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The X-Minute City: Analysing Accessibility to Essential Daily Destinations by Active Mobility in Seville

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Abstract: The concept of the "x-minute city" emphasises connected, mixed-use, and functionally dense urban areas where residents can access most daily necessities within a short walk or bike ride. By promoting proximity to essential destinations and sustainable transport options, this approach reduces the need for extensive travel and minimises environmental impact. This paper analyses the readiness of cities to function as x-minute cities and identifies necessary interventions. Using a reproducible and scalable methodology based on open data and software, the study assesses the accessibility of key urban amenities within specified timeframes. Cumulative accessibility metrics are calculated for different destination categories, considering both walking and cycling. In the case of Seville, accessibility requirements outlined in policy documents are already met for many essential services, particularly public facilities. The study identifies neighbourhoods that excel in accessibility and others that require improvement in adhering to x-minute city principles. The methodology and findings can inform planning and policy decisions in other cities, guiding efforts to enhance amenity provision, test accessibility scenarios, and target intervention areas.

Keywords: x-minute city; accessibility analysis; sustainable urban mobility; methodological overview; open data

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1. Introduction

Due to the COVID-19 pandemic, the demand for compact, mixed-use, multi-centred cities that provide easy access to amenities where most daily activities can be carried locally has unexpectedly increased [1]. Among various potential solutions, the 15-minute city concept aims to address these challenges by proposing a self-explanatory, yet flexible, urban planning concept where most everyday essential destinations should be available within a 15-minute-long walking or cycling trip. Similar urban planning concepts have been also emerging recently, such as the 20- and 30-minute neighbourhoods.

The concept of the x-minute city or neighbourhood is an innovative approach that highlights the importance of access-oriented planning. (We refer to the x-minute city or neighbourhood concept as a general term that covers various concepts of chrono-urbanism such as the 15-minute city or 20- and 30-minute neighbourhoods. These related concepts are discussed later in this paper.) Due to the communicability and pragmatism of the concept, the x-minute city has the potential to drastically change the perspective of contemporary urban and mobility planning by catching the attention of policy makers or the public. The concept introduces a spatiotemporal dimension to policy measures and allows the monitoring of the current state and the evolution of accessibility in the city for different types of amenities or for different user groups and needs. The adoption of the x-minute city principles has direct effects on mobility, both in terms of demand and supply, and can constitute an important element of local transport policy. The x-minute city concept can be an effective tool for combatting urban sprawl, reducing the need for long daily travel, and, thus, meeting the emission reduction targets.

Currently more than half of the world's population live in urbanized areas, and it is estimated that this figure will increase to 60% by 2030. The current figure for the European Union is 75%, while for Spain, it is 81% [2]. The growing land consumption of cities is even more dramatic than the growth of the urban population. For a sample of cities in developed countries between 1990 and 2015, the expansion of urban areas (1.8-fold) in relation to the growth of the urban population (1.2-fold) increased by a ratio of 1.5. At the same time, cities also generate 70% of global carbon emissions and account for two-thirds of the global energy consumption. As a reaction to these trends, the World Cities Report 2020 [3] suggests that cities should act. Cities play an important role in the transition towards more efficient and less excessive land use; furthermore, cities can take more efficient actions to respond to climate change and to create more equitable and affordable living places for people.

After signing the Paris agreement [4], the European Union set the goal in the European Green Deal of decreasing greenhouse gas emissions by at least 55% compared to 1990 levels by 2030 and becoming climate-neutral by 2050 [5–7]. Among other efforts to decarbonise cities in Europe, the Cities Mission aims to deliver 100 climate-neutral and smart cities by 2030 [8]. The need for travel and for commuting longer distances in cities inspired by modernist urban planning concepts causes various problems, such as car dependency, congestion, and air and noise pollution, which consequently affect health and the living quality of cities [1,9]. Reducing these negative effects of urban mobility is also under the scope of policy making in the European Union; these objectives are defined by the New EU Urban Mobility Framework [6].

Climate change mitigation and energy-efficient transitioning are two of the most urging issues of urban mobility. In cities with optimum density and urban structure, infrastructure can be developed and operated more efficiently, and the provision of public and private services can be optimised, as well as the transport demand amongst many other human activities [10]. Consequently, such efforts can contribute to the reduction of energy consumption and the environmental impact of cities.

In this paper, the potential applicability of the x-minute city concept is analysed through the example of a Spanish city: Seville. The main objectives are the following: (1) to explore how the x-minute city is defined or implemented by researchers and decision makers; (2) to develop and showcase a methodology to assess to what extent cities are prepared to function as x-minute cities; and (3) to understand what interventions are needed to meet the x-minute city requirements. To answer these research questions, we developed a reproducible and scalable quantitative methodology using open data and open-source software to assess whether key urban destinations are accessible within the given timeframe. This approach helps us to identify and investigate patterns that characterise accessibility to various public and private services in the city. To test the presented methodology, we assess and describe to what degree the city of Seville meets the x-minute city criteria, considering the current situation (current location and distribution of services and transport infrastructure) as a baseline for future potential developments. The methodology and the results of this work can contribute to policy and decision making to identify development needs regarding the provision of essential amenities and the introduction of the x-minute city concept. The results can be used to identify patterns that characterise the accessibility to various public and private services in cities. The effects of scenarios for developing accessibility (transport infrastructure or service provision improvements) can be also assessed. The present paper contributes to the state of the art by presenting a reproducible methodology and literature review to facilitate the assessment of compliance of cities in terms of the spatial accessibility principles of the x-minute city concept. The presented scalable and reproducible methodology can be applied in other cities due to its modest data and computational needs, and it can be used to compare the characteristics of different cities in terms of the x-minute city principles.

The present paper is structured as follows. After the present Introduction section, the related literature is discussed, focusing on the main principles and the operationalisation of the x-minute city concept. In the following section, the introduced methodology is discussed. In the subsequent sections, the application of the methodology is showcased through a case study, including a discussion on the results.

2. Literature Review

2.1. The X-Minute City Concept

The concept of the 15-minute city in Europe is among the most prominent interpretations of contemporary urban planning concepts that puts particular emphasis on temporal access. In our understanding, the x-minute city principles can be generalised as a concept that covers various similar concepts such as the 15-minute city or 20- and 30-minute neighbourhoods. We introduce the x-minute city concept dominantly, but not exclusively, through the principles of the 15-minute city concept, which has a well-documented theoretical framework and a wide range of literature.

The 15-minute city concept, in essence, covers the idea of highly accessible, mixed-used, and connected cities where most daily needs can be reached via a short trip (preferably by walking or cycling) not taking longer than 15 min. In such cities, function density and transport options allow their residents to travel less to meet their daily needs and to access most activities that are required for good living [11]. As Moreno [12] defines, the 15-minute city can be framed within the broader concept of chrono-urbanism [13], which addresses in depth what services a city can offer to its residents for the use of their time. As Moreno argues in his philosophical reasoning [12], time has become a limited resource, and cities of proximities and short distances can help people to save time on travelling and to make better use of time.

As Moreno et al. [1] claim, the 15-minute city was initially introduced by Carlos Moreno in 2016. Moreno acknowledges [14] that he was inspired by the well-known work of Jane Jacobs [15]. Moreover, the concept of the 15-minute city builds on various planning principles that encourage the mixed-used development, diversity, and proximity of urban functions [16] such as the Neighbourhood Unit introduced by Perry [17] or New Urbanism [18]. Such concepts are referred to as proximity city concepts by Alberti and Radicchi [19], who introduce similar historic and more recent urban planning concepts to the 15-minute city. The 15-minute city concept can be a good complementary or framing concept for various contemporary movements that aim to reclaim and revitalise public spaces and to promote people-centred urban design (such as the work of Jan Gehl [20]), highlighting the importance of green, walkable, liveable, active cities or slow life [14].

Moreno et al. [1] introduce four dimensions that should frame the development of a 15-minute city: density, proximity, diversity, and digitalisation. Proximity to daily destinations, both by temporal and spatial interpretation, is crucial to allow people to reduce their travel time while fulfilling all their needs. This can be achieved with optimal function and population densities, which also create a good balance of economic, social, and environmental benefits of mixed-used areas. Besides that, diversity should be considered as well. Different types of destinations and functions should be in a healthy mix (mixed-used neighbourhoods with residential, commercial, and leisure components, among others), while the mix of cultures and people with different socio-economic backgrounds is also important to create inclusive and liveable cities. Digitalisation and emerging collaborative and flexible working spaces can further facilitate the successful implementation of the concept [21]. For example, regular teleworking or online shopping allows people to commute and travel less. Pozoukidou and Angelidou [22] and Büttner et al. [23] further detail the principles of the 15-minute city.

Papadopoulos, et al. [24] discuss the results of their systematic literature review on 15-minute city applications in a more recent publication. Additionally, Lu and Diab [25] provide an overview on how North American and Australian cities define and operationalise the x-minute city concept and discuss their policies and potential measures.

The 15-minute city became widely well known during the 2020 mayoral election campaign in Paris, when the implementation of the concept of the “ville du quart d’heure”, the quarter-hour city, became a central issue [26]. The 15-minute city is an emerging concept that is applied or planned to be applied in various cities. For example, a comprehensive analysis on five cities was carried out in Ireland in 2021 [27]. The development plan of the city (Official Plan) of Ottawa, Canada, also integrates the concept of building walkable, 15-minute neighbourhoods [28]. The 15-minute city concept is popular in the Spanish context as well. The applicability of the concept has been examined in Barcelona [29], Madrid [30], and Malaga [31]. Seville is also considering integrating the principles of the concept [32]. Further examples can be found in a project document delivered under the Driving Urban Transitions Partnership, which gives an overview on cities that are in the process of implementing 15-minute city policies worldwide [23].

The 15-minute threshold frames the concept; however, it should be tailored to the local context in such areas as urban morphology, urban dynamics, and the needs of people living in the city [1,14]. Besides the 15-minute timeframe, many researchers and urban development policy focus on other thresholds, especially from the Anglosphere and in cities that have a long tradition of car-oriented urban planning (see, for example, [33]).

One of the earliest adoptions of chrono-urbanism in this context is the Portland Plan [34], which is the long-term development strategy of the city of Portland, Oregon. The plan is framed by the idea of creating 20-minute neighbourhoods, where residents can reach daily activities within 20 min (ideally by walking, but also by cycling, by public transport, or, alternatively, by car). One year earlier, as part of the implementation of the Community Climate and Energy Plan, a 20-minute neighbourhood assessment was carried out in Eugene, Oregon [35]. The 20-minute neighbourhood is part of the long-term development plan of Melbourne as well [36]. One of the main priorities of the Future Transport Strategy of Greater Sydney is the 30-minute city [37]. Due to the variety of these concepts, they are also referred to as the x-minute city or -neighbourhood concept in the literature (see for example [38]).

The concept of the x-minute city received increased interest during the COVID-19 pandemic. Travel restrictions and a reliance on local amenities due to confinement measures highlighted the importance of easily accessible daily services [1,39–41]. Besides the short-term benefits of the implementation of the concept during such a crisis, various medium- and long-term effects can be expected.

The x-minute city is a responsive urban planning concept to various contemporary urban challenges, and, as such, it is a potent solution for urban sustainability transition [1,14,23]. People-oriented urban planning principles, the creation of places for interactions through the revitalisation of public spaces, participatory planning, and decision making can improve social cohesion, and form and engage local communities [22], and, as a result, it can improve general well-being [42]. The positive health impacts of regular physical activity, such as walking and cycling, are also considerable [43]. Positive environmental impacts and a reduction in air and noise pollution can be expected by the uptake of active mobility [44], while additional benefits make the x-minute city concept a potential tool for creating climate-neutral cities [14]. The concept can also offer economic benefits by potentially boosting the local economy and local spending, among other benefits, as discussed by Büttner et al. [23]. However, there are potential drawbacks of the x-minute city as well, especially if the concept is adapted in such a way that social threats are not addressed by effective measures or policies. The 15-minute city concept is often criticised for being elitist, and its implementation could contribute to gentrification or higher housing expenses. Therefore, affordable housing and social inclusion must be considered to avoid the marginalisation of vulnerable groups and gentrification [23,45–47]. To create more vital and inclusive cities by the implementation of the 15-minute city principles, the needs of disadvantaged groups must be considered, and the potential social threats (e.g., risk of social isolation or inadequate service access) and inequities must be addressed (including socio-economic inequalities and people's physical characteristics or age) [48].

2.2. Main Dimensions of the X-Minute City Relevant for the Present Paper

Based on the previous section, we define the x-minute city concept as an urban planning principle where the aim of development is to provide access to the most commonly visited daily destinations within a pre-defined time threshold that is adapted to the local needs. To operationalise the x-minute city, the following should be considered:

- A list of destinations or amenities (D_d) that should be accessible in an x-minute city has to be defined;
- The analysis should be restricted to those modes of transport (M_m) that people would preferably use in the x-minute city;
- Potential indicators that can be used to quantify the x-minute city should be reviewed.

There are various research papers that have analysed the adaptability of the x-minute city concept. Besides the policy documents that were mentioned in the previous sections, research papers were reviewed with the aim of understanding how the x-minute city concept is operationalised in different contexts and to explore the methodologies they use.

The identification of essential amenities for daily life is a core part of the analysis presented in this paper. The six main categories of living, working, commerce (supplying), healthcare (caring), education (learning), and entertainment (enjoying) were identified by Moreno [49] and Moreno et al. [1] for the 15-minute city. Most of the papers that analyse the applicability of the x-minute city or -neighbourhood concept focus on a wide spectrum of services and cover mostly similar categories. The list of the reviewed papers from the literature with the considered types of destinations can be found in Appendix A. Although there are major differences in the characteristics of the reviewed cities, no major differences can be observed in the amenity categories. The differences lay more in the methodology of the analysis and in the number of different amenity types that are considered in each of the groups of amenities. For example, most of the reviewed works consider accessibility to public transport, walking and cycling infrastructure, and shared micromobility, while car sharing and assisted mobility are considered in one study only [27]. Access to data regarding the location of workplaces is generally more limited compared with other categories. Therefore, the category of working is not considered in most of the reviewed papers.

Regarding the mode of transport, Moreno et al. [1] suggest that the 15-minute city should be planned for walking and cycling. Most of the reviewed papers cover only walking as a mode of transport to access services in the x-minute city and often apply a universal speed of walking in their analysis for simplification. Although this simplification can be beneficial for lower computational requirements or make communicating the results easier, a more sophisticated approach is to model the different characteristics of users. For example, Hosford, Beairsto, and Winters [16] considered both walking and cycling and different travel speeds to model differences in age. Willberg [48] studied the joint impact of age, diurnal, and seasonal variation on walking accessibility in the Helsinki metropolitan area, considering the 15-minute city. Public transport is also sometimes included in the analysis. For example, Da Silva, King, and Lemar [50] studied the 20-minute accessibility by walking, cycling, and public transport in Tempe, Arizona. As argued by Khavarian-Garmsir et al. [51], the potentials of active mobility can be better exploited when such modes are combined with public transport to efficiently connect more distant neighbourhoods.

In addition to papers that cover all or most of the destination categories, there are articles that focus only on one of the specific types of amenities considered to be essential for the x-minute city. For example, the accessibility to grocery stores within 10 min by walking and cycling was analysed by Kesarovski and Hernández-Palacio [52] in Stavanger, Norway, and access to grocery stores within the 15-minute threshold was analysed by Hosford et al. [16] in Vancouver, Canada. Di Marino et al. [21] discussed how new forms of working places (such as coworking spaces or libraries that provide spaces for remote working) have been considered in recent chrono-urbanism approaches in Oslo, Norway and Lisbon, Portugal.

