Analysing Bicycle Parking in Barcelona: Geospatial Insights

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Abstract– This paper examines the often overlooked topic of bicycle parking infrastructure and it's implications for urban mobility from a geospatial perspective. Bicycles offer numerous benefits over cars, being healthier, greener, and more affordable, particularly in urban environments. However, inadequate bicycle parking can lead to damage and theft, hindering cycling adoption. Existing literature mainly treats bicycles as dynamic entities while ignoring their static nature during parking. This study addresses this gap by investigating bicycle parking distribution, proximity, and occupancy data in a city. The goals involve analyzing parking facility distribution across the city, quantifying walking time to access and return from facilities, and investigating correlations between occupancy and proximity to municipal infrastructure. The research findings provide valuable insights into optimizing bicycle parking, thus fostering a transition towards more sustainable urban mobility.

Keywords– Bicycle Parking, GIS, Urban Mobility, Distribution, Proximity, Occupancy.

Resum– Aquest article estudia els aparcaments de bicicletes des d'una perspectiva geoespacial. Les bicicletes ofereixen nombrosos avantatges respecte als cotxes, sent més saludables, ecològiques i assequibles, especialment en entorns urbans. No obstant això, un aparcament inadequat pot provocar danys i robatoris, obstaculitzant l'adopció de la bicicleta com a mitjà de transport. La literatura existent sol tractar les bicicletes com a entitats dinàmiques i ignora el seu caràcter estàtic durant l'aparcament. Els objectius principals inclouen analitzar la distribució dels aparcaments a la ciutat, quantificar el temps necessari per accedir-hi i tornar-ne, i investigar correlacions entre l'ocupació i la proximitat a la infraestructura municipal. Els resultats aporten informació valuosa per optimitzar l'aparcament de bicicletes, fomentant així una transició cap a una mobilitat urbana més sostenible.

Paraules clau– Aparcament de Bicicletes, SIG, Mobilitat urbana, Distribució, Proximitat, Ocupació.

1 INTRODUCTION

Bicycles are a healthier, greener, and cheaper than cars. They use less space and are faster in urban environments. However, like cars, bicycles spend most of their lifetime immobilized and secured waiting for their next trip [4],[6]. Most of the literature about cycling infrastructure treats bicycles as dynamic entities and focuses on cycle paths [4], mostly ignoring the fact that bicycles are static most of the time. It is true that the purpose of bicycles, and vehicles, is to move people from one place to another in a comfortable and safe way. Nonetheless, adequate, and well-designed bicycle parking can prevent bicycle damage, contribute to lower theft, and encourage people to cycle [5].

Unlike cars and motorbikes, non-anchored bicycles are vulnerable to theft as they can be easily taken away. Bicycle users are aware of how vulnerable unanchored bicycles are, and in the absence of proper bicycle parking facilities, they often opt for anchoring them to lampposts, road signs, railings, and other kinds of urban street furniture [6]. This practice is called 'fly-parking' and is often not allowed by local regulations [6]. Some municipalities, such as Valencia or Bogotá, allow some typologies of fly-parking in the absence of proper parking facilities [10]. The regularization of fly-parking is an interesting measure to encourage cycling, as it can allow cyclists to park near most of their destinations, thus making cycling a more competitive option in urban areas where parking is often an issue.

Even if bicycle parking has not been given as much attention as other cycling topics, the number of peer-reviewed publications has greatly increased in the last two decades [4]. Most of the studies include bicycle parking as an independent variable, among others, in a multivariable statistical analysis [4]. Heinen and Buehler argue that studies can be classified in four relatively distinct categories based on the location of the bicycle parking infrastructure [4], with

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many focusing on employment and education locations, a considerable number focusing on public transport stations and stops, few focusing on residential locations, and then, multiple studies focusing on cities and other location [4]. In this context, there seems to be a lack of studies that analyse bicycle parking from a spatial point of view. Not as another variable in a cyclability index or any other spatial or statistical product, but as a crucial and fundamental piece of infrastructure to foster the transition to a more sustainable mobility.

The hypothesis of this study is that analysing bicycle parking from a geospatial point of view can provide insights useful to make urban mobility more sustainable. The goal of this study is threefold. First, it aims to examine the distribution of bicycle parking facilities across the study area. Subsequently, it seeks to quantify the walking time required to access and return from bicycle parking facilities. Lastly, the study will utilize occupancy data to investigate areas with higher average occupancy and explore potential correlations between occupancy and proximity to specific municipal infrastructure. The walking time required to access and return from bicycle parking facilities has been estimated for residential and working locations, shops, and municipal infrastructure.

Examining the distribution of bicycle parking facilities is crucial for obtaining a comprehensive overview of the city and provides valuable context for interpreting subsequent analyses. This examination has facilitated the identification of areas characterized by high and low densities of parking locations, as well as areas where no facilities are present. The distribution analysis encompasses five distinct administrative and statistical boundaries, ranging from districts to census units. To better comprehend the current distribution, the results have been correlated with the area of the divisions, population, and income data. Regrettably, in many cases, no significant correlation appears to exist among the variables studied.

