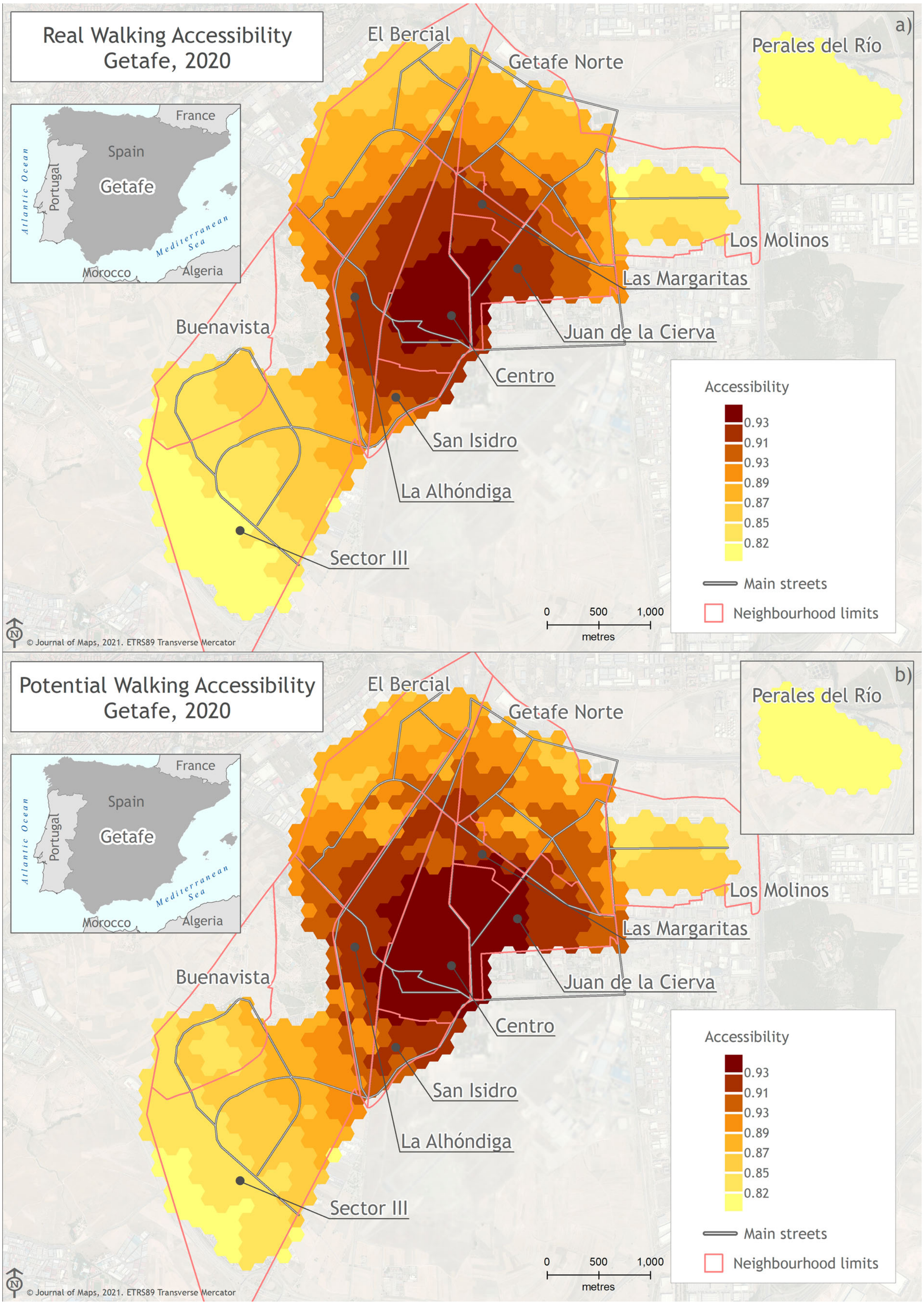

Figure 4. Real and potential accessibility to in-store retail.

4b, respectively), detailing the main spatial differences. It also presents the final map of the distribution of accessibility places in closing (Figure 4).

5.1. Real and potential walking accessibility

Mean values of real and potential walking accessibility were very similar (0.85 and 0.87 respectively) and

Figure 4 shows how they followed a similar spatial pattern in Getafe. However, the higher values for potential accessibility might indicate that the participants' maximum willingness to reach retail locations on foot was almost always higher than the actual time spent. This is particularly true for daily retail, while less evident in the case of non-daily retail. At spatial scale, it was seen that potential accessibility was higher than the real accessibility in neighbourhoods such as La Alhóndiga, Centro, Juan de la Cierva, and Las Margaritas, which are distinguished by large and diverse in-store retail locations. For example, the retail gallery C.C. Getafe II, located between Las Margaritas and Juan de la Cierva, houses a large number of both daily and non-daily stores. This might create better accessibility perceptions among residents, leading to higher willingness to walk.