The reviewed papers predominantly apply two distinct methodologies to approach the problem of quantifying the 15-minute city. A general approach is by calculating the number of accessible destinations for each of the types of destination that the researchers decide to include in their analysis (cumulative accessibility). For instance, Da Silva, King and Lemar [50] identified 12 destination groups and classified residential parcels based on the number of accessible destination groups using a single threshold of 20 min for the modes of walking, cycling, and public transport. Ferrer-Ortiz et al. [29] identified five groups and 24 essential types of destinations for Barcelona, and for each type of destination, a temporal threshold was assigned (5, 10, or 15 min), within which the destinations were supposed to be accessible. Based on these thresholds, the number of accessible destination types were calculated for each parcel in Barcelona. Staricco [53] applied a similar methodology for Turin. However, in this case the 5-, 10-, and 15-min thresholds were applied to each destination type, while in the previous case for Barcelona, only one desirable threshold was assigned to each type of destination. Akrami, Sliwa, and Rynning [54] calculated the number of facilities (education, entertainment, healthcare, and commerce) accessible within 15 min, with a universal walking speed of 5 km/h in Oslo, Norway, using a 250 × 250 m grid. Marín-Cots and Palomares-Pastor [31] defined 18 types of destinations and distance-based thresholds (300, 500, 900, or 1000 m) for calculating the share of the population having access to each type of destination by walking in Malaga. The analysis by Abdelfattah, Deponte, and Fossa [39] was also based on the share of the population, in this case, 5-, 10-, and 15-minute accessibility to general services were again considered, which were represented by buffers of 300, 600, and 900 m. Calafiore et al. [55] followed a different approach: after defining 12 categories of service, the authors calculated the shortest walking travel time for each destination category from each postcode in the Liverpool City region and formulated an accessibility score out of these values based on whether the services were reachable within 10 min.

Other researchers introduced composite indicators to quantify the x-minute city. Knap et al. [56] developed an x-minute city cycling accessibility metric and tested it in a case study in Utrecht in the Netherlands to assess spatial and socio-economic inequities in the access to essential services. Badii et al. [57] introduced a 15-minute city index based on open data and developed an online dashboard for Florence, Italy. An additional example from Italy is the NExt proXimity Index (NEXI), which was tested in the cities of Ferrara and Bologna [58]. Liu et al. [59] developed and tested 5, 10 and 15-minute accessibility indices (referred to as chrono-urbanism status composite indices) in Macau by incorporating the location data of services and check-in data of individuals obtained from a Chinese social media platform. The check-in data was used to assign the attraction (weight) to each service or destination (POIs). A 15-minute city index was developed and tested in Bogota, Columbia, by Guzman, Oviedo, and Cantillo-Garcia [60] on the accessibility to opportunities, diversity (of opportunities), and walkability that incorporates individual preferences. Besides the examples focusing on one specific study area, Bartzokas-Tsiompras and Bakogiannis [61] calculated a 15-minute city index for 121 European cities based on seven walking performance indicators of the Urban Access Framework of the OECD. In another study, x-minute city proximity was measured in the 500 largest cities in the US and 43 urban areas in New Zealand [38]. Elldér [62], in their unique study, examined how the built environment has influenced the development of the 15-minute city in the 200 largest Swedish cities over a 15-year period.

Most of the reviewed papers use network analysis and consider the actual route of the trips when travel times or distances are calculated (network distance). However, there are some studies that consider only bee-line distances, such as the works of Marín-Cots and Palomares-Pastor [31] and Abdelfattah, Deponte and Fossa [39] (Euclidean distance).

Besides exploring the conditions cities provide in terms of the x-minute city principles, there are researchers who address the relationship between mobility patterns and accessibility to urban amenities to see whether current travel patterns meet the x-minute city vision. For example, geographically aggregated mobile phone data was used in Barcelona to analyse how the location of amenities and services affects travel behaviour and origin–destination flows in the city [45] in relation to the 15-minute city. Birkenfeld et al. [63] used a more traditional data source, an origin–destination survey based on travel diaries, to identify households that already live a 15- or 30-minute city lifestyle in Montréal, examining which built-environment and socio-economic characteristics determined such lifestyles.

3. Materials and Methods

In this section, the applied methodology is discussed in detail. We developed a set of indicators for the operationalisation of the x-minute concept for mobility applications.

3.1. Cumulative Opportunity Accessibility

Access or accessibility in the context of transport and urban planning refers to the ability of people to reach goods, services, or activities by one particular mode of transport or by combining various modes within an acceptable cost of travel (e.g., time) [64–66]. The four main types of components of accessibility are the land-use component (location or supply of opportunities, demand and potential competition for the opportunities); the transportation component (transport system that allows people to reach opportunities including the characteristics of the service such as mode, network, schedule, level of comfort, pricing, etc.); the temporal component (temporal availability of opportunities, opening hours); and the individual component (needs, abilities, and opportunities of individuals based on personal and socio-economic characteristics) [65]. Accessibility measures incorporate the four components of accessibility at different degrees of complexity. Ideally, accessibility measures encompass all four components; however, in practice, measures only focus on certain components to optimize computational and data needs.

For the present analysis, the measure of cumulative opportunities-based accessibility was selected due to its simplicity, modest data requirements, and communicability [65]. Despite the disadvantages of the measure, many researchers use it for the same domain. By calculating cumulative opportunities-based accessibility values, we can assess the accessibility of a point or other spatial units, such as grid cells or administrative units, to different types of amenities. The cumulative opportunities-based accessibility values represent the number of accessible amenities within a given threshold. These values can be accumulated to other spatial units, such as neighbourhoods or census tracts, for further analysis. Equation (1) explains the calculation of cumulative opportunities-based accessibility values in general (adapted from Higgins et al. [67]).

$$A_i = \sum_j D_j \cdot f\left(c_{ij}\right) \tag{1}$$

where

A_i is the cumulative opportunities-based accessibility (number of destinations accessible from location i);

D_j represents the destinations at location j; and

$f\left(c_{ij}\right)$ is the impedance function between locations i and j, with a value of 1 if $f(c_{ij}) \leq c_{max}$ (e.g., within the maximum acceptable travel time) and 0 otherwise (this is also a special case of the gravity-based accessibility measure with a simple impedance function).

3.2. Calculation of the Population within the Desired Reach

Besides identifying areas having access to a list of facilities, a further indicator was calculated to quantify the x-minute city concept: the percentage of the population having access to a set of types of destinations. We can use the cumulative accessibility metrics to analyse the spatial aspects of accessibility, while this measure helps us to incorporate the population density and to connect space and population.

If the cumulative accessibility value for a given location (A_i) is greater than zero, the population living at that location has access to the given service. If the accessibility value equals zero at a given location, that means that the population at that location does not have access to the service. Equation (2) explains the calculation.

$$AP = \frac{\sum_i P_i \cdot g(A_i)}{\sum_i P_i} \quad (2)$$

where

AP is the percentage of the population having access to a given service for a selected area (broken up into $i \in [1, 2, \ldots n]$ sub-areas or locations);

P_i is the number of inhabitants living at location i;

A_i is the cumulative opportunities-based accessibility at location i; and

$g(A_i)$ is a function that takes on two values: 0 if $A_i < 0$ or 1 if $A_i > 0$.

3.3. Street Network

After the definition of the measures we use, we explain the process of the analysis. As a first step, the street network (including cycling and pedestrian layers) was obtained from OpenStreetMap (OSM) [68]. Even though the point-of-interest layers of OSM might not be complete or accurate, the quality of the street network data tends to be better than the point-of-interest data, especially in developed countries [69]. Although there could be missing links in the network, it is still the best available open-data source for a scalable methodology, since OSM covers the whole world. The OSM base map with full metadata was downloaded from the website of Geofabrik (Geofabrik GmbH, Karlsruhe, Germany), a German consulting and software development firm that regularly updates OSM data files and makes them available free to download [70]. Then, the raw OSM data was manipulated with Osmosis (version 0.49.2), a command-line Java application that was developed for OSM data processing [68].

3.4. Grid-Based Analysis

The chosen methodology is a grid-based accessibility analysis. A hexagon grid was chosen for the analysis as it reduces sampling bias and is the closest to a circular shape, which is the most recommended for movement analysis [71–73]. Other potential approaches could be a parcel-based or administrative-unit-based analysis (such as the work of Ferrer-Ortiz et al. [29]). However, we chose a grid-based analysis because we found it to be the most scalable approach that can be reproduced in other cities, while it also facilitates the comparison of cities.

3.5. Travel Shed Generation

For the travel shed generation, Openrouteservice, an open-source geoinformation routing service was used [74]. Similar open-source routing applications are available that are suitable for different purposes [67]. Openrouteservice was chosen for its ability to calculate reliable isodistance polygons. Isochrone algorithms of other routing services often failed due to the low time threshold applied in the current study. The maximum walking distance for the travel sheds were calculated by multiplying the average walking speed and the time threshold.

The origins of the travel sheds are the centroids of the hexagon grid that covers the populated parts of study area. The origins are snapped to the closest link of the walking network if the centroid of the grid cell is not on any of the links. Other studies calculate the travel sheds directly from the destinations (such as [50,52]). In this case, the generation of the travel sheds must be recalculated for each type of destination, which is the most computation-intensive part of the analysis. Therefore, we decided to define a fine grid that still results in high accuracy with a significantly lower computational need.

Based on the related literature, various factors influence walking and cycling speed; therefore, it is difficult to define a universal average walking speed. Some factors affecting speed are gender, age, land use, location (local habits), inclination, temperature, and trip purpose. As Bosina and Weidmann [75] confirm, a 1.34 m/s (4.82 km/h) average walking speed, as proposed by Weidmann [76], is a good estimation. For simplification and scalability reasons, we use 4.82 km/h as the universal walking speed. For cycling speed, we use the average value of 14 km/h, as suggested by Marqués et al. [77] in their study examining the implications of cycling infrastructure developments in Seville.

The routing algorithm and applied speed factors can be further adapted to the local context or to the characteristics of different user groups (e.g., the application of varying walking and cycling speeds across age groups or the incorporation of a barrier-free design or further walkability factors in the routing algorithm).

4. Case Study

4.1. Study Area

We tested the presented methodology in a study area through the example of the city of Seville. Seville is located in Andalusia, in the southernmost autonomous community in Peninsular Spain. Seville is the capital of Andalusia and the province of Seville. The city is the fourth-largest city in Spain with a population of 684,283 inhabitants, and its area is 114.33 km^2. Seville has an extensive functional urban area with 1,555,472 inhabitants (fourth largest in Spain), covering 4682.63 km^2 (second largest after the functional urban area of Madrid) [78]. The populated area of the city and the population density map are illustrated by Figure 1.

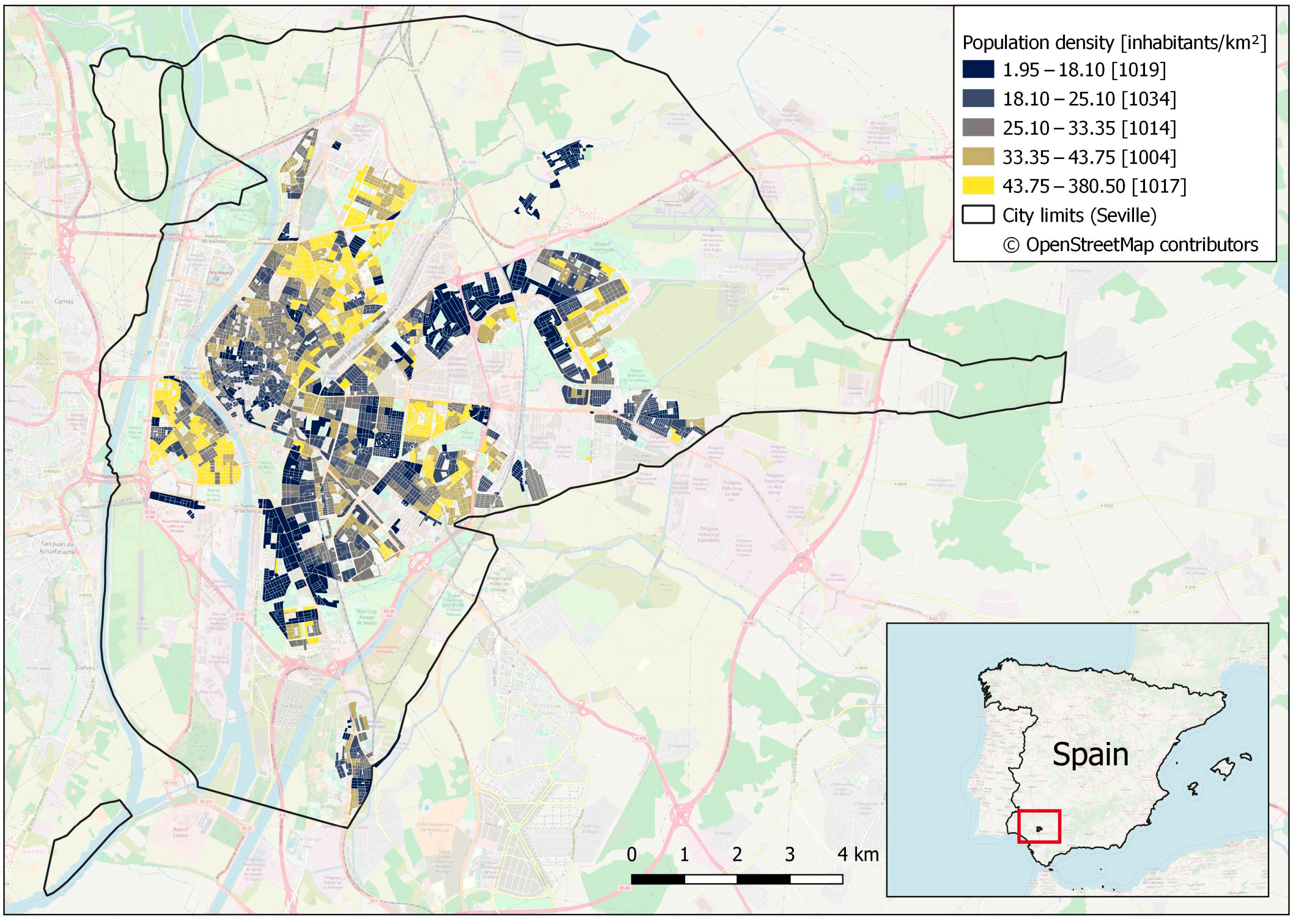

Figure 1. Population density map of Seville (own elaboration based on data from the Urban Atlas [79]).

According to the Sustainable Urban Mobility Plan of Seville [80], in 2018, 28.6% of all trips were estimated to be carried out by foot in the city, while the figure for cycling was 3.4% (excluding trips that are shorter than 5 min) (see Table 1). Having a look at the distribution of trips by purpose, the top three were work-, leisure-, and shopping-related trips. If we have a look at the percentage of walking trips for each purpose category, we can observe that work-related trips were least likely to be covered by walking (only 12.9%). In contrast, more than 70% of all daily shopping and almost 50% of leisure trips were carried out by walking. The values for cycling were relatively low; however, these figures have probably increased since 2018 due to the behavioural changes of the COVID-19 pandemic, the increasing uptake of cycling that is observed in Spain, as well as the popularisation of shared and private electric scooters [81].