The quantification of walking time required to access and return from bicycle parking facilities plays a pivotal role in assessing the effectiveness of the distribution of bicycle parking infrastructure. Excessive walking time may lead individuals to opt for alternative modes of transportation or engage in fly parking practices. The proximity of parking facilities to the destination is a significant factor in evaluating their convenience [1]. According to the Bicycle Parking guide published by the Spanish Government, it is recommended that parking locations near shops be situated within 30 meters, while those near public infrastructure should be within 25 meters from the entrance [9]. For facilities near workplaces or residences, the recommended distance should not exceed 100 meters [9]. The measurement of walking distance will be conducted separately for work and residential locations compared to shops and public services, due to differences in parking duration and the nature of the available data. Residential and work addresses are utilized to calculate the distance required to access and return from these locations, whereas the location data for shops and public services is extracted from the open data.

Occupancy is one of the crucial indicators to measure the success of a bicycle parking facility. An empty facility may mean a lack of purpose or perceived safety, wherever it's saturation may lead to fly parking practices or event to a modal change [5]. Unfortunately, occupancy data is scarce and an unbalanced sample may lead to wrong conclusions. In this case, the student has used data from three different sources and periods. What the student has done is to evaluate the distribution and consistency of the available data for Barcelona, and study the occupancy.

The study has been structured in the following way, first, the context is described. The, the methodology of the three research questions. Then the results of using the aforementioned methodology. Afterward, there is the discussion, the future lines of work and the conclusions. At the end, you can find the references and the appendices.

2 Context

Obtaining accurate and up-to-date information about bicycle parking facilities in municipalities can often be a challenge. Such data is frequently unavailable or not provided in a geospatial format. OpenStreetMap (OSM) serves as an alternative source for geospatial information on bicycle parking facilities, but even in OSM, the data may not always be up-to-date. When considering the ten most populated cities in Spain, only a subset of them has geospatial information available for bicycle parking facilities A.1. Furthermore, the number of facilities documented in OSM is generally lower compared to the data provided by municipal open data sources.

Bicycle parking occupancy data is almost non-existent. In the case of Barcelona, there are three sources of data in process of being unified. First, we have data from a study made in 2021 and recently published [5], then we have the data that was collected by the members of the city lab team using the Bicycle Parking App, and lastly, we have the data from BiciZen, a project that aims to make city regions more bikeable [2]. BiciZen has been designed to be able to collect such data, and the other two datasets are in progress of being integrated to BiciZen. Even with the promising opportunities that BiciZen may bring, the project official launch was the 5th of July, and it only recently surpassed the 1100 bicycle parking observations, of which, 300 are from Barcelona.

Barcelona has been selected as the case study due to its significant presence of on-street public bicycle parking facilities, totalling 3.936 according to the open data [5]. The city also boasts a substantial number of bike sharing stations, with 519 stations as reported in reference [6]. However, it is noteworthy that Barcelona has a limited number of safe public bicycle parking facilities, with only six available [2]. An interesting observation is that Barcelona declined to install BiciBox, the safe parking facilities developed by the regional government, Area Metropolitana de Barcelona (AMB) [8]. This decision may indicate a prioritization of bicycle sharing stations over the establishment of secure bicycle parking facilities.

The on-street public bicycle parking in Barcelona has witnessed a steady growth since 2002 [5], even though it has not received significant attention [5]. Additionally, a recent analysis of bicycle parking in Barcelona utilized sample data from various districts of the city [5]. The study collected observations ranging from 4 to 15 for a total of 163 parking locations, aiming to examine usage patterns, occupancy rates, duration times, and rotation rates of on-street parking

[5].

Since February 2022 the student has been working as the bicycle parking intern in the City Lab BCN, a research group in the ICTA-UAB. During the first semester, the student worked on organizing the Bicycle Parking workshop. He was also involved in the creation of the BiciZen project, digitalized bicycle parking locations using the Bicycle Parking Project app, and even created and progressive web app to digitalize bicycle parking as a bachelor thesis [7]. During the current academical year, he has been working mainly on BiciZen. Now, he is working on the management of the BiciZen back office and the website.

3 METHODOLOGY

3.0 Architecture

During the study, various geographic and alphanumeric data will be imported to GIS tools to be processed with the goal to generate information. Two GIS software have been used for the study, QGIS and ArcGis Pro. To store, access, update, and export the data and information used and generated during the analysis, PostgreSQL, a relational database management system, has been selected. R has been used to explore the data and to create infographics.

The geographic database hosted with PostgreSQL will have six schemas, a first schema to store raw data, and five other schemas to store the intermediate and final tables generated during each of the three research questions. Initially, it was only four schemas, nonetheless, the results of the second research question have been separated into three different schemas. Each schema will then have its own tables, imported though pgAdmin 4 in case of raw alphanumerical data, and though QGIS or ArcGis Pro in case of geographical data. This approach allows to easily load data from the database to the analysis tools, to perform basic statistical calculations from the same database management system, and to have all the information stored in an organized and coherent way.