Despite this general pattern described above, it should be highlighted that the real accessibility values of some locations where higher than those for potential accessibility, for example, in Las Margaritas, La Alhóndiga, El Bercial, and San Isidro. Finally, lower levels for both real and potential accessibility were found in the outskirts of Getafe. [2]Figure 3 shows that the differences between the two accessibility levels were lower in the periphery than in the city centre. This may be because of the urban and retail characteristics of those areas would not favour walking as the primary mode. For example, land use in Sector III and Buenavista is based on single-family homes and residential developments highly dependent on a single shopping centre, mainly accessible by car (Asamblea ciudadana de Getafe, 2015).

5.2. Walking accessibility places

The spatial distribution of the four walking accessibility places described in Section 4.3 is depicted in the final map (Figure 5). Comprising 60.23% of all analysed cells, advantageous accessibility places dominate in Getafe. They are mainly located in traditional neighbourhoods (e.g. Centro, La Alhóndiga, Las Margaritas, Juan de la Cierva), marked by pedestrian streets and a well-connected network of wide sidewalks. Furthermore, both small and medium-size retail are present, with considerable store diversity (e.g. food, clothes, health). An important aspect to highlight is that these locations are mainly inhabited by seniors (around 80% of the total population) (Asamblea ciudadana de Getafe, 2015). Ensuring adequate walking accessibility levels was seen as key for this vulnerable population group, as they may face physical limitations to walk longer times or to access alternative transport modes such as cars.

Moderately advantageous accessibility places were found in only 6.54% of cells, mostly in El Bercial and Getafe Norte. Characterised by low real and high potential walking accessibility values, they are transition areas between advantageous and disadvantageous accessibility places. Retail opportunities are moderate, and mainly families with small children live there. Parents usually face time and resource constraints due to childcare, and the lower retail supply could pose additional constraints for those with a low willingness to reach retail on foot. Additionally, this could also originate a shift from walking to the car as the primary transport mode for shopping purposes.

The moderately disadvantageous accessibility places, noted in only 2% of cells, were the least present type. Characterised by high real and low potential walking accessibility values, they are found in sparse spots between the Buenavista and Sector III neighbourhoods. Sector III neighbourhood is one of the most populous in Getafe, where single-family houses are common (Asamblea ciudadana de Getafe, 2015). Due to the urban configuration and despite the higher walking time-willingness, in-store retail was not close enough to be reachable on foot.

Finally, disadvantageous accessibility places represented almost one-third (31.22%) of cells. Distinguished by low real and low potential walking accessibility values, they were mainly found in the municipality's outskirts (e.g. Sector III, Perales del Río, Los Molinos). While the urban characteristics were quite similar to the moderately disadvantageous accessibility places, retail in these places was practically non-existent. As a result, people living there would experience the most disadvantageous situation in terms of accessibility. Nevertheless, it must be noted that the most common population group living there was young people (17–30 years old) with access to a car (Asamblea ciudadana de Getafe, 2015). Due to the lack of retail, most people did their shopping after work in other municipalities throughout Madrid. Finally, it must be considered that some neighbourhoods (e.g. Los Molinos) are still being developed and have weak retail offerings.

6. Conclusion

While a growing number of studies address the analysis of accessibility-related inequalities, the dominant approach is still to use a single indicator, either actual, recorded, or assumed travel time (Achuthan et al., 2010; Cubbin et al., 2012; Hahm et al., 2019). However, and considering that accessibility can be measured in multiple ways, it has been argued that the identification of spatial inequalities originated by accessibility would benefit from using several accessibility measures (Allen & Farber, 2020). The paper presents a methodological framework that combines two complementary walking accessibility measures: (1) real walking accessibility, which indicates the actual