Table 1. Modal share by trip purpose for Seville in 2018 (data source: [80]).

Purpose of Trips	Percentage of Trips, All Modes [%]	Percentage of Trips by Mode for Each Trip Purpose					
		Walking	Cycling	Public Transport	Car	Other	Total
Work	31.2	12.9	4.3	19.7	56.4	6.6	100
Studies	8.7	21.6	7.7	43.4	24.1	3.2	100
Medical	5.7	22.6	0	35.6	34.5	7.4	100
Daily shopping	5.9	71.6	0.1	10.7	16.6	1.1	100
Non-daily shopping	6.3	33.4	1.3	22.9	41.3	1.1	100
Personal matters	9	24.6	2.1	27.7	41.4	4.2	100
Leisure	20.8	48.2	3.9	21.2	23.1	3.6	100
Taking someone somewhere	5.5	28	1.5	4.4	63.3	2.8	100
Visiting someone	5.2	16	2.3	28.3	49.5	3.8	100
Other	1.7	28.5	4.4	17.7	40.5	8.9	100
Total	100	28.6	3.4	23	40.5	4.5	100

The cumulative distributions of trips taking longer than 5 min by mode and by purpose relevant for this study are illustrated in Figure 2. Overall, 40% of all walking trips were less than 15 min long, while the same figure for cycling was 27.8%. In comparison, 28.5% of all trips, regardless of the mode of transport, were 15 min long at maximum. Daily and non-daily shopping tended to be the shortest if we compared trips with different purposes, followed by the rest of the four categories, which followed a similar pattern.

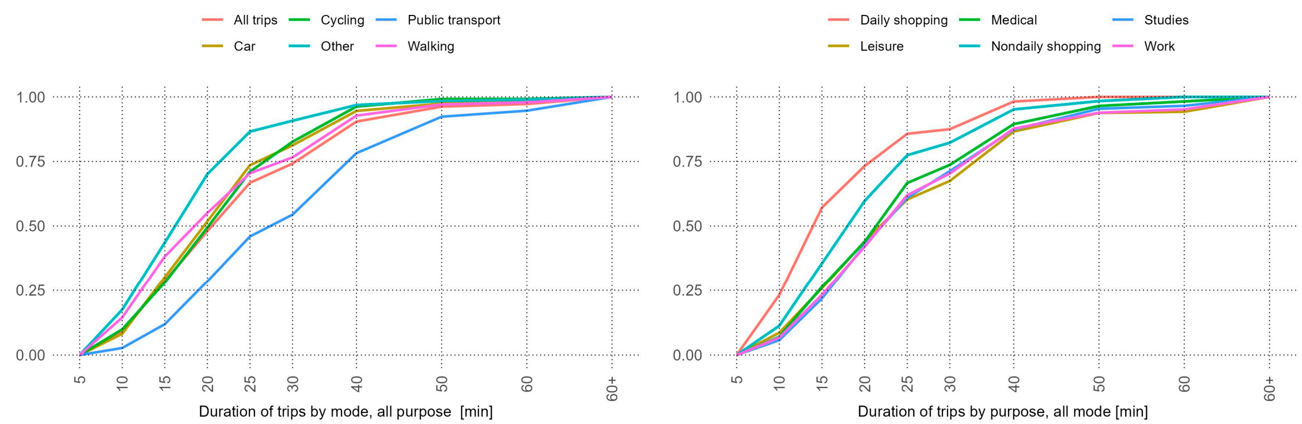

Figure 2. Cumulative distributions of trip duration for different modes of transport (all trip purposes; **left**) and for selected trip purpose categories (all modes of transport; **right**). (Own elaboration based on data obtained from the Sustainable Urban Mobility Plan of Seville [80]).

4.2. Types of Destinations Considered

After the definition of the study area, the destination types listed in Table 2 were selected for analysis based on the list of amenities discussed in the literature. The selected types of destinations were identified as general services and amenities that people tend to visit daily and that should be accessible within the x-minute city. In total 23, types of destinations were selected. The destination categories, the type of destinations, and the data sources are listed in Table 2.

These types of destinations and the desired accessibility targets, however, should ideally be tailored to the local needs. As Da Silva, King, and Lemar argue [50], "*accessibility is a metric, but what are acceptable parameters of what is considered accessible must be set through policy*". Therefore, various documents were reviewed to adjust the thresholds to the local needs. The document *Special Plan for Environmental Sustainability Indicators of Urban Development Activities in Seville* [82] identifies a list of basic amenities and defines accessibility requirements for each of the amenities (thresholds in metres and minutes). Besides that, the more recent Spanish Urban Agenda [83] also sets requirements for the provision of basic services. The city of Seville is among the cities that voluntarily implement the Spanish Urban Agenda [84], the national interpretation of the New Urban Agenda of the United Nations [85] and the Urban Agenda for the European Union [86]. The Spanish Urban Agenda defines a list of services and the thresholds at which these services should be available in the proposed ideal city model. In Table 2, for each type of destination, the data source is indicated to justify the reason for choosing the given time threshold.

The above-listed authoritative open-data platforms tend to be up-to-date, complete, and accurate. Our first intention was obtaining location data only from OSM or from other similar platforms that cover larger areas than the study area for scalability reasons, but the data quality did not meet our requirements. For the OSM data, there is no information available about the accuracy or completeness of the data, which poses an important limitation for the analysis. For some destination types, important tags are missing (for example schools might appear in the database, but the tags describing the type of the schools are often empty), or the list of destinations is incomplete compared with authoritative data sources. For some destination types, however, especially for the category of commerce, data had to be obtained from OSM. Due to the poor data quality of OSM, we decided to only include food stores, fresh-food stores, and markets in the category of commerce. Daily non-food stores, such as drugstores, hardware, or houseware stores were excluded, as well as services, such as hairdressers.

Table 2. List of destinations and destination groups of the analysis.

Destination Categories (D_w)	Destination Types (D_d)	Data Source	Time Threshold (TT_j)	Evidence for the Chosen Time Threshold
Transport (public transport and active mobility)	City-level public transport stops (catchment ≤ core city)	GTFS	5	[82,87]
	FUA-level public transport stops (core city < catchment ≤ functional urban area)	GTFS	10	[29]
	Regional-level public transport stops (catchment > functional urban area)	GTFS	≥15	Own definition
	Night public transport service (catchment ≤ functional urban area)	GTFS	10	[29]
	Bike-sharing stations	IDE.SEVILLA [88]	5	Own definition
	Bike parking facilities	IDE.SEVILLA [88]	5	[82]
	Cycling infrastructure	IDE.SEVILLA [88]	5	[82]

Table 2. *Cont.*

Destination Categories (D_w)	Destination Types (D_d)	Data Source	Time Threshold (TT_j)	Evidence for the Chosen Time Threshold
Commerce	Food stores (grocery stores, supermarkets, etc.)	OSM [68]	5	[83]
	Fresh-food shops (greengrocer, bakery, butcher, etc.)	OSM [68]	5	[83]
	Markets (food)	IDE.SEVILLA [88]	10	[82]
Healthcare (public)	Healthcare centres	IDE.SEVILLA [88]	10	[82]
	Hospitals	IDE.SEVILLA [88]	≥15	Own definition
	Social care centres	IDE.SEVILLA [88]	10	[82]
	Pharmacies	IDE.Andalucía	5	Own definition
Education (public)	Preschool education	IDE.SEVILLA [88]	5	[82]
	Primary education	IDE.SEVILLA [88]	5	[82]
	Secondary education	IDE.SEVILLA [88]	10	[82]
Leisure	Playgrounds	OSM [68]	5	[29]
	Sport facilities	OSM, IDE.SEVILLA [68,88]	10	[82]
	Squares and parks ≥ 1000 m^2	OSM, IDE.SEVILLA [68,88]	5	[83]
	Squares and parks ≥ 10,000 m^2	OSM, IDE.SEVILLA [68,88]	10	[83]
	Libraries	IDE.SEVILLA [88]	10	[82]
	Civic centres	IDE.SEVILLA [88]	10	[82]

4.3. Accessibility Analysis

We focused on walking and cycling as active modes that should be prioritised in the x-minute city. Due to the short target travel times set in Table 2, public transport was not included in the analysis, only the potential of combined trips, since public transport stops are in the list of destinations. Car use was left out as well since we did not consider it an essential mode for the x-minute city. However, in a larger scale analysis (e.g., at a metropolitan level), it would be important to include driving to analyse the competitiveness of public transport over car use.

We applied accessibility analysis to examine whether the introduced types of destinations were accessible, as discussed in the methodology. We used three time thresholds—5, 10, and 15 min—across the study area. We decided to use these thresholds based on the literature discussed earlier; in addition, this helps us to compare the accessibility of destinations for these three different thresholds. A travel shed, or isodistance polygon from the origin point (similar to an isochrone), represents the area that is reachable within the given timeframe. The maximal diameter of a hexagon grid cell of the raster we use equals the distance of a two-minute walk, which is 160.8 m.

Equation (3) is the adaptation of Equation (1) for the purpose of the present analysis. Figure 3 is the visual representation of the calculation for a better understanding.

$$A_i^{d,\,t,m} = \sum\nolimits_{j,d,t} D_j^d f\left(c_{ij}^t\right) \quad (3)$$

where

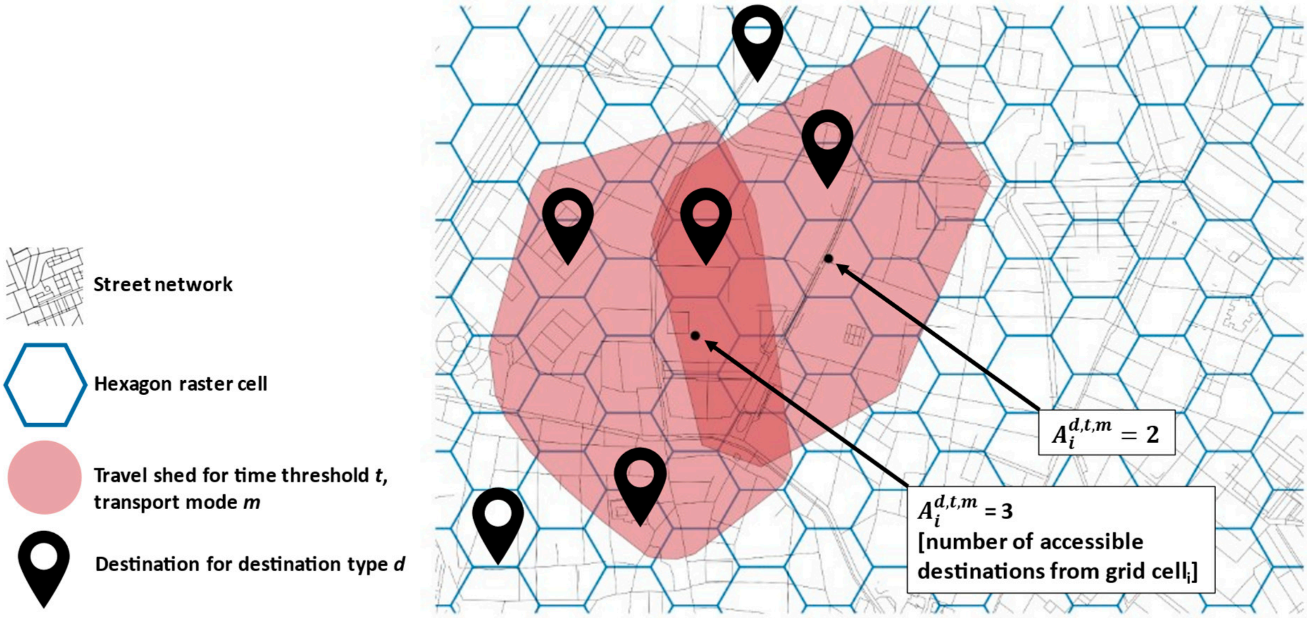

Figure 3. Visual representation of the accessibility analysis (own elaboration).

$A_i^{d,\,t,m}$ is the number of destinations accessible from grid cell i for destination type d, within time threshold t, using mode m;

D_j^d represents the destinations for destination type d at location j (defined by the travel sheds); and

$f(c_{ij}^t)$ is the impedance function between locations i and j, with a value of 1 if $f(c_{ij}) \leq t$ (for destinations within the travel shed for time threshold t) and 0 otherwise;

$m \in [walking,\ cycling]$; $t \in [5,\ 10,\ 15]$; and $d \in$ list of destinations are presented in Table 2.

4.4. Population within Reach: Data and Calculation

Data on land use was obtained from the General Urban Development Plan of the city [89]. The population for each hexagon grid cell was estimated using a 250 m × 250 m population grid that was obtained from the Institute of Statistics and Cartography of Andalusia [90]. Besides the population grid, aggregated population data at a census block level were also used, which were obtained from the Spatial Data Infrastructure of Seville [88].

For other cities, such datasets might not be available; however, for European cities, these sources can be substituted by the population and land-use data of the Urban Atlas [79] or a European population grid [91].

The percentage of the population having access to the defined list of destinations is calculated for the modes of walking and cycling by the adaption of Equation (2):

$$AP^m = \frac{\sum_i P_i \cdot g(A_i)}{\sum_i P_i} \tag{4}$$

where

AP^m is the percentage of the population having access to a given service for mode m in Seville;

P_i is the number of inhabitants living at grid cell i;

A_i is the cumulative opportunities-based accessibility at grid cell i; and

$g(A_i)$ is a function that takes on two values: 0 if $A_i < 0$ or 1 if $A_i > 0$;

$m \in [walking,\ cycling]$.

4.5. Operationalisation

To facilitate the reproducibility of the present study, we briefly describe the pipeline of operationalisation of the presented methodology and measures as follows (see list below and Figure 4). The data curation, accessibility analysis, and, partially, the data visualisation were carried out in R, in an open-source programming language. The maps were created using QGIS (version 3.34), a free and open-source software. These software were used based on the personal preferences of the authors, but the presented pipeline can be operationalised either in another scripting environment or by using a GIS tool only. The pipeline details are as follows:

1. Identification of destination types that should be present and accessible in the study area.
2. Data collection: street network and destinations (geodata) (D_j^d).
3. Grid generation based on the defined study area: hexagon cells, which are the units of the analysis.
4. Travel shed generation for all the applied time thresholds and modes of transport for each grid cell (polygons).
5. Calculating the number of accessible destinations for all destination types for each hexagon cell by counting points (destinations) in polygons (travel sheds) ($A_i^{d,\,t,m}$)
6. Data aggregation and visualisation.