During the analysis, the geographic operations will be performed using python and the statistical ones using SQL and R. Python will be mainly used though PyQgis and ArcGis Pro Notebooks. The goal is to provide flexibility to the analysis as it will be easy and fast to reproduce and re-run the whole process, or the different parts.

3.1 Analysing bicycle parking distribution

The analysis of bicycle parking distribution, has been done using QGIS and data from the Open Data Barcelona, concretely, the datasets D1,D2 (See A.2) . First, a spatial join between the bicycle parking locations in Barcelona and the census sections of the city of Barcelona has been done, associating each parking location with the census section it is located into. As census sections also contain data about greater administrative areas, this operation allows to associate to each parking location with the ID of each of the administrative areas of Barcelona it's contained in. Once the previous layer has been stored in the database, we combine it with the tables that contain the various administrative boundaries, summarizing the bicycle parking data into the following indicators, and then importing the data back to QGIS to visualize it:

- BP_FACILITIES: Number of bicycle parking facilities in the administrative areas.
- BP_CAPACITY: Total capacity of the bicycle parking facilities in the administrative area.
- BP_AVG_CAPACITY: The average capacity of the bicycle parking facilities in the area.

To calculate the correlation between the number of bicycle parking facilities and the area of the examined administrative divisions, the area of the division has been calculated in QGIS using the field calculator. The population and income data have been extracted from D3 and D4 (See A.2). In the case of income, there was only data per districts and census divisions, due to that, the correlation was not calculated at the neighbourhood level not the statistical units one.

3.2 Analysing walking distance to bicycle parking facilities

Based on the bicycle parking guide made by the MITM, the recommended distance between a bicycle parking and the destination of the trip depends on the time that the bicycle will be parked. In the study, we will estimate the walking distance to residence and work locations, shops, and public facilities. For each of the aforementioned destinations, the MITMA guideline establishes the following recommended distances:

- Public facilities: 0-25 m.
- Shops: 0-25m .
- Work and Home: 50-100 m.

The analysis of the walking distance to bicycle parking facilities has been done using ArcGis Pro, data from the CNIG (Centro Nacional de Información Geográfica), and from the Barcelona's open data. From the CNIG, the addresses and the road network of the province of Barcelona have been downloaded (See D5 and D7 at A.2). The road network (D7) has been used to create the network of Barcelona, and the addresses (D5) as destinations for the network analysis when the distance to work and homes has been estimated. From the open data, the bicycle parking facilities of Barcelona (D1), the shops of Barcelona (D6) and the public infrastructure (A.2.1) have been used. The parking facilities have been used as origins, and the shops and the public facilities as destinations.

First, a spatial selection has been used to extract the addresses relevant to the study, and a spatial selection with distance has been used to extract the streets that are relevant to the study. After that, the cost of crossing each segment needs to be calculated. When the study started, the METIP had not released the bicycle parking guide yet [6], and apart from estimating the walking distance, it was also estimated the walking time needed to reach the bicycle parking facilities. To do that, an estimation of the average time that an adult takes to cross 1km walking from the Gencat was used. After the release of the guide, it was decided to focus on the distance and leave the estimation of the time needed aside. Due to that, the only cost calculated was the length of each of the network segments.

After the cost of crossing the streets has been calculated, a network dataset can be built from the network data. Once we have the network dataset, we can use the network analysis tools to generate an Origin Destination Matrix (ODM). The ODM matrix returns a table with the distance or time needed to reach the nearest destination from each of the origins, and the ID's of the origins and the destinations. Before calculating the ODM matrix, is necessary to load the origins and the destinations. As described below, the data has been grouped by topic and an ODM matrix has been calculated for each of the three topics: Work and home, shops, and public facilities. The results of the ODM matrix include an ID of the origin and of the destination, needing to be joined to the origin or destination dataset.

3.2.1 Measure walking distance to work and home

Addresses data from the CNIG has been used as origin on the ODM matrix. Unfortunately, for privacy reasons there is no data about the number of inhabitants of each address, nor it's clear if the address is residential or not. Nonetheless, for the current purpose, the use of addresses is optimal, as it allows to measure the walking distance to almost all the locations of the city, where anybody could work or live.

The results of the ODM matrix are loaded to pgAgmin, where the ID of the origin is used to join the results with the original addresses and give the results spatial resolution. The resulting layer undergoes a spatial join with the census units layer to get the ID's of the various administrative units of the city of Barcelona. Then, the data is loaded into R, where is treated to identify the percentage of addresses in each of the following distance intervals:

- 0-50 m.
- 50-100 m.
- 100-150 m.
- 150-200 m.
- +200 m.

The same operation is performed again, but this time, grouping the data by districts, to calculate the percentage of addresses in each district that are in each of the different distance intervals. After that, the distance to each address has been grouped by census unit, and the average distance between the addresses of each of the census units and the nearest parking has been calculated. This has been joined to the spatial census addresses to visualize it spatially.