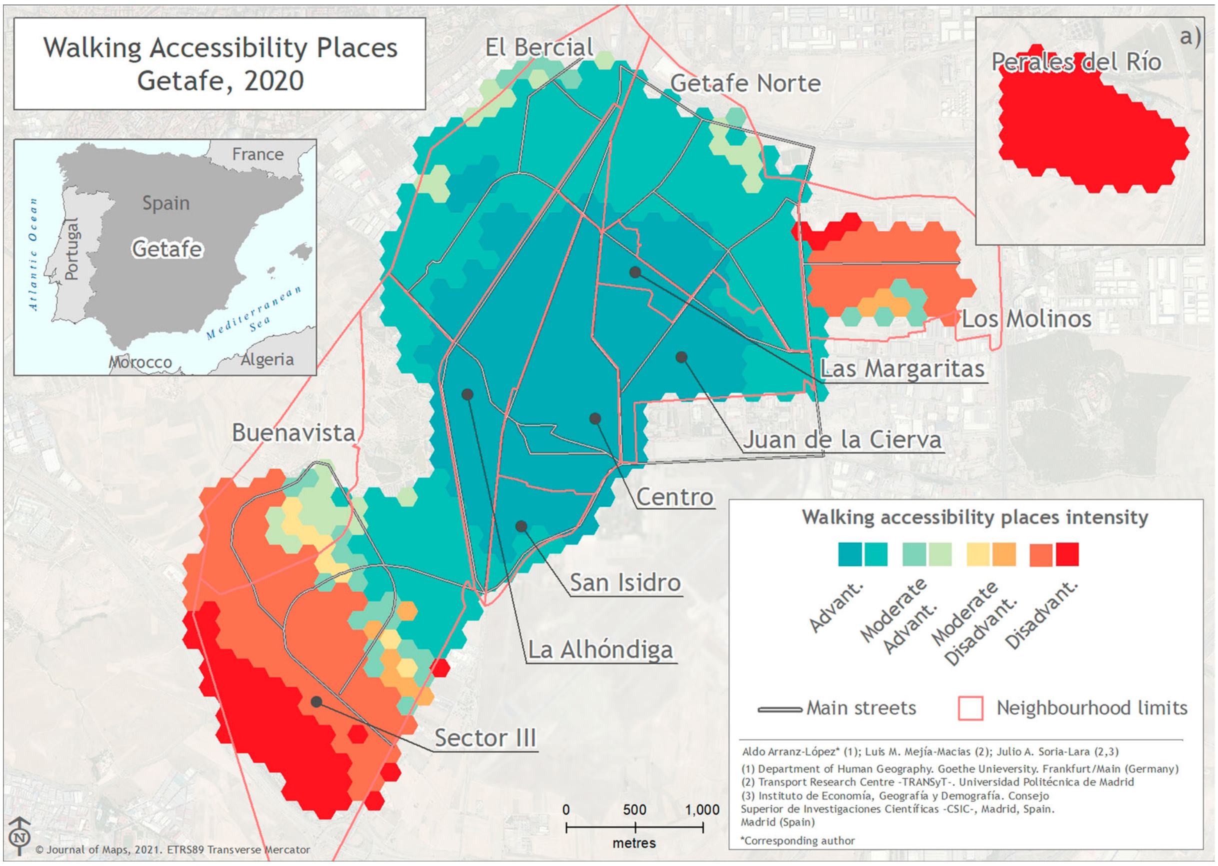

Figure 5. Accessibility places in Getafe.

time that people have to walk to reach retail; and (2) potential accessibility, which denotes the maximum time that people are willing to spend to reach retail locations on foot. By combining these accessibility measures in a study of Getafe (Madrid, Spain), we could identify and map four accessibility places: advantageous, moderately advantageous, moderately disadvantageous, and disadvantageous.

The obtained results show that potential accessibility levels are generally higher than real accessibility levels across Getafe. This result in a higher percentage of advantageous and disadvantageous accessibility places, while the moderately advantageous and moderately disadvantageous places are identified less frequently. Despite these results can be expected, gain insights into the differences between real and potential accessibility measures may allow the identification of valuable walking time thresholds for choosing optimal in-store locations during planning processes. Moreover, the obtained results can be useful for practitioners to identify specific places to find the right balance between actual walking and the maximum willingness to reach in-store on foot.

Possibly, Getafe's proximity to a big city such as Madrid may explain the spatial configuration of these accessibility patterns, especially for non-daily retail. In this respect, three main assumptions must be considered. First, it is expected that people travel to Madrid to buy non-daily goods due to the more prominent retail supply. Second, shopping tasks could be associated with other activities (e.g. leisure, food, family visits) usually carried out during the weekend days. Third, a substantial share of Getafe residents work in Madrid and might do their shopping on their way back home from work. To validate the proposed methodology, further research should aim to replicate results in larger urban contexts with higher spatial heterogeneity than Getafe, where the real accessibility could significantly differ to the potential accessibility levels. Furthermore, a number of relevant issues can be considered for future studies. On the one hand, accessibility analysis could be enriched by applying Huff models, which estimate the likelihood that a consumer visits a specific retail area according to the time to reach that area, its attractiveness, and the attractiveness of other available alternatives. On the other hand, the use of a more complex legends (e.g. bi-dimensional legends) capable to show the internal variations of accessibility places. It will yield a different and richer cartography.

Software

ArcMap 10.8.1 was used for calculating the network-based origin-destination cost matrix and elaborating the final map. A customised RStudio script was used for calculating real and potential accessibility.

Data availability statement

Since the data that support the findings of this study are part of a current research project, data will be available from the corresponding author, AAL, upon reasonable request.

Note

1. Daily retail includes corner shops, fruit and vegetable, fish, bakery and butcher's shops. Non-daily retail includes travel agencies, beauty and cosmetics, electronics and informatics, pharmacies, bookshops, pet shops, fashion and accessories.

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ORCID

Aldo Arranz-López http://orcid.org/0000-0002-6635-1386
Julio A. Soria-Lara http://orcid.org/0000-0002-2383-6332

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