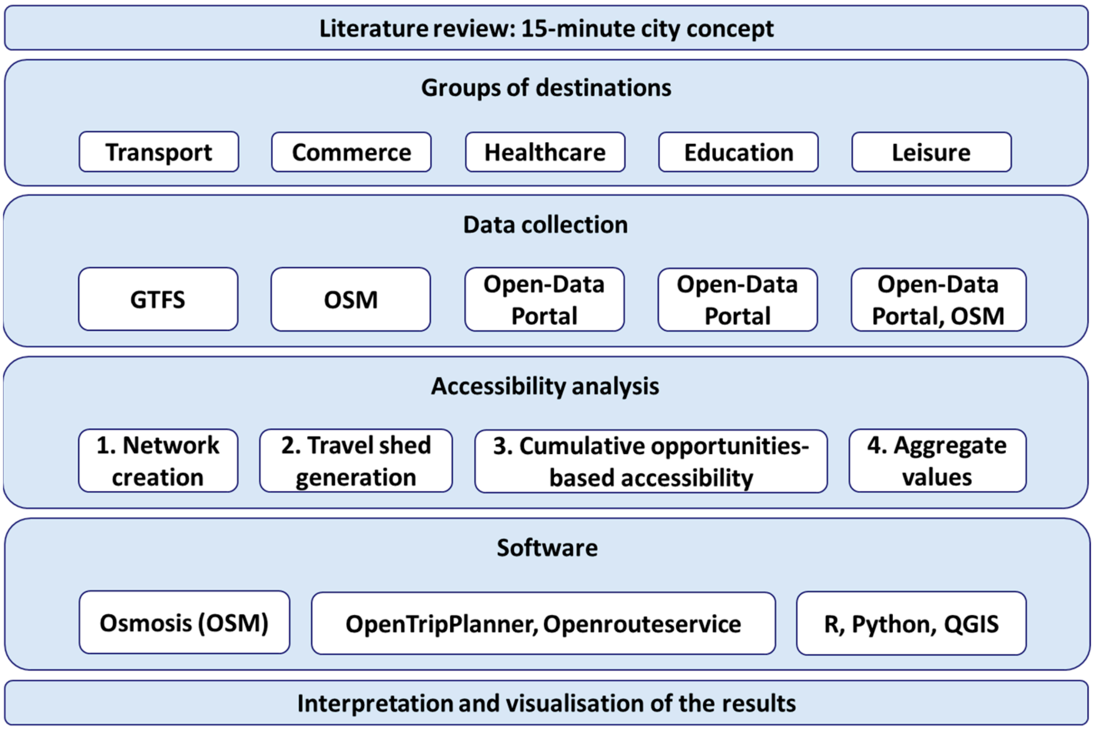

Figure 4. Main steps of the study (own elaboration).

5. Results

5.1. Share of the Population within Reach

First, we discuss the share of population having access to the introduced urban functions within a 5-, 10- and 15-minute walking or cycling distance (see Figure 5). We can observe that almost the whole population has access to most public services within a 15- and 10-minute walk: to local public transport, to cycling infrastructure, to public healthcare, to public education, and to green spaces. In some categories, we can even observe that amenities are accessible within 5 min for most of the population. However, the population having access to regional public transport, social care centres, or hospitals is significantly lower. Nevertheless, in the case of these categories, the 15-min walking access might not be feasible or desirable since the optimal service area (threshold population) can be larger than the 15-minute walking travel shed. Table 3 includes the detailed results, where highlighted cells refer to the desired time thresholds that are defined in Section 4.2.

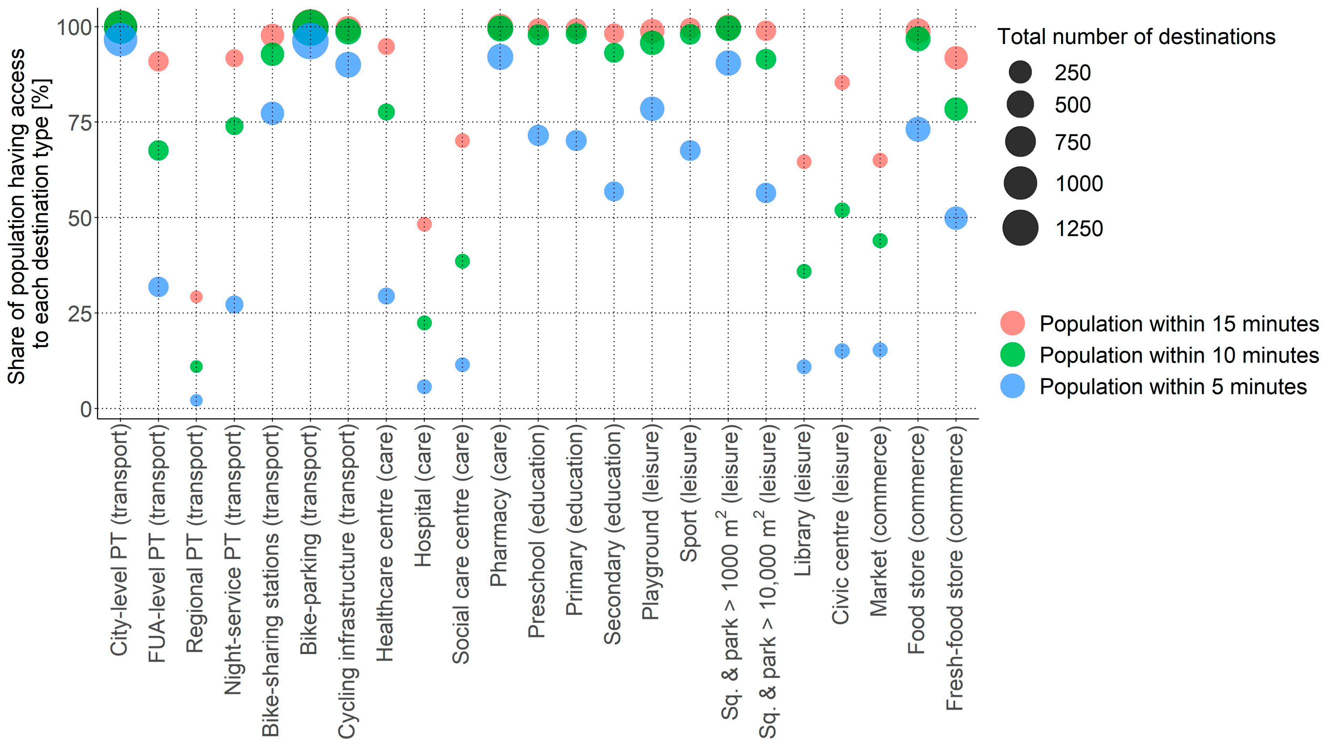

Figure 5. The share of the population having access to the introduced destination types within a 5-, 10- and 15-minute walk. The colours of the points represent the threshold and the size of the points the number of destinations in the whole city. (Own elaboration).

On the right side of Figure 5, those types of destinations are visualised for the data obtained from OpenStreetMap (destination types of food and fresh food). In the case of these types of destinations, we have approximate results only since we do not know to what degree the OpenStreetMap database is complete and accurate.

When cycling is considered as the mode of transport used to access the same services, we can observe significantly higher percentages (see Figure 6). These results are not surprising since the area of the travel sheds for cycling are, on average, 6.1, 7.3, and 6.4 times larger than the area of travel sheds for walking for the 5, 10, and 15 min thresholds respectively (see Figure 7). In the case of Madrid, these figures are higher, reaching 15.5, 13.1, and 13.6 [92], which shows that we might be underestimating the travel speeds. However, while the work of Romanillos and Gutiérrez [92] is based on GPS tracking, our assumptions on travel speeds are based on multiple surveys and studies.

Table 3. The share of the population having access to the introduced urban functions within a 5-, 10- and 15-min walk and cycle. (Bold and highlighted cells reflect on the desired thresholds defined in Table 2).

			Walking			Cycling		
Destination Category	**Destination Type**	**Number of Elements**	**Population within 5 min [%]**	**Population within 10 min [%]**	**Population within 15 min [%]**	**Population within 5 min [%]**	**Population within 10 min [%]**	**Population within 15 min [%]**
Transport	City-level PT	1001	**96.7**	99.9	100	**99.8**	100	100
Transport	FUA-level PT	139	31.8	**67.6**	90.9	78.1	**99.8**	100
Transport	Regional PT	7	2.2	11	**29.3**	18.7	52	**70.6**
Transport	Night-service PT	67	27.3	**74**	91.8	85	**98.8**	100

Table 3. *Cont.*

Destination Category	Destination Type	Number of Elements	Walking: Population within 5 min [%]	Walking: Population within 10 min [%]	Walking: Population within 15 min [%]	Cycling: Population within 5 min [%]	Cycling: Population within 10 min [%]	Cycling: Population within 15 min [%]
Transport	Bike-sharing stations	260	**77.3**	92.8	97.8	**95.6**	99.5	100
Transport	Bike parking	1300	**96.2**	99.7	99.9	**99.7**	100	100
Transport	Cycling infrastructure	386	**90**	98.7	99.4	**99.1**	99.5	100
Care	Healthcare centre	45	29.5	**77.7**	94.8	86.6	**99.9**	100
Care	Hospital	16	5.7	22.4	**48.3**	31.3	75.9	**83.1**
Care	Social care centre	16	11.5	**38.6**	70.2	52.4	**96.1**	98.7
Care	Pharmacy	408	**92.1**	99.5	100	**99.7**	100	100
Education	Preschool	169	**71.5**	97.9	99.4	**99**	99.5	100
Education	Primary	161	**70.2**	98.2	99.4	**99**	99.5	100
Education	Secondary	120	56.8	**93.2**	98.2	96.1	**99.6**	100
Leisure	Playground	317	**78.5**	95.8	98.9	**97.8**	99.4	99.8
Leisure	Sport	148	67.6	**98**	99.6	99.2	**99.9**	100
Leisure	Squares and parks > 1000 m^2	375	**90.5**	99.6	99.8	**99.7**	100	100
Leisure	Squares and parks > 10,000 m^2	137	56.4	**91.4**	98.9	96.8	**99.7**	100
Leisure	Library	17	11	**36**	64.6	48.9	**89.3**	99.3
Leisure	Civic centre	21	15.1	**52**	85.4	68.8	**96.2**	99.8
Commerce	Market	18	15.4	**44**	65	52.4	**91.1**	99.2
Commerce	Food store	341	**73.1**	96.8	98.9	**98.1**	99.6	100
Commerce	Fresh-food store	264	**49.9**	78.5	91.9	**87**	97.4	99.1

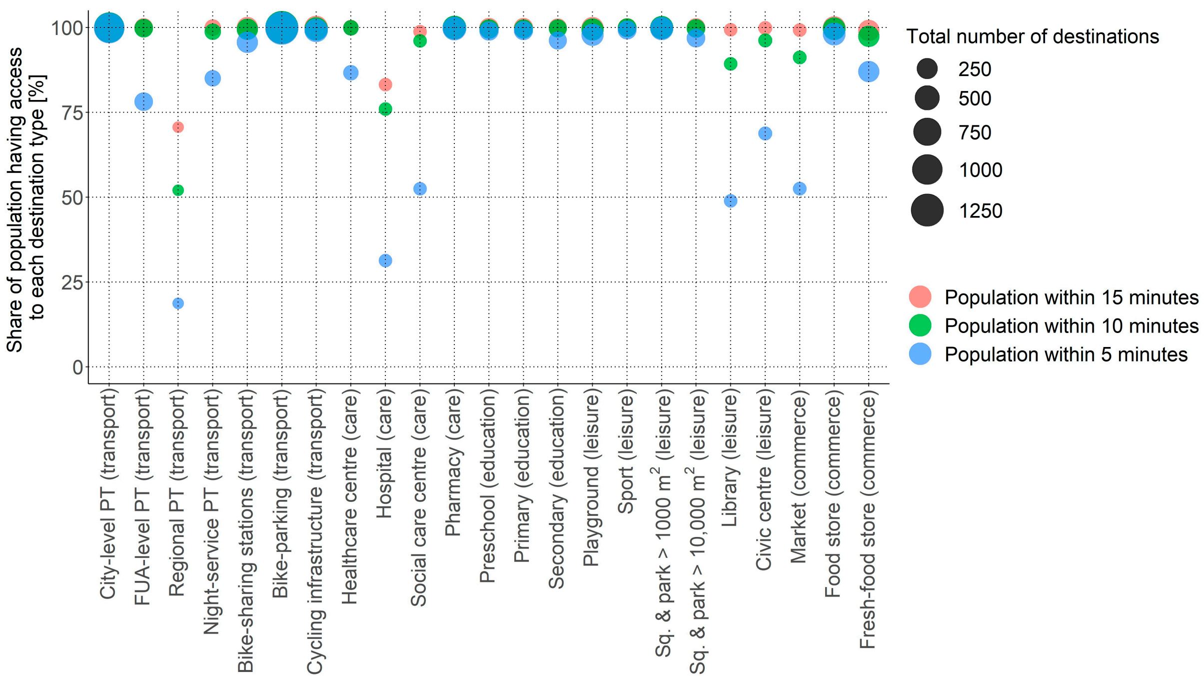

Figure 6. The share of the population having access to the introduced destination types within a 5-, 10- and 15-minute cycle. The colours of the points represent the threshold and the size of the points the number of destinations in the whole city. (Own elaboration).

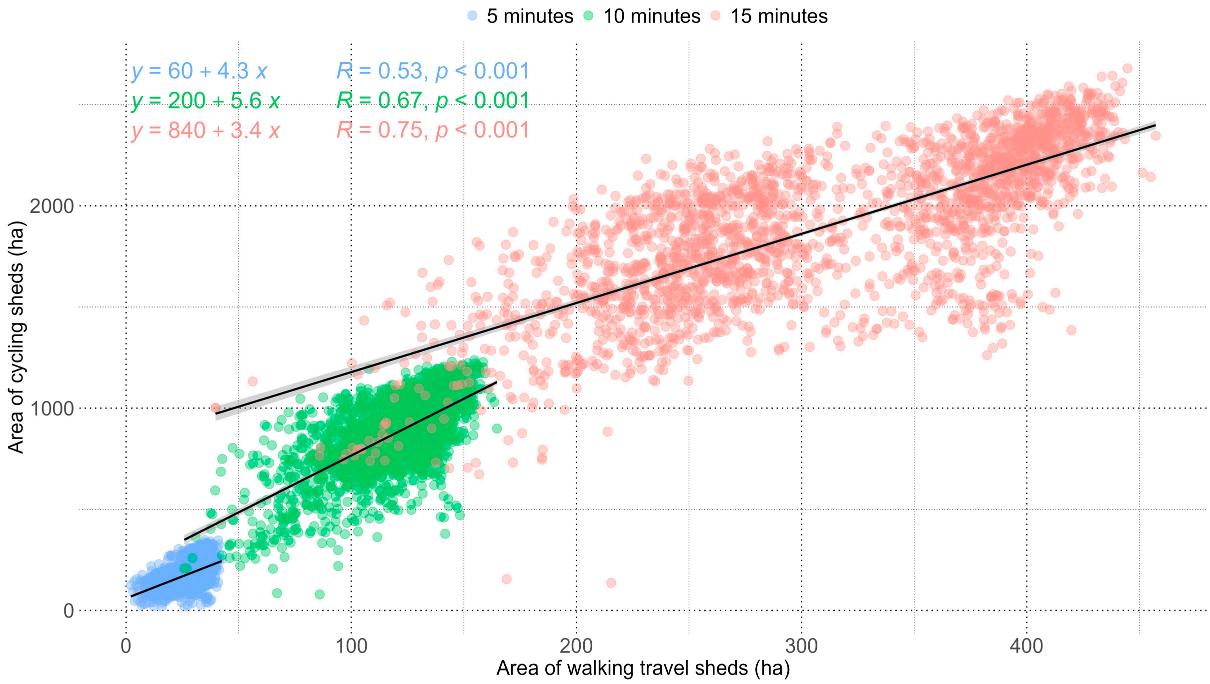

Figure 7. Scatter plot showing the size of walking and cycling sheds across the city (each point represents a grid cell and the corresponding size of the walking and cycling sheds). (Own elaboration).

Using the above visualised three thresholds helps us to quickly analyse the distribution of the population in terms of accessibility to the 23 types of destinations. However, these thresholds should be adapted to the local needs as was indicated earlier. In Figures 8 and 9, only those thresholds that are set in the previously discussed Table 2 are visualised.