3.2.2 Measure walking distance to shops

Shops data from the open data Barcelona has been used as origin on the ODM matrix (A.2). It was tricky to treat the data as some of the text fields include commas, what caused the loss of more than a 30% of the data when importing it directly to QGIS. To prevent it, the data was first imported to excel, using the import wizard to ensure that the coordinates were treated as text. Once it was in excel, all commas were searched and replaced with dots, and the unnecessary columns were deleted. It was then imported to QGIS, and from QGIS to postgres. With this process, it was possible to keep the information of all the 80.554 registers, of which 18.996 were deleted as those were register of shops without activity such as empty locals or cases where there was not information. The data was then classified in 6 categories in a similar way to how it was classified in reference [3].

The data is then imported to ArcGis Pro and used in the ODM matrix. The results are loaded to postgres, where are joined with the original shops data to get it's attributed. The ODM matrix is generated again, this time specifying the maximum search distance as 25, and the number of destinations as 10. The results will allow to know the proportion of shops that have a bicycle parking in range, the average distance to the parking in range and the average number of parking facilities available. The results of the second ODM matrix are also loaded to postgres and joined with the shops data. The results are grouped by the category of the shop, and the statistics of each category are calculated in postgres. The data of the first ODM matrix is loaded into R, where is treated to identify the percentage of addresses in each of the following distance intervals:

- 0-25 m.
- 25-50 m.
- 50-75 m.
- 75-100 m.
- 100-250 m.

The same operation is performed again, but this time, grouping the data by shops category, to calculate the percentage of shops in each typology that are in each of the different distance intervals.

3.2.3 Measure walking distance to public services

The information about the public facilities has been downloaded from open data Barcelona and comes from various datasets detailed in A.2.1. The data has been grouped in four different categories, transport, health, leisure, and education. The datasets have been unified manually with excel and QGIS, due to many of them needed special treatment such as reprojection to a common CRS. From each dataset, the coordinated of the facility and the ID were extracted, and a general category and a subcategory were assigned. In this case, it was also necessary to use the import wizard to ensure that the coordinates were imported correctly. Then, the 4.962 public facilities were imported to ArcgGis Pro and used in the ODM matrix as origins. In this case, the ODM matrix was calculated again with the same parameters used with the shops. The results of both matrixes were imported to postgres and treated in the same way as the ones from the shops.

The results of the first matrix were used to estimate the percentage of public facilities in each category that are in each of the distance intervals, and the results of the second were used to calculate the indicators described above. The intervals used to classify the data were the same as the ones used to measure the walking distance to shops.

3.3 Analyze bicycle parking occupancy

The analysis of bicycle parking occupancy has been done using GIS and postgres. The three datasets have been loaded, projected, and imported to postgres from QGIS. Once on Postgres, it has been treated to standardize the information creating, transforming, and renaming the fields to allow a smooth integration. The data has then been aggregated by bicycle parking facilities, calculating the average occupancy of each kind of vehicle and the average number of each kind of vehicle.

The first part of the occupancy analysis has consisted in doing a spatial join between the occupancy data and the administrative units of Barcelona, as has already been done previously for the other datasets. The data has been then summarized by districts and neighbourhoods to estimate the average occupancy per district, estimate what is parked on the facilities of each district and evaluate the data. It has been decided to visualize the results grouped by districts, and two maps have been made, a bivariate map about the number of facilities vs the average number of observations and a map about the average occupancy per district.

After that, the student has used Postgres to group the facilities by the number of observations, similar to [8], using the following intervals:

- 1 observation.
- 2-10 observations.
- 11-20 observations.
- More than 20 observations.

Postgres has also been used to group the facilities by the average occupancy, similar to [5],classifying the facilities using the following intervals:

- Low (0-30%).
- Healthy (30-60%)).
- High (36-90%)).
- Saturated (+90%)).

4 Results

According to the data from the first semester of 2023, Barcelona has 3952 bicycle parking facilities. These facilities collectively have a capacity of 41,366 bicycles, resulting in an average capacity of 10.45 bicycles per facility. The capacity of the individual facilities ranges from 1 to 60 bicycles, encompassing a total of 34 different capacity variations.

4.1 Bicycle parking distribution

The distribution of bicycle parking facilities in Barcelona is not uniform, as evidenced by the fact that nearly half of the facilities (48.2%) are concentrated in the districts of Eixample and Sant Martí. The remaining districts account for between 11% and 3% of the bicycle parking locations, with Horta-Guinardó and Nou Barris having the lowest number of parking facilities. Fig. 1 illustrates this concentration of bicycle parking facilities in the Eixample and adjacent districts, with their availability gradually decreasing as one moves away from the city epicentre.

The analysis of bicycle parking facilities involved associating them with five different administrative and statistical areas. This examination considered the number of sections the city was divided into, the proportion of divisions without any bicycle parking facility, and the average number of facilities and capacity per area (refer to 1). The findings reveal that in administrative areas larger than the census divisions, the vast majority of sections (98.7%) have at least one bicycle parking facility. However, when examining