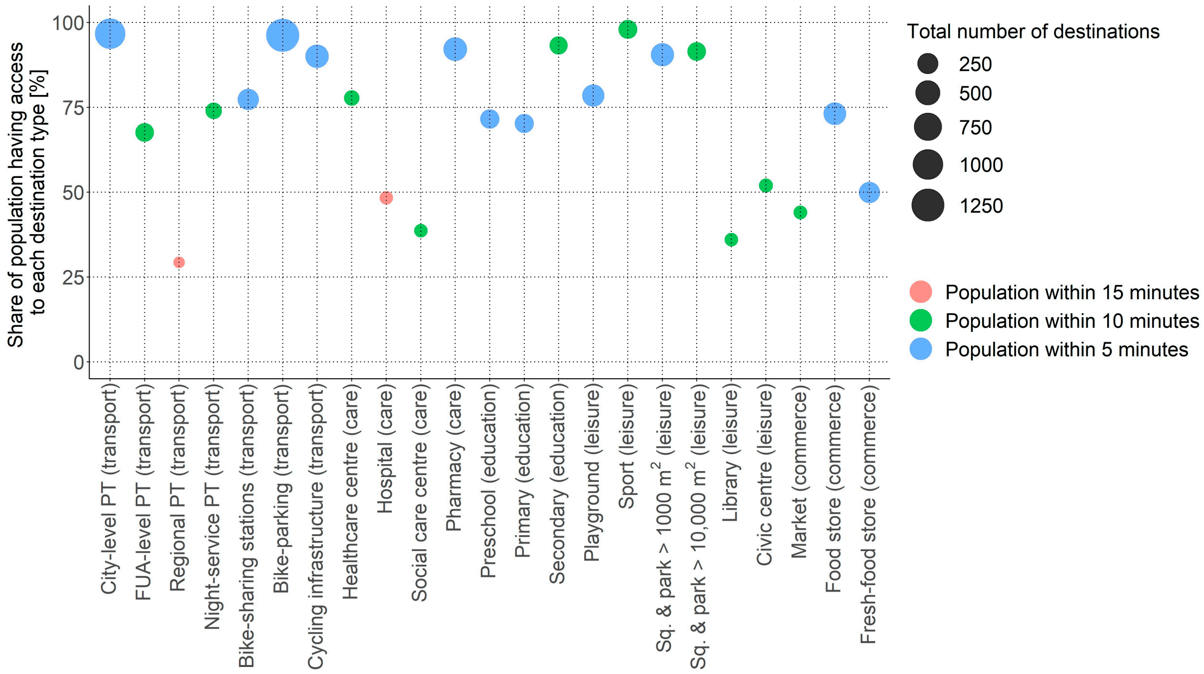

Figure 8. The share of the population having access to the introduced destination types within the desired time thresholds by walking, as indicated in Table 2. The colours of the points represent the threshold and the size of the points the number of destinations in the whole city. (Own elaboration).

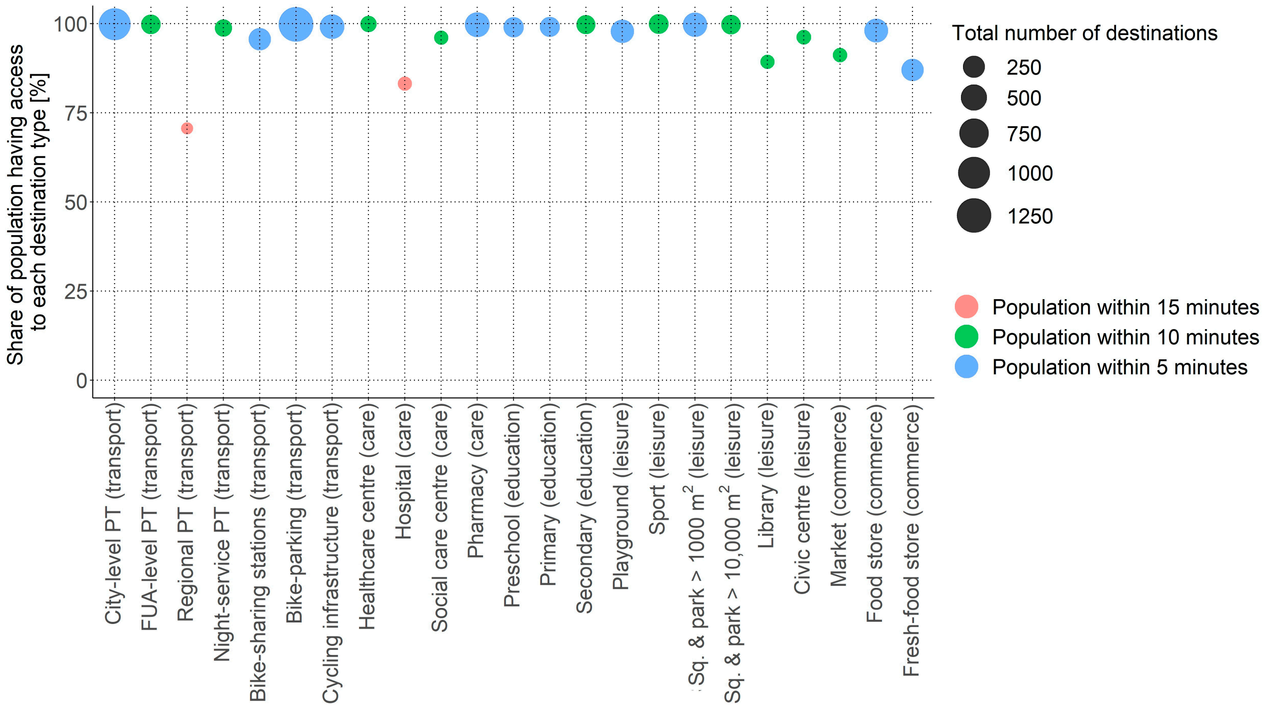

Figure 9. The share of the population having access to the introduced destination types within the desired time thresholds by cycling, as indicated in Table 2. The colours of the points represent the threshold and the size of the points the number of destinations in the whole city. (Own elaboration).

We can observe that local public transport stations and cycling infrastructure are accessible for 95.9% and 90.1% of the population, respectively, by walking. The same figure for bike sharing is lower at 77.3%, since stations are not available in some neighbourhoods at the periphery of the city. Public transport services reaching the functional urban area of the city are available for 66.9% of the population. Although these figures do not indicate the quality of the cycling network or public transport services (frequency, travel time, or fares), we can conclude that sustainable urban mobility options are widely accessible for most of the population.

In comparison, 99.8% of the population can reach public transport stops and stations serving the city or the functional urban area by cycling. Moreover, 70.6% of the population can access regional public transport stops by cycling. These high figures suggest great potential in combined trips when the public transport stops and stations are reached by cycling.

Local healthcare centres are accessible for 75% of the population by walking. The figures for hospitals and social care are significantly lower at 47.4% and 37.9%, respectively. Pharmacies are accessible for 90.7% of the population. In the case of healthcare facilities, the higher travel speed of cycling drastically increases the share of the population living within the desired travel times. The figure for local healthcare centres is 99.9%, while it is 96.1% for social care and 100% for pharmacies.

The category of public education shows that around 70% of the population has access to preschool and primary education within a 5 min walking distance. Although the number of secondary schools is 20% lower than that of primary schools, the same figure for secondary education is 92.3% due to the longer acceptable walking distance. The figures increase to more than 99% for all types of educational facilities if cycling is used.

In the case of the category of leisure, we can see that sporting facilities and green areas are accessible for more than 90% of the population, while the figure for playgrounds is above 75% by walking. Due to the low number of municipal libraries and civic centres compared with other types of destinations in this category, the figures for these two types of destinations are significantly lower, 36% and 52%, respectively, by walking. When accessibility by cycling is considered, public libraries are accessible for 89.3% of the population, while for all the other destination types considered in the category of leisure, the figures are close to 100%.

In the case of commerce, municipal markets are within a 10 min reach for 44% of the population, while food and fresh-food stores can be reached by 73.1% and 49.9% of the population by foot. However, the latter two figures are only indicative results due to the limited data availability that was discussed earlier. Cycling makes these destinations accessible for at least 90% of the population.

5.2. Spatial Representation of the Results

The above discussed figures cumulate the results for the whole city and hide the spatial differences. To complement these results and to analyse the spatial differences in accessibility, we visualised the number of destination types for each destination category that are accessible throughout the city. This method helps us to compare the performance of different parts of the city and to identify those areas where essential services are missing. Similar cumulative representation is applied by other researchers, such as by Ferrer-Ortiz et al. [29] or Da Silva et al. [50]. In this section, the results represent accessibility within the desired time thresholds that are indicated in Table 2.

To better understand the spatial differences between walking and cycling, we visualised the differences in the size of the travel sheds for the two modes of transport (see Figure 10). The numbers in the legend represent by how many times the cycling shed is larger than the walking shed for a given grid cell.

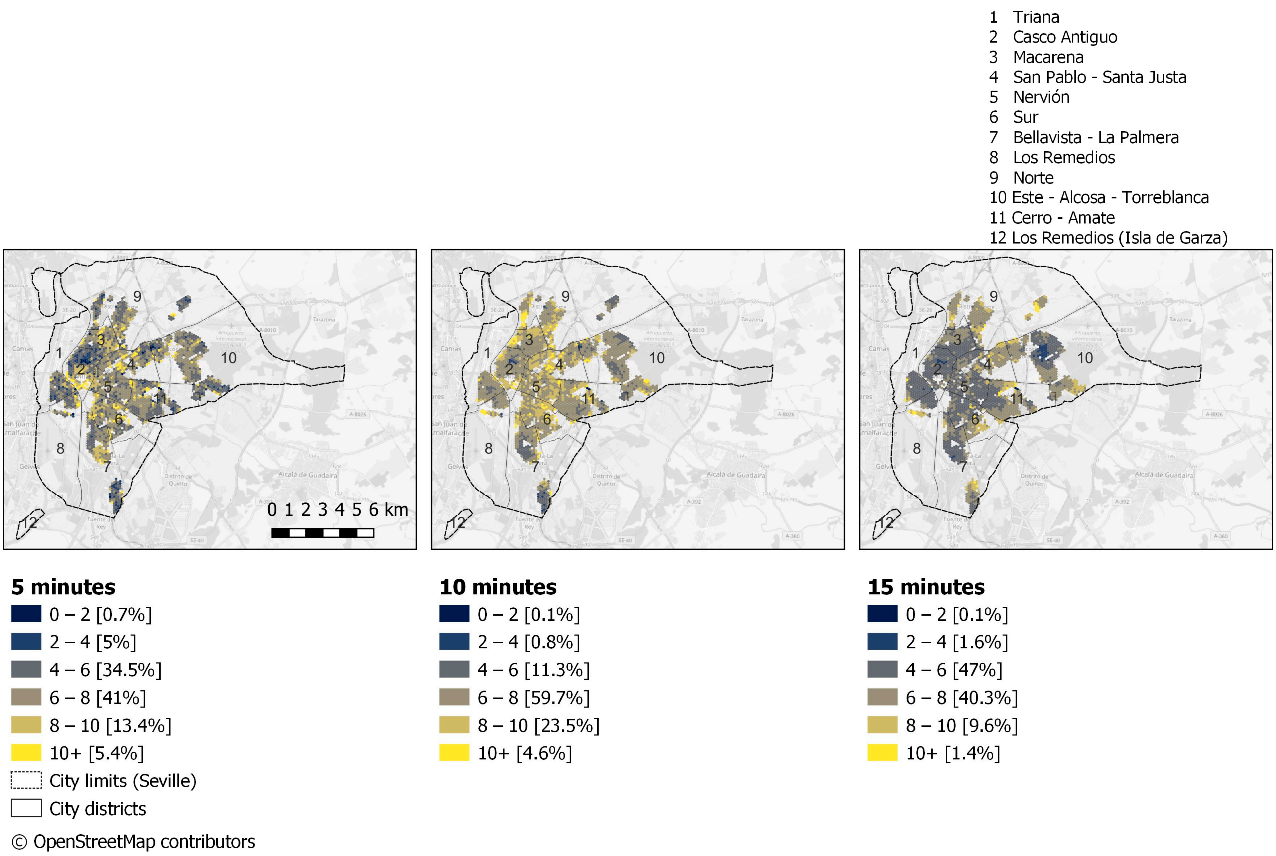

Figure 10. Comparison of the size of walking and cycling travel sheds across the study area. The numbers in the legend represent how many times the cycling shed is larger than the walking shed for a given grid cell. (Own elaboration. For better readability, see Appendices B–D).

Figure 11 shows the number of accessible types of destinations for the category of transport. The hexagon grid covers the residential area only, and the colours represent the number of accessible types of destinations for each cell. For example, 2 in the legend means that two out of the seven types of destinations for the category of transport are accessible for a given cell (the number of destinations is not indicated on the map). In the legend, the numbers in square brackets represent the share of residential areas with access to a given number of types of amenities by walking and cycling.

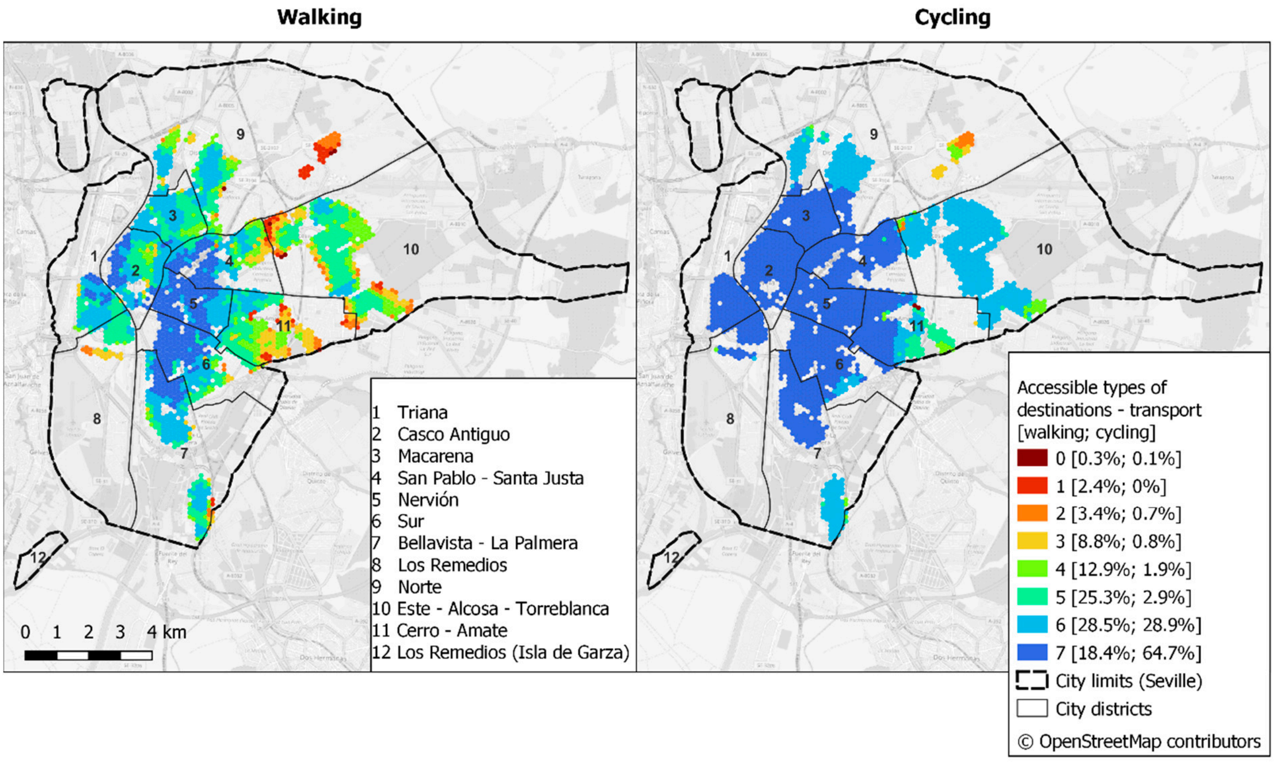

Figure 11. Number of accessible types of destinations for the category of transport. The numbers in square brackets represent the share of residential areas for walking and cycling (same order) for each category of the legend. (Own elaboration).

The best-served areas by walking are around the regional public transport stations (bus and railway stations), since the number of such stations is low compared with other types of destinations. These areas are typically in the historic centre (Casco Antiguo) and in the city district of San Pablo–Santa Justa (where the Santa Justa central railway station is located), while in the south, these are in Nervión, Sur, and some parts of Bellavista that are close to the bus terminals of the city. Where six types of destinations are accessible, these are typically those areas that are further from regional public transport stations but that still have good access to other types of destinations. We can observe that around 72.2% of residential areas have access to at least five types of destinations, while a further 12.9% have access to at least four types. The worst-served areas are on the edges of the city, in the south of Triana, in Cerro–Amate, in Este–Alcosa–Torreblanca, and in Valdezorras, a peripheral neighbourhood that belongs to the Norte city district.

At least six types of destinations are accessible throughout the rest of the city by cycling, except for some neighbourhoods at the periphery of the city. The areas where only six types of destinations are accessible are typically those where regional public transport stations are more than a 15-minute cycling ride away.

In Figure 12, we can observe the spatial distribution of the types of destinations belonging to the category of care. The areas with highest accessibility by walking are around hospitals, in the historic city centre, in Macarena, and in Nervión. Besides the low number of hospitals, the number of social care centres is also a limiting factor. Around 6.7% of the residential areas do not have access to any type of destination for the category of care. Although the areas with low accessibility are similar to the category of transport, low-access areas in the eastern parts of the city (San Pablo–Santa Justa and Este–Alcosa–Torreblanca) are more extensive and more visible on the maps.

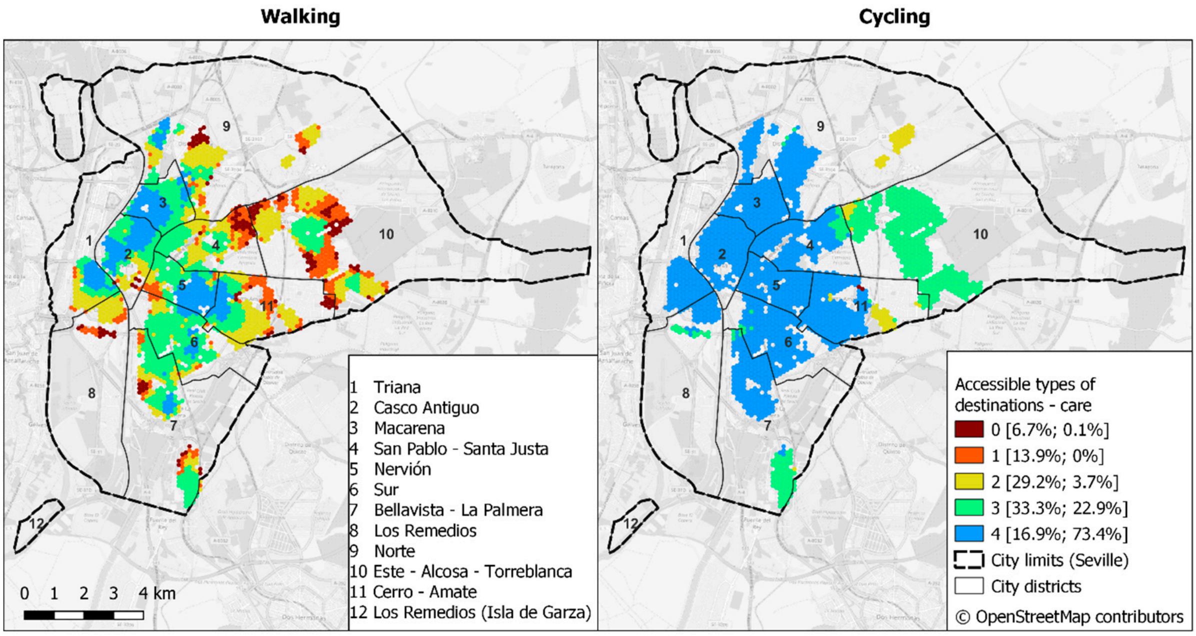

Figure 12. Number of accessible types of destinations for the category of care. The numbers in square brackets represent the share of residential areas for walking and cycling (same order) for each category of the legend. (Own elaboration).

Looking at the map of cycling, we can also observe areas with lower accessibility values similar to the category of transport along the eastern outskirts of the city. Although these areas cover a relatively large part of the populated area, due to the low density, the share of the population having access to the services of care remains close to 100%, as discussed earlier.

In the case of the category of education (see Figure 13), the differences between city districts are less visible compared with those of the previous categories, and the destinations are distributed more evenly. Although accessibility values on the edges of the city remain lower for walking, areas with accessibility to one type of destination only represent 25.3%; this covers areas throughout the whole city. Based on our results, 60.3% of the populated area have access to all three types of destinations, while 9% of residential areas do not satisfy the accessibility requirements of any type of educational destinations. All three types of destinations in the category of education are accessible by cycling throughout the whole city except in Valdezorras, where the accessibility for all categories is generally low.

For the categories of leisure (Figure 14) and education (Figure 13), we can observe that areas at the edges of the city, especially on the east, have relatively high accessibility by walking. However, the south of Triana and Valdezorras remain poorly served. In the case of leisure (Figure 14), due to the good coverage of parks and squares in the whole city, 40.6% of the residential area have access to at least five types of destinations, and 76.2% have access to at least four types of destinations. Accessibility by cycling in San Pablo–Santa Justa and Bellavista–La Palmera is lower due to the low number of libraries and civic centres; however, the share of the population having access to these destinations is 89.3% and 96.2%, respectively.

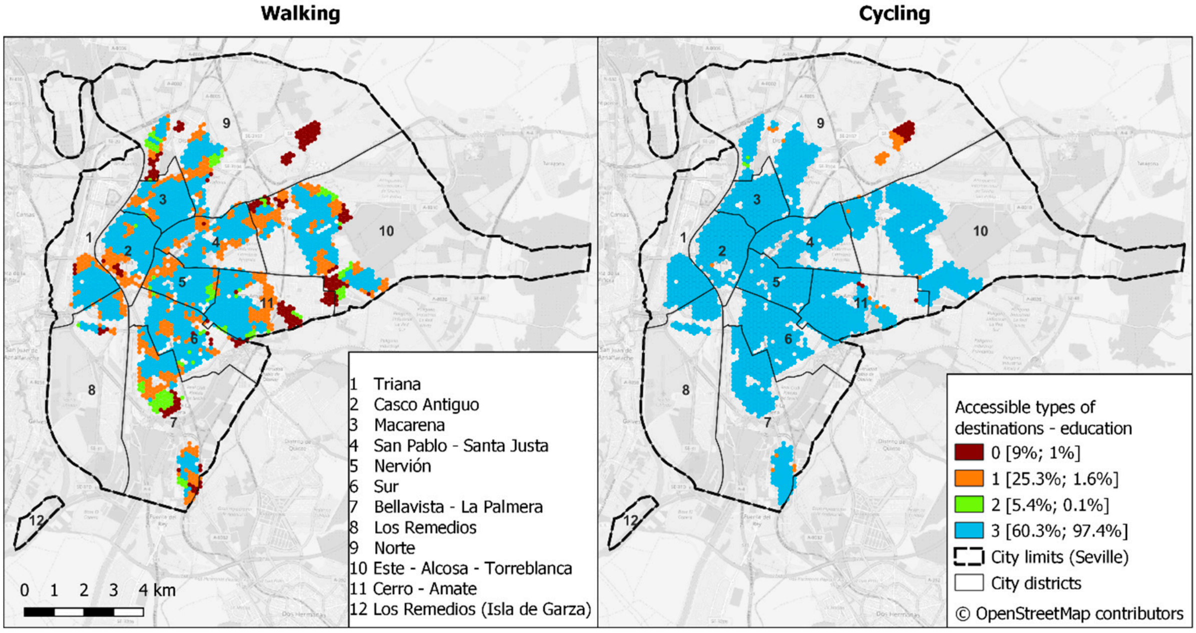

Figure 13. Number of accessible types of destinations for the category of education. The numbers in square brackets represent the share of residential areas for walking and cycling (same order) for each category of the legend. (Own elaboration).

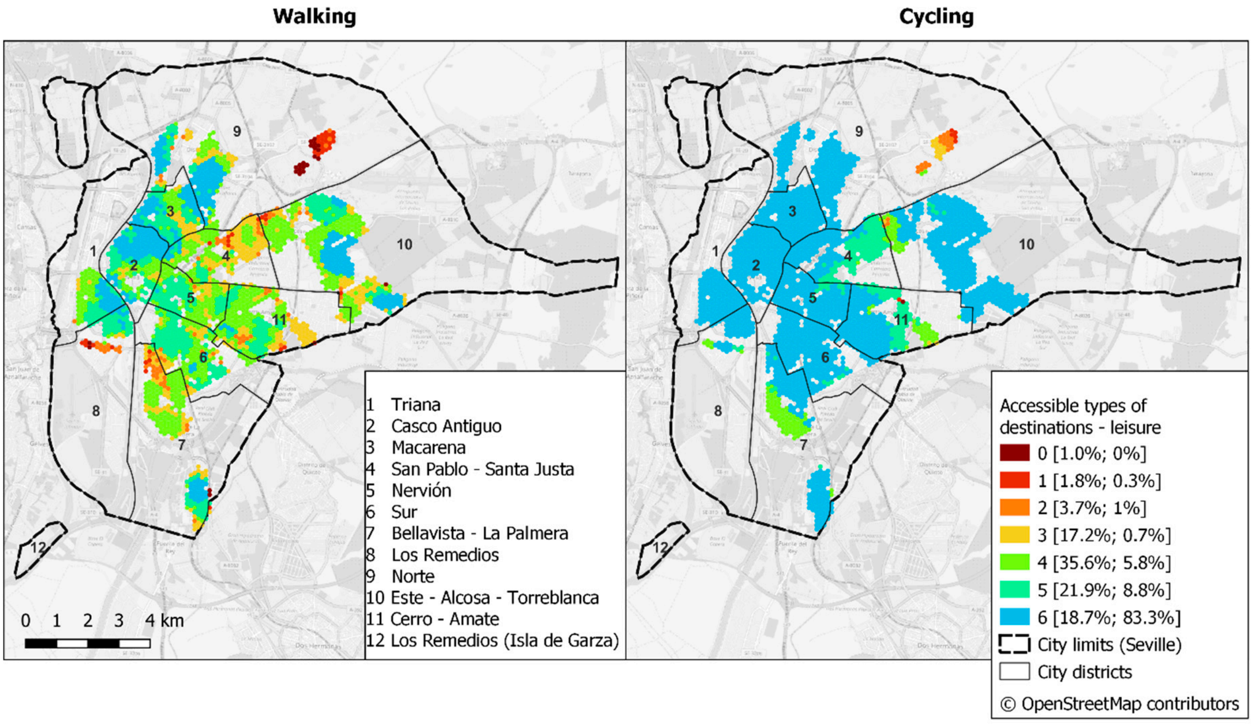

Figure 14. Number of accessible types of destinations for the category of leisure. The numbers in square brackets represent the share of residential areas for walking and cycling (same order) for each category of the legend. (Own elaboration).

Since we can only present indicative results for the category of commerce, they have to be interpreted cautiously as their certainty has not been demonstrated. What we can observe on the map (Figure 15) is that the destinations are concentrated in the city centre, which seems to be a realistic result. However, the underserved areas at the edges of the city should be reviewed in the future by complementing the open OSM data with commercial data sources such as Google or TomTom.

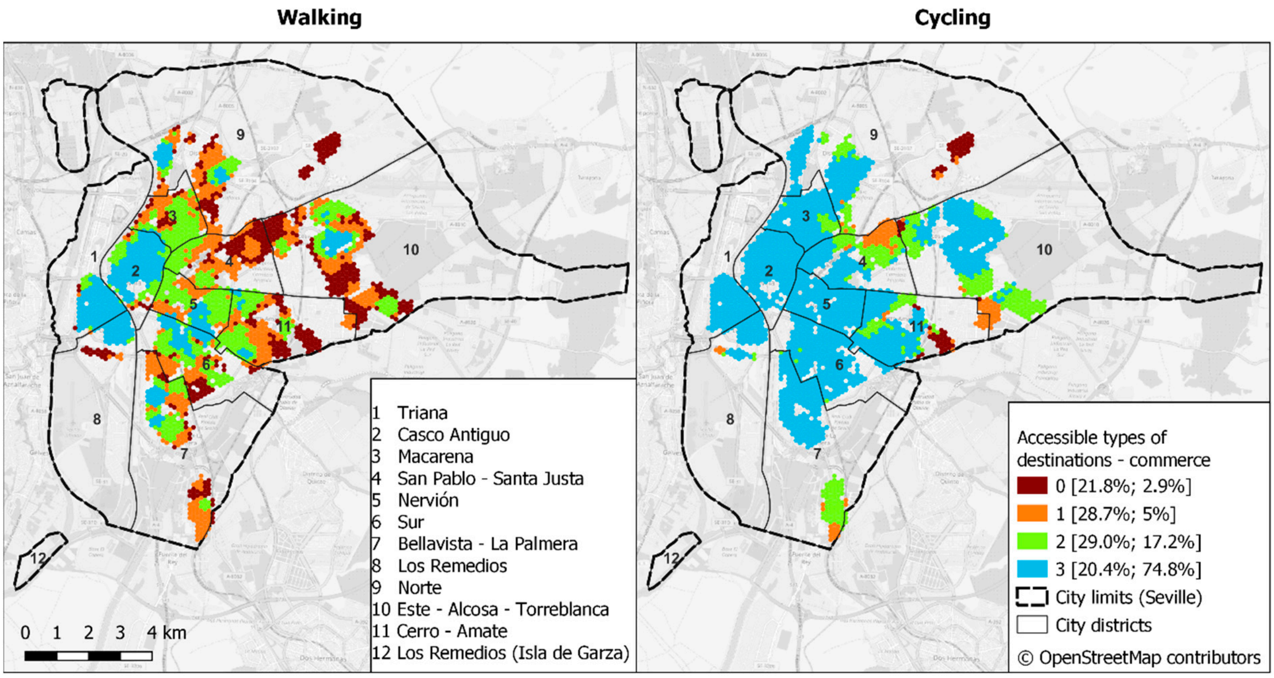

Figure 15. Number of accessible types of destinations for the category of commerce. The numbers in square brackets represent the share of residential areas for walking and cycling (same order) for each category of the legend. (Own elaboration).