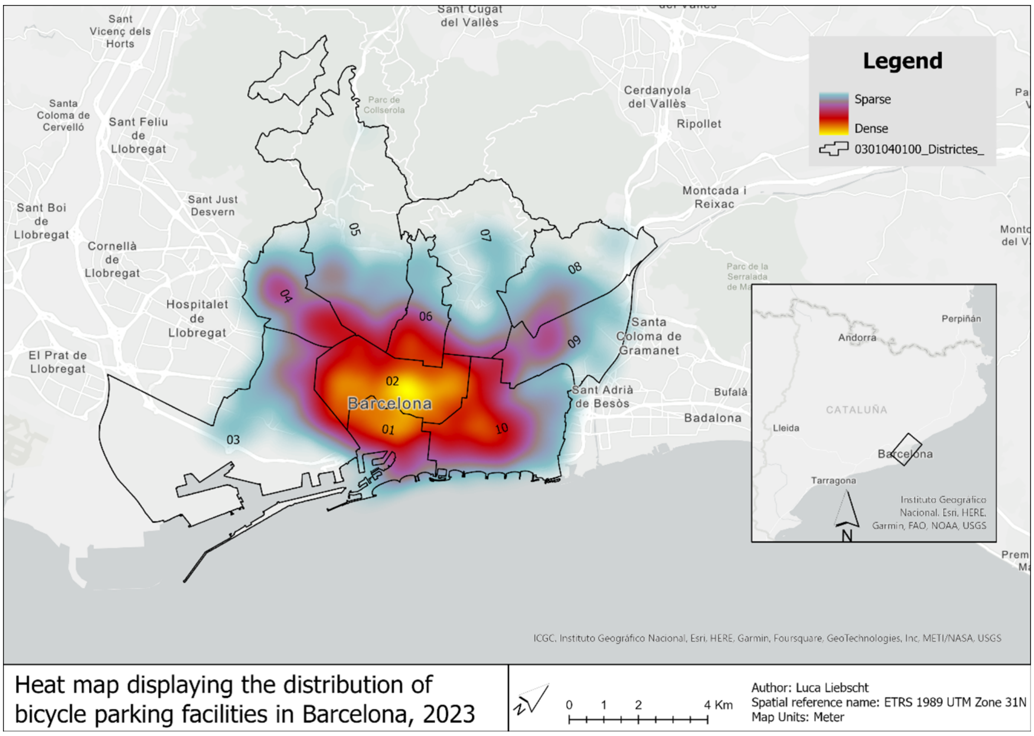

Fig. 1: Bicycle parking facilities distribution

Area	Number of divisions	Empty ones	%	Average facilities	Average capacity
District	10	0	0%	395.2	4126.6
Gran Barri	40	0	0%	98.8	1034.15
Neighbourhood	73	1	1.3%	54.2	574.53
Statistical units	233	3	1.2%	16.96	179.85
Census divisions	1068	244	22.8%	3.7	50.20

TAULA 1: Table with lines between rows

census divisions (as shown in 1), it was observed that 244 of them lack any bicycle parking facility, with only 7 of those located in the Eixample. It is important to note that census divisions exhibit significant variation in size compared to other administrative divisions, with the largest administrative division being 321 times larger than the smallest one. For graphical representations of the bicycle parking distribution in the studied area, please refer to B.2.

In an attempt to comprehend the existing distribution of bicycle parking, correlations have been computed between the number of bicycle parking facilities and the area of the examined administrative divisions, as well as the population and income per person. This analysis aims to explore the potential relationships and connections between these variables and the distribution of bicycle parking facilities across the different administrative boundaries. The findings presented in B.1 indicate that there is no strong correlation observed between the variables. However, it is noteworthy that a moderate correlation exists between the number of bicycle parking facilities and the population in larger administrative areas.

4.2 Walking distance to bicycle parking

4.2.1 Measure walking distance to homes and workplaces

The address data obtained from the CNIG encompassed all the addresses within the province of Barcelona, totalling 931.057 addresses. From this dataset, we extracted the addresses located within the municipality of Barcelona, resulting in a subset of 164.157 addresses. Each of these addresses was then matched with its nearest bicycle parking facility, enabling us to measure the distance and time between the address and the closest facility. Of all the addresses 64 were not matched.

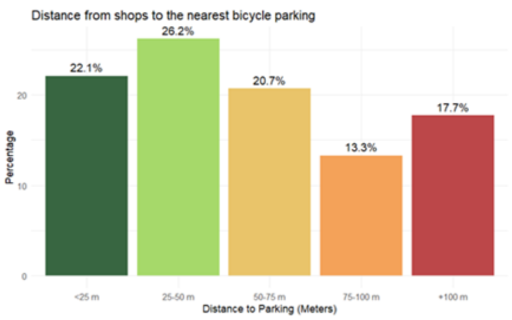

Fig. 2: Distance to the nearest parking

In the 2, the addresses have been categorized into five groups based on their distance from the nearest facility. As displayed in the figure, approximately 59.2% of the addresses in Barcelona have a bicycle parking facility in less than 100 meters. Furthermore, 21% of the addresses have a facility within less than 200 meters. However, it is worrisome that around 20% of the addresses do not have any bicycle parking facilities within a reasonable proximity.

When visualizing the previous results spatially in 3, it becomes evident that the north-west and south areas of Barcelona exhibit a higher average distance to bicycle parking facilities, while the centre of the city demonstrates a shorter average distance.