The map in Figure 16 shows the overall situation, where all the types of destinations from all categories are included in the map. It is visible that areas closer to the city centre have a higher potential to function as an x-minute city with the suggested accessibility time thresholds. Large areas of the historic city centre, Triana, Macarena, Nervión, and Sur are the areas with the highest accessibility values. In total, 50.1% of the residential area have walking access to at least three-quarters of all the destination types considered in this analysis (at least 17 out of 23). A further 36.3% of the residential areas have access to at least half of the destination types. People living in the remaining 13.6% of the residential areas can access only half of the destinations. The areas where the need for interventions is the highest are the south of Triana, Valdezorras, Este–Alcosa–Torreblana, and in Cerro–Amate. Since cycling can cover larger areas in the same amount of time, it can be a good complementary mode to access destinations further away. Even though some areas on the outskirts still remain underserved by cycling, the share of the population living in these areas remain relatively low.

In conclusion, it can be stated that sustainable urban mobility options are widely accessible for a large proportion of the population in Seville. The current conditions provide a good base for an interconnected x-minute city where the use of public transport and active mobility could dominate. However, there are areas where interventions are necessary to expand the cycling infrastructure and the bike-sharing system. In the case of the other destination categories, the presented results could help us to identify areas where further interventions are necessary and that should be examined in detail in the future.

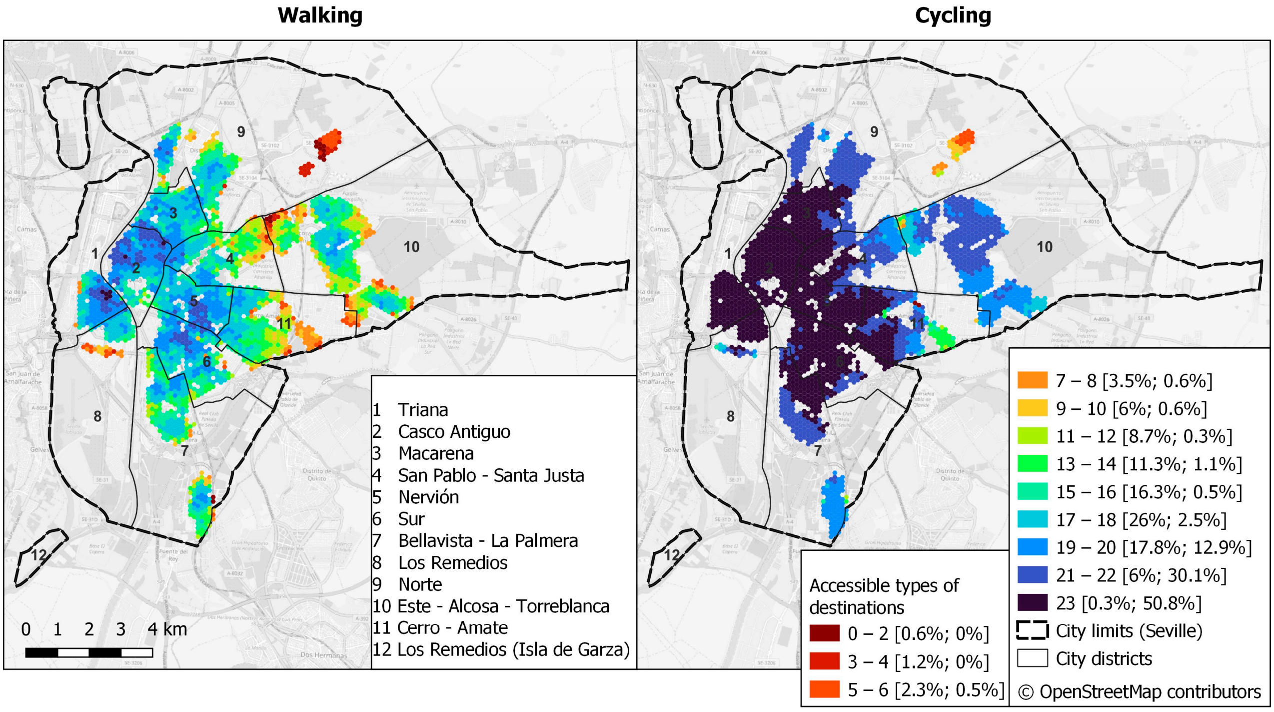

Figure 16. Number of accessible types of destinations for all categories. The numbers in square brackets represent the share of residential areas for walking and cycling (same order) for each category of the legend. (Own elaboration).

6. Discussion on the Limitations

The advantages of the developed scalable and robust methodology lie in its relatively low data and computational requirements, which make the present analysis reproducible in other contexts. However, to achieve these advantages, we had to apply various simplifications. Therefore, we should mention the limitations of the current study, which can otherwise be mitigated by a more detailed analysis focusing on specific issues or on a smaller study area.

The presented methodology could be further developed to have a more inclusive accessibility measure. For instance, to adapt the methodology to the local needs, further aspects can be incorporated into the travel shed generation that affect the willingness for or characteristics of walking. Such an approach could include the integration of walkability or cyclability analyses, for instance. An example could be the classification of street segments by stress level, considering comfort and inclusive design, as Da Silva, King, and Lemar [50] did with cycling. Another option would be adjusting speed factors to accommodate the characteristics of individuals based on their abilities or age. As a result, the size and shape of the travel sheds would represent the actual reach in a more realistic and sophisticated manner. Once the areas to be developed are identified, there are various tools for further micro- or street-scale analysis (e.g. ,walkability assessment) and methods to involve people living in the area in the planning process (participatory planning) and to incorporate their perceptions.

Although the presented results represent a good overview on the provision of various types of destinations essential for a 15-minute city, two important amenities are missing that could be incorporated in the future. Although workplaces and affordable housing are fundamental for living, as defined by Moreno et al. [1], these were excluded from the analysis due to their limited data availability and for scalability reasons. For example, work-related trips accounted for 31.2% of all trips in Seville [80], which were not covered by our analysis. However, as Mouratidis [93] argues, having jobs accessible within 15 min for the whole urban population is unrealistic, even in larger cities, since the profile of workers should match the skills in need (e.g., consider highly specialised job market segments).

Although some other trips were excluded from the analysis for simplification, such as non-daily shopping trips or trips related to visiting someone, potentially half of the trips in the city of Seville were related to the introduced types of destinations.

The applied cumulative opportunities measure, by its nature, does not incorporate perceptions and preferences. All destinations falling in the isodistance are treated equally, regardless of the distance from the origin or the quality of service [65]. A potential improvement in the methodology would be the incorporation of the travel time required to reach each destination in the impedance function. The perception of travel time and distance depends on various factors, as well as on the acceptance of or willingness to utilise the different modes of transport [67]. The calculated cumulative opportunity accessibility metrics potentially overestimate the perceived accessibility of disadvantaged groups by overlooking their needs [48]. The incorporation of temporal aspects of spatial accessibility could be also important (considering night shifts, the varying public transport service frequencies throughout the day, or the opening hours of shops) [61].

As Allam et al. [42] emphasise, the participation of the local community is critical for ensuring the successful implementation of the 15-minute city concept. People have different expectations, and their decisions on choosing a service not only depend on the proximity of the services but on other characteristics too. The presented methodology assumes that people visit destinations accessible within the defined time thresholds regardless individual preferences, which does not necessarily represent the reality if these amenities do not meet the preferences of people. Such aspects could include customer satisfaction, which is related to the quality of services, pricing, or capacity. For example, Vu et al. [94] present a methodology to assess the phenomenon that occurs when a destination further away is chosen instead of the closest one, referred to as amenity bypass, by using detailed movement data obtained from connected vehicles. Since data on the quality of services are hardly available, incorporating these aspects was not feasible. However, in the case of some services, ratings from recommendation and review platforms might be used to define a more accurate impedance function. Another potential approach to map local preferences could be the application of PPGIS (Public Participation GIS), a GIS tool that could support public participation. In the case of online tools, it is important to mention that equal access should be emphasised, and alternatives should be available for the non-digital population.

Despite the discussed disadvantages of the cumulative opportunities measure, it satisfies the needs of the presented research, while its modest data and computational requirements make it ideal as a scalable methodology [65]. However, it is inevitable that there are more sophisticated ways for accessibility analysis, as discussed by various authors [16,65,95]. For example, a gravity-based measure could incorporate the quality and travel time or distance that was discussed above; however, cumulative opportunity and gravity-based measures often strongly correlate [16].

As discussed, the results of the analysis rely on the accuracy of the OSM data. The walking network as well as data on some destination categories were obtained from OSM. OSM has the advantage of being regularly updated, and it is also easy to obtain for other cities. Although it was the best available option, there might be errors and accuracy problems in the data that must be noted as an important limitation. Other researchers, such as Hosford, Beairsto and Winters [16], also faced similar limitations. However, this limitation can be overcome by using local authoritative data sources or commercial data sources, and the types of destinations can also be tailored to the available data sources (some categories can be left out or new types can be added based on the available data).

The study area is limited to the core city of Seville; however, current movement patterns show intensive interactions with the functional urban area [80]. Although we decided to limit the research to the core city in this study, a potential future line of research could be an extended analysis on the functional urban area. The results of such an analysis could highlight the patterns of how accessibility to essential amenities characterises commuting habits. Local preferences were incorporated by the review of local planning documents on accessibility requirements; however, this data could have been complemented by further data, such as surveys or big-data sources that have been mentioned in this paper, to achieve more accurate results.

7. Conclusions

The x-minute city has become a widely researched topic that has also caught the attention of policy makers worldwide. The communicability and implementation pragmatism of the x-minute city are important abilities from a political or policy-maker perspective [42]. The x-minute city concept is easy to interpret by politicians, decision makers, or people living in the city. Besides the potential benefits of the x-minute city concept discussed in this paper, these characteristics make the x-minute city concept a capable urban planning concept to tackle various contemporary urban challenges.

In this paper, an analysis of the x-minute city concept was presented using the methodology of accessibility analysis to evaluate accessibility to a list of essential destinations. A scalable quantitative methodology was presented that can be reproduced in any other city. The presented methodology and results can help urban planners and policy makers to evaluate the provision of various amenities, test scenarios for improving accessibility, and identify areas where interventions are needed, be they improvements in the provision of services (amenity gaps) or in the network (for example, the introduction of missing links).

We can conclude that in the case of Seville, the x-minute city concept is a feasible concept, and in many parts of the city, the requirements are already being fulfilled for the majority of essential destinations. As Bartzokas-Tsiompras and Bakogiannis [61] showcase, Seville is one of the high performers among European cities when the 15-minute city requirements are compared. We expect that in many European cities, especially in historic areas that have been shaped by natural organic growth for centuries or in other areas where the provision of services was among the planning principles, the x-minute city concept could be a viable option too. The questions are how the x-minute city is defined, what types of destinations are considered to be essential, and how well these destinations meet local needs. It is also important to examine how feasible the x-minute city is in areas where certain services are not accessible today. For example, whether it is realistic to establish a service in a particular area if it is not economically rational or if the population density does not meet the minimum requirements necessary for optimal operations (take the example of the minimum number of children to open a new school, for instance). Further aspects could be topography and weather conditions, which could pose important limitations, especially in extreme cases. These are important aspects that will certainly need to be examined, as well as the characteristics of different cities in terms of the availability of different services, and the differences between urban and rural and urban and suburban areas.

Some further concerns and future research lines that arise related to the x-minute city concept should be also mentioned, since there are many open questions related to the operationalisation of the concept [58]. The characteristics of cities and their problems vary widely; therefore, the x-minute city should not be considered a one-size-fits-all solution [96]. There are various aspects that should be considered when the concept is implemented. For example, x-minute city policies should be developed in a way that reflect the complexities of cities [51] and the existing and future spatial and social inequalities, focusing on specific needs of people across different social groups, ages, abilities, individual preferences, lifestyles, and cultural references [55]. Public engagement, participatory planning, and decision making must, therefore, be emphasised when x-minute city policies are elaborated. The 15-minute city concept is aligned around four pillars (density, proximity, diversity, and digitalisation) [1], and the presented paper focuses on the first three. However, as Moreno et al. [1] highlight, the implementation of the 15-minute city concept requires a holistic approach in which all the main pillars of the concept are addressed, including that of housing and affordability.

Considering that many of the contemporary mobility problems can be efficiently tackled at the metropolitan or higher level, an important future line of research could be the extension of the x-minute city concept to metropolitan areas so that this issue can be addressed adequately. For instance, Poorthuis and Zook [97], using the example of the Netherlands, raise the question of how concepts for just and sustainable communities, such as the x-minute city concept, can be operationalised in suburban or rural areas.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. List of destinations and destination groups of selected articles that analysed the x-minute city/neighbourhood concept (the number in square brackets represents the assigned temporal or distance-based accessibility thresholds in minutes or in metres, as used by the authors in their analysis.).

Location	Source	Comment	Destination Categories and Destinations						
			Living and Transport	Working	Commerce and Catering	Healthcare	Education	Entertainment, Leisure	[Other]
-	[1,12]	theoretical framework of the 15-minute city concept (predominantly descriptive requirements are listed for each category)	housing, energy, environment, facilities, transportation	atmosphere, access, diversification, services	eating, non-food purchase, public services	access to care, prevention, emergency, living environment, well-being, sport, pollutions	access, availability, accessibility, performance, guidance	holidays, culture, entertainment, associations	
Tempe, Arizona, US	[50]	20 min accessibility assessment	-parks (parks, dog parks, and preserves)		-grocery stores -retail goods/services (pharmacy/drug stores, hardware stores, bike shops, shopping districts, and convenience stores) -restaurants -civic institutions (city offices/facilities, fire stations, and police stations) -services (banks, post offices, beauty salons/barber shops, and laundries/cleaners)	-health services	schools (day care, K–12 (from kindergarten to 12th grade), and higher education)	-festivals and special-event spaces (stadiums, theaters, concert halls, and other festival and special-event venues) -city recreational and cultural amenities (community centres, museums, libraries, public art, aquatic centres, gardens, zoos, and "points of pride") -fitness centres	faith-based organisations (houses of worship and faith-based community services)
Melbourne, Australia	[98]	20-minute neighbourhoods	-bus stops -train stations -tram stops		-ATMs or banks -bars, pubs, and nightclubs -dine-in places (café, fast food, food court, restaurant) -post offices -pharmacies -shopping centres	-aged care -health facilities, including dental -maternal and child health centres	-childcare centres -kindergartens -primary schools -secondary schools	-community centres -neighbourhood parks -libraries -playgrounds	places of worship (church, mosque)

Table A1. *Cont.*

Location	Source	Comment	Destination Categories and Destinations						
			Living and Transport	Working	Commerce and Catering	Healthcare	Education	Entertainment, Leisure	[Other]
Melbourne, Australia	[99]	part of the long-term development plan of the city	-safe streets and spaces -affordable housing options -ability to age in place -housing diversity -transport: walkability, safe cycling network, local public transport	-well connected to public transport -local employment opportunities	-local shopping centres	-local health facilities and services	-local schools -lifelong learning opportunities	-local playgrounds and parks -green streets and spaces -community gardens -sport and recreation facilities	
Barcelona, Spain	[29]	15-minute accessibility	-collective rapid transit [10 min] -day buses [5 min] -night buses [10 min] -shared bike stations [5 min] -bike lanes [5 min]		-supermarkets [10 min] -markets [10 min] -fresh food [5 min] -daily non-food [5 min] -catering [5 min] miscellaneous services [5 min]	-health [10 min] -social services [15 min] -day centres [10 min]	-preschool education [5 min] -primary education [5 min] -secondary education [10 min]	-shows [10 min] -libraries [15 min] -civic centres [10 min] -children's playgrounds [5 min] -sports facilities [10 min] -squares and parks > 1000 m^2 [5 min] -squares and parks > 10,000 m^2 [5 min]	
Malaga, Spain	[31]	15-minute accessibility	-bus stops [300 m] -metro stops [500 m] -bike lanes [300 m]		-grocery shops [300 m] -markets [500 m]	-health centres [500 m] -hospitals [1000 m] -social centres [500 m]	-kindergartens [300 m] -elementary schools [300 m] -secondary schools [500 m]	-playgrounds [300 m] -green areas between 1000 and 5000 m^2 [500 m] -green areas over 10,000 m^2 [900 m] -sports centres [500 m] -cultural centres [500 m]	