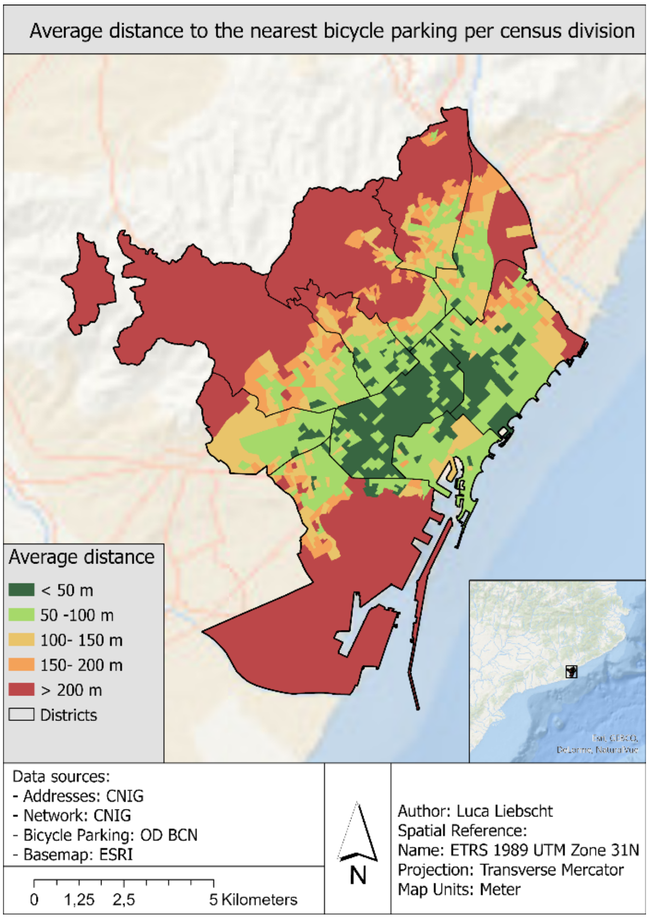

Fig. 3: Average distance to nearest parking

Upon aggregating the results by district, Sants-Montjuïc emerges as the district with the highest average distance of 418 meters and a significant 27% of its addresses located over 200 meters away from a bicycle parking facility. Similarly, Horta-Guinardó exhibits a high percentage of addresses (58%) situated at more than 200 meters from a bicycle parking facility, along with an average distance of 301.5 meters to the nearest parking. In contrast, the district of Eixample showcases the best values, with an average distance of 45 meters and 61% of its addresses located within a mere

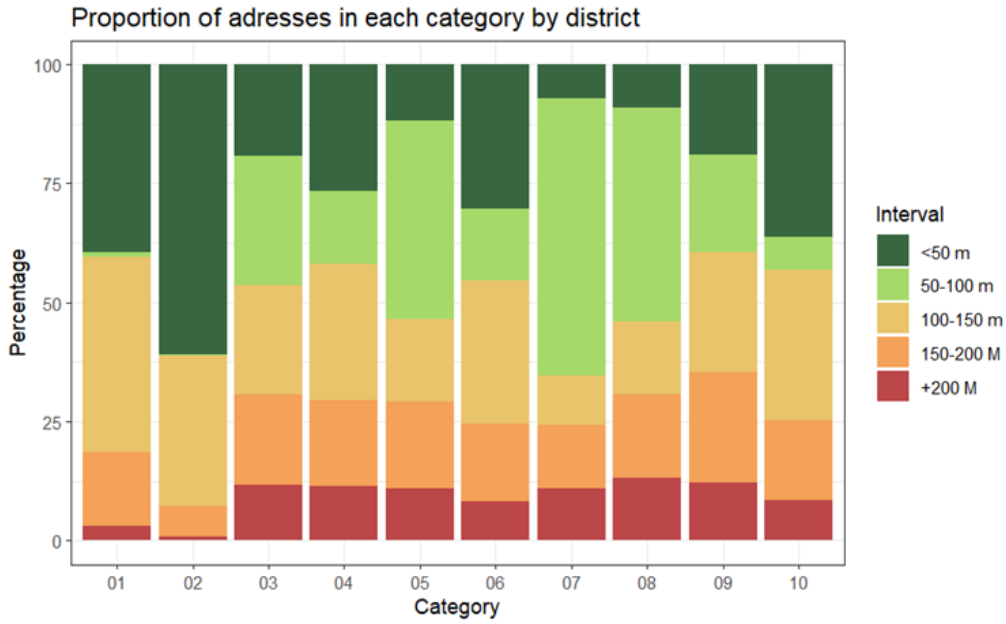

Fig. 4: Proportion of addresses in each category by district

50 meters of a bicycle parking facility. See 4.

4.2.2 Measure walking distance to shops

From the 61.558 shops considered, 57.949 (93,4%) have at least a bicycle parking facility in less than 250m, and a 94.86% of those at least two facilities. In this case, the average distance to the nearest bicycle parking is 73.576 meters, the average has been calculated without considering the shops where the nearest bicycle parking was located more than 250 meters (6% of all shops).