Table A1. *Cont.*

Location	Source	Comment	Destination Categories and Destinations						
			Living and Transport	Working	Commerce and Catering	Healthcare	Education	Entertainment, Leisure	[Other]
Valencia, Spain	[87]	spatial plan defining the optimal density of various urban functions				-health centres [600 m] -social centres [900 m] -senior centres [600 m] -day-care centres [900 m] -youth centres [900 m]	-kindergartens [300 m] -elementary schools [300 m] -secondary schools [600 m]	-cultural centres, libraries [900 m] -minor sports centre [750–1000 m] -major sports centres [2000 m]	
Ireland	[27]	analysis of 5 cities in Ireland	-bus stops and stations -light-rail stations -train stations -safe pedestrian networks -safe cycling networks -active travel facilities -bicycle- and scooter-sharing stations -car-sharing schemes -assisted-mobility services	-offices -co-working hubs -workshops and factories -institutions, facilities, and services -remote/online jobs -field jobs and jobs in the community -building and construction sites -print shops and tech support -banks and post offices (supporting)	-grocery shops -markets -supermarkets -places selling healthy meals -cafés, pubs, and restaurants -shops and retail stores -post offices and newsagents	-health centres and GPs -dentists -pharmacies -physical and mental therapy centres -childcare centres and nurseries -senior care and nursing homes -community support -legal and financial support	-primary schools -secondary schools -third-level institutions -special-needs schools -libraries -online courses (and online access) -community classes -educational environments -skill hubs	-parks and green spaces -sports grounds and gyms -playgrounds -theatres and cinemas -museums and art galleries -hotels and tourism destinations	-allotments -community gardens -community kitchens -food banks -open orchards -faith groups and places of worship
Liverpool City region, UK	[55]	equity analysis	-buses (bus stops) -trains (railway stations, junctions, and halts)		-specialised food shops (bakeries, butchers, confectioners, delicatessens, fishmongers, tea and coffee, merchants, herbs and spices, grocers, farm shops, and pick-your-own farms) -general food shops (supermarkets)	-doctors -health products (chemists and pharmacies)	first, primary, and infant schools	-sporting facilities (sports complexes) -public parks -recreational spaces -places of cultural and entertaining activities (cinemas, nightclubs, social clubs, theatres, and concert halls)	-places of worship

Table A1. *Cont.*

Location	Source	Comment	Destination Categories and Destinations						
			Living and Transport	Working	Commerce and Catering	Healthcare	Education	Entertainment, Leisure	[Other]
Milan, Italy	[39]	15-minute city analysis			-food/grocery stores -commercial stores (including clothes shops, electronics shops, etc.) -restaurants -other (post offices, banks, etc.)	-health facilities	-educational facilities	-cultural venues -parks and green spaces -sports facilities	
Turin, Italy	[53]	15-minute city analysis			-post offices -open-air markets	-neighbourhood health centres -counselling centres -social care services -registry offices	-nurseries -kindergartens -elementary schools -middle schools -secondary schools	-green areas -playgrounds -playrooms -sports facilities (swimming pools, tennis courts, etc.) -libraries -theatres -cinemas	-police stations -churches
Toruń, Poland	[100]	15-minute city analysis	Multiple tags from OSM						
Spain	[83]	Spanish Urban Agenda	-road space for pedestrians, bicycles and PT [target not defined] -ISDG 11 indicator: access to PT [target not defined]		everyday food and products: -supply of basic foods [300 m] -municipal markets [500 m]	medical centres: -health centres [500 m] -hospitals [1000 m] social centres: -community social service centres and day centres for seniors [500 m]	Schools: -children's school [300 m] -primary schools [300 m] -secondary schools [500 m]	sports centres: -sports facilities for public use [500 m] cultural centres: -public libraries, museums, and other cultural centres [500 m] Entertainment centres: -cinemas, theatres, and other leisure centres [500 m] Green urban spaces or leisure areas: -green/recreation > 1000 m^2 [300 m] -green/recreation > 5000 m^2 [500 m] -green/recreation > 1 Ha [900 m]	separate waste collection points: -points for separate waste collection (organic, paper, glass and plastic) [100 m]

Table A1. *Cont.*

Location	Source	Comment	Destination Categories and Destinations						
			Living and Transport	Working	Commerce and Catering	Healthcare	Education	Entertainment, Leisure	[Other]
Seville, Spain	[89]	Special Plan for Environmental Sustainability Indicators of Urban Development Activies in Seville	-public transport stops [300 m] -cycling networks [300 m] -bike parking [300 m]		-municipal markets [10 min]	-healthcare centres [10 min] -social care services [10 min]	-pre-school education [5 min] -primary education [5 min] -secondary education [10 min]	-civic centres [5 min] -libraries [10 min] -municipal sports facilities [10 min]	-urban complexity -mixed functions in residential areas (commerce, services) -mixed use on ground floor areas (services, commerce) -pedestrian streets
Florence, Italy	[57]	comprehensive 15-minute city index	-housing viability -government services -safety services -culture and cults services -environmental quality -slow-mobility services -fast-mobility services -sport services	economy and sustainability	food services	health services	education services	entertainment services	
Oslo, Norway	[54]	15-minute city analysis (15-minute walking catchment)			-bank buildings, post offices -shopping centres -shops, commercial buildings -restaurants, fast food, food courts -bakeries -cafés -supermarkets, convenience stores, kiosks	-hospitals -clinics, doctor's offices, medical centres, emergency, animal hospitals -health centres, health stations -dental clinics -pharmacies	schools, kindergartens	-libraries -playgrounds -museums, art galleries -sports halls -indoor ice rinks -swimming pools -gyms -cinemas, theatres, opera, concert halls -green spaces	
121 European urban areas	[61]	15-minute city index based the new urban accessibility framework (ITF, 2019)			-food shops -restaurants	-hospitals	-schools	-recreation -green spaces	

Table A1. *Cont.*

Location	Source	Comment	Destination Categories and Destinations						
			Living and Transport	Working	Commerce and Catering	Healthcare	Education	Entertainment, Leisure	[Other]
Barcelona, Spain	[45]	15-minute city analysis and mobility flows	-public transport (bus stops, metro stations, bike stations, etc.)		-finance (banks and similar) -food (restaurants, bars, cafes, etc.) -retail (malls, supermarkets, shopping venues)	-health facilities (hospitals, primary care centres, medical offices, etc.)	-education (schools, universities, etc.)	-entertainment (indoor places where people pay for access) -recreational areas (parks, outdoors, etc.)	-government facilities -professional services -religious venues
Bogotá, Columbia	[60]	15-minute city index (diversity, walkability, accessibility, individual preferences)	-bus stops -BRT stations -bike sharing -cable car stations		-grocery shops -commerce -restaurants -drugstores -hairdressing -laundry services -bars -clothing stores -banks	-medical services -hospitals	-vocational training -preschools -schools -universities	-parks (>5000 m^2) -sport venues -cultural venues	-veterinaries
Ferrera, Italy	[58]	15-minute city index for Italian cities based on OSM data			-grocery shops (15+ related OSM features) -post offices and banks -catering -shops (50+ related OSM features)	-health	-education (all levels, including language schools and other specialised schools)	-entertainment (10+ related OSM features) -parks	

Appendix B

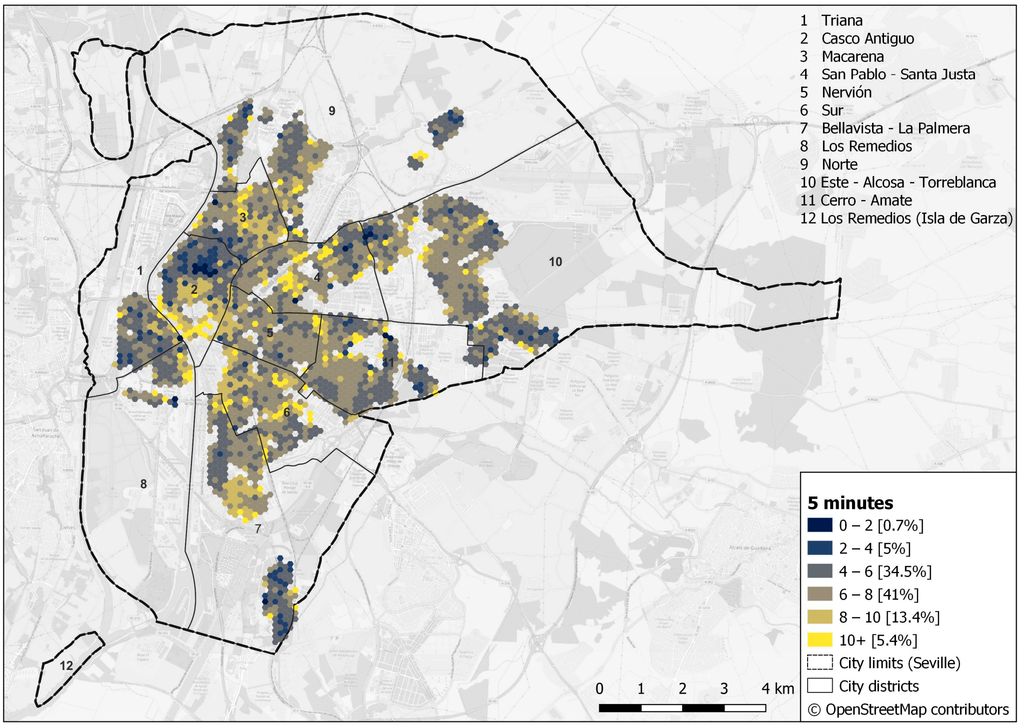

Figure A1. Comparison of the size of walking and cycling travel sheds across the study area (5 min). The numbers in the legend represent how many times larger the cycling shed is than the walking shed for a given grid cell. (Own elaboration).

Appendix C

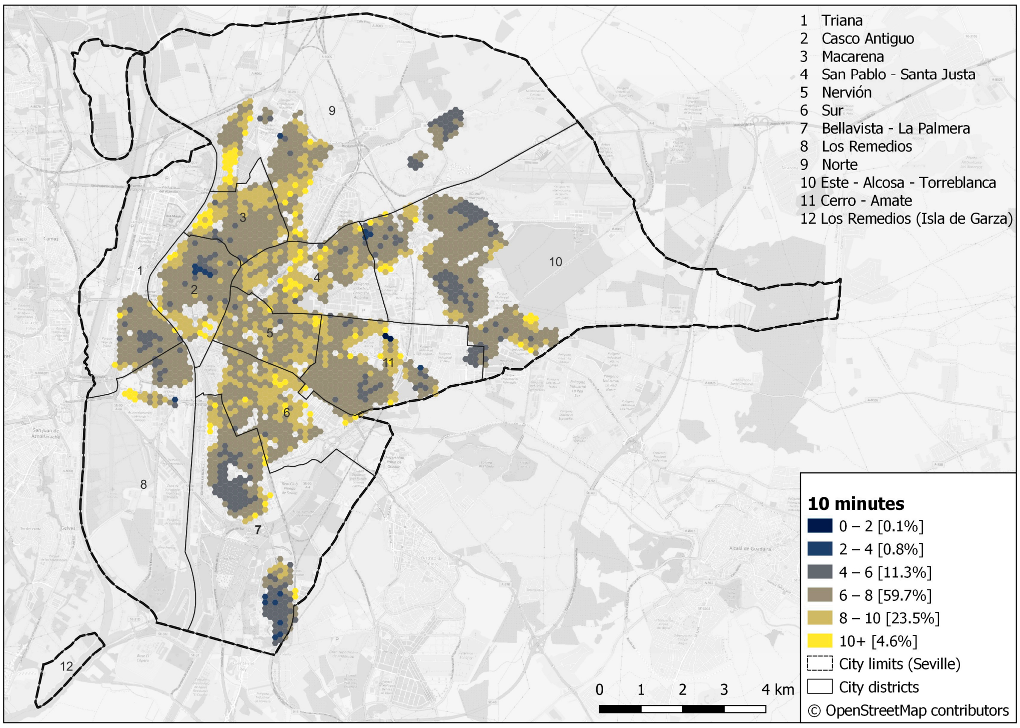

Figure A2. Comparison of the size of walking and cycling travel sheds across the study area (10 min). The numbers in the legend represent how many times larger the cycling shed is than the walking shed for a given grid cell. (Own Elaboration).

Appendix D

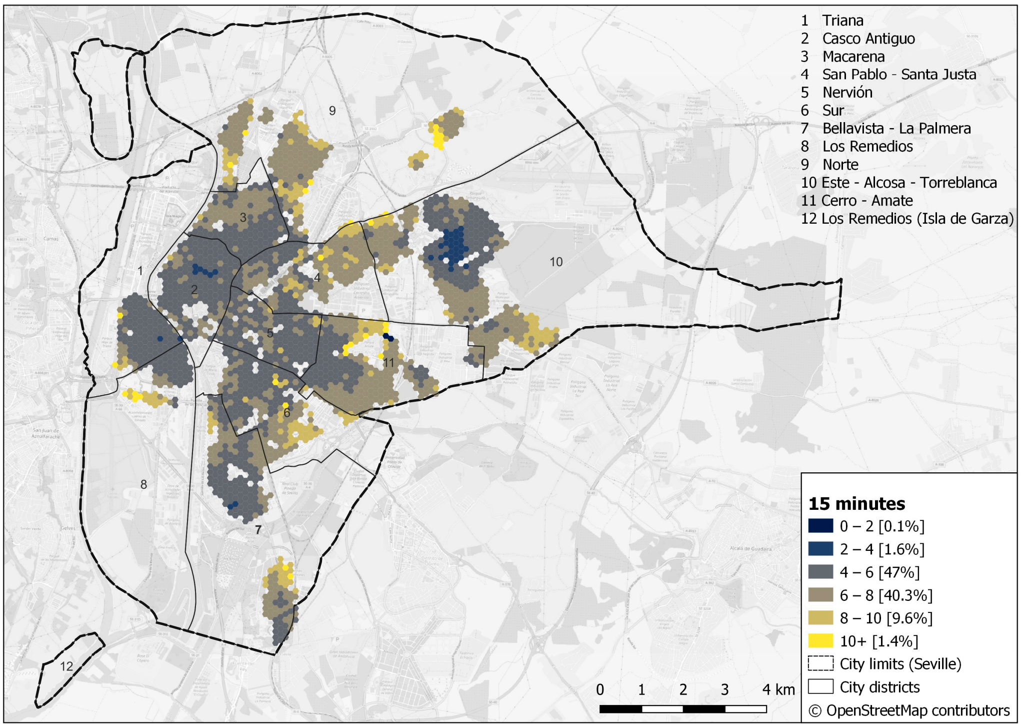

Figure A3. Comparison of the size of walking and cycling travel sheds across the study area (15 min). The numbers in the legend represent how many times larger the cycling shed is than the walking shed for a given grid cell. (Own elaboration).

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