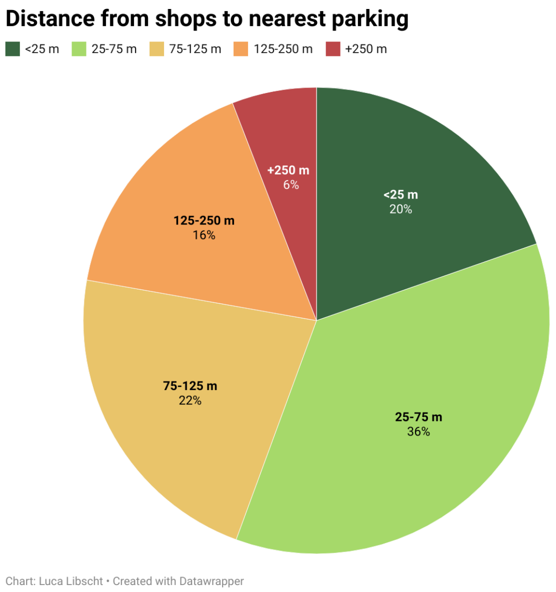

Fig. 5: Distance from shops to the nearest parking

Figure 5 shows that a 20% of shops have a bicycle parking in less than 25 meters, the recommended distance by the bicycle parking guide [9]. In contrast, the nearest bicycle parking to a 38% of shops is located at a distance between 75 and 250 meters. The fact that a 56% of the shops have a bicycle parking in less than 75 meters can be considered positive, even if not ideal.

Figure 13 in C.2 displays the proportion of shops in each of the selected distance intervals, and as can be easily seen, there isn't any notable difference between the different shop categories. The percentage of shops with a parking facility in less than 25 meters varies from 17 to 23 percent, the ones with a parking in more than 100 meters vary from 12 to 13 %, and the ones with a parking in a distance between 25 and 100 meters vary from 70 to 75%.

The results of the second ODM matrix show that the parking locations in the recommended distance are on average at a distance 13 meters. The shop category with the shortest average is the "Various" category, that has an average distance of 12.3 meters, and the highest is the "Fresh food" category with an average of 14.3 meters. See all the details at C.1.

4.2.3 Measure walking distance to public facilities

From the 4962 public facilities considered, 4381 have at least a bicycle parking facility in less than 250m, and an 89.39% of those at least two facilities. In this case, the average distance to the nearest bicycle parking is 70.71 meters. Figure 6 shows that a 25% of public facilities have a bicycle parking in less than 25 meters, the recommended distance by the bicycle parking guide [9]. In contrast, the nearest bicycle parking to a 12% of public facilities is located more than 250 meters away. The fact that a 71.3% of the municipal facilities have a bicycle parking in less than 75 meters can be considered positive.

Figure 7 illustrates the distribution of public facilities within selected distance intervals for each facility category. In contrast to the findings for shops presented in Annex C.2, notable distinctions are observed among the four categories. Education facilities exhibit the highest proportion of facilities within the recommended distance (34%), closely followed by transport (30%), leisure (25%), and care facilities (16%). Furthermore, examining the facilities with

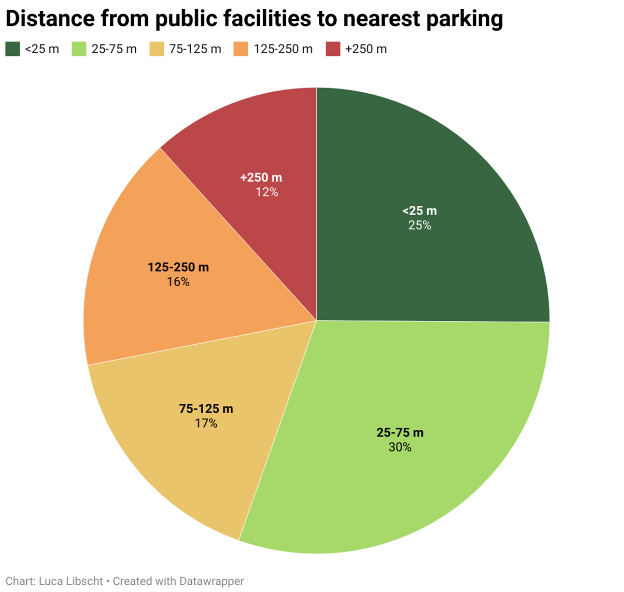

Fig. 6: Distance from public facilities to the nearest parking

the lowest percentage of parking locations situated between 100 and 250 meters, we observe that transport facilities have the lowest percentage (20%), followed by leisure (27%), education (28%), and care facilities (31%). These variations highlight the differences in accessibility to bicycle parking among various types of public facilities within the city of Barcelona.

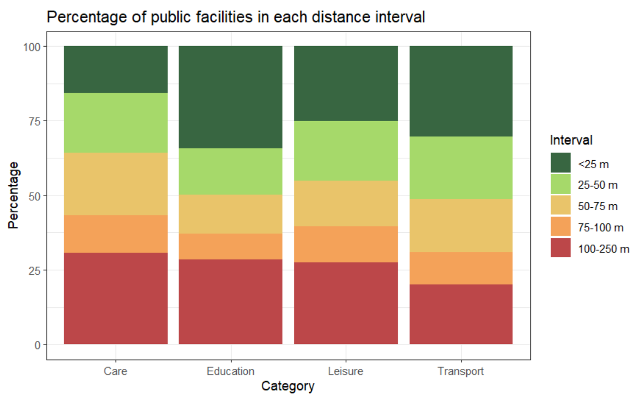

Fig. 7: Percentage of public facilities in each distance interval

4.3 Analysing Bicycle Parking Occupancy

After combining the data from the three datasets, the number of bicycle parking facilities we have data about are 778. Due to the data having been collected thought different means at different times, some stations may be duplicated, and some may not event exist anymore. Nonetheless, this is acceptable as the purpose is to explore possible uses of occupancy data. The total number of observations is 2746, and the average number of observations per station is 3.53 observations. As seen in figure 8, most of the stations only have one observation, and only one station has more than 20 observations. The reason that explains the high number of cases with between 11 and 20 observations is that 90% of the observations from the study [5] had more than 10 observations.

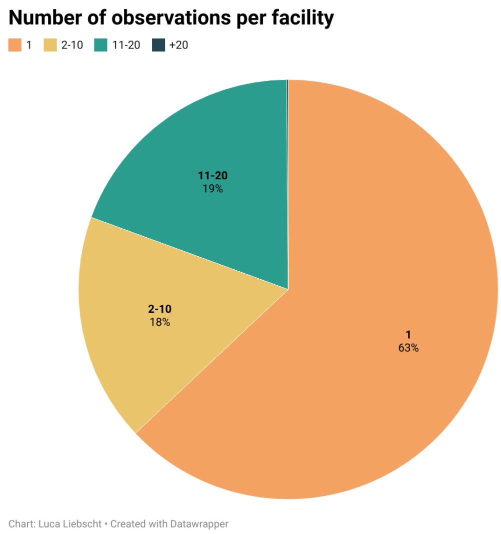

Fig. 8: Number of observations per facility

Figure 9 shows the distribution of the data over the districts, showing the number of facilities versus the average number of observations per facility. As it can be seen, the

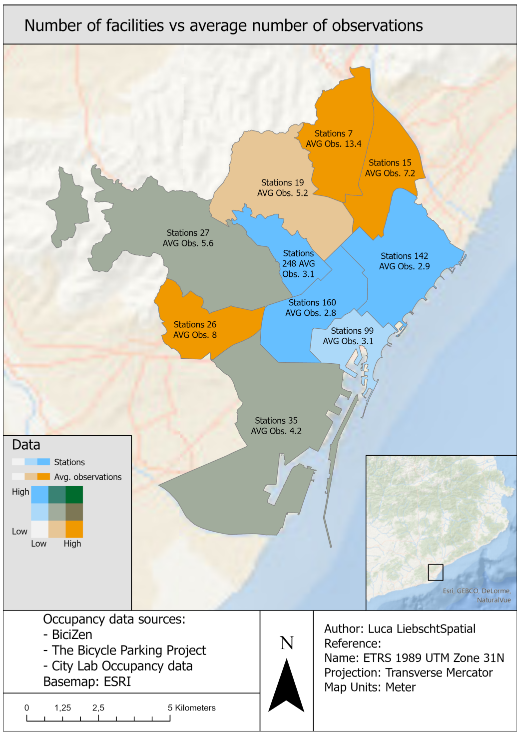

Fig. 9: Number of facilities vs average number of observations

results are quite polarized, we have three districts with a high number of facilities and a low average of observations per facility, and three districts with a high number of observations per facility and a low number of facilities . The other four districts divide in two categories, the ones that have a moderate amount of data of both categories, and the ones with a moderate amount of data of one of the two categories.

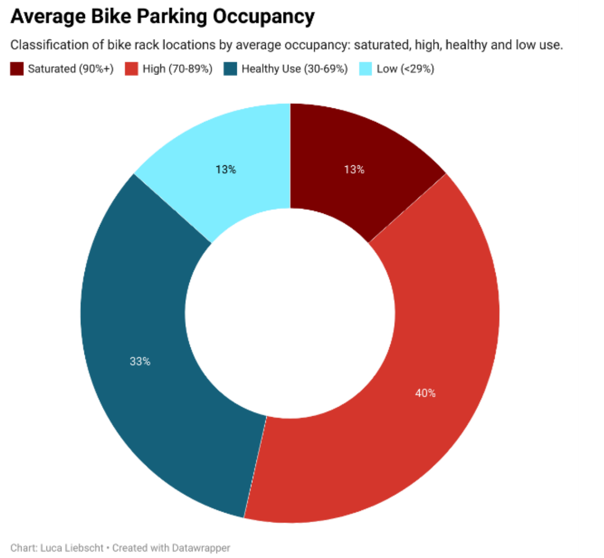

Fig. 10: Distance from public facilities to the nearest parking

In the figure 10 stations have been grouped by their average occupancy, dividing them into four categories. From the available data, we have a 40% of facilities with a high use and a 33% of them with a healthy use. From the remaining 26%, half is composed of facilities with a low occupancy and half of facilities that are saturated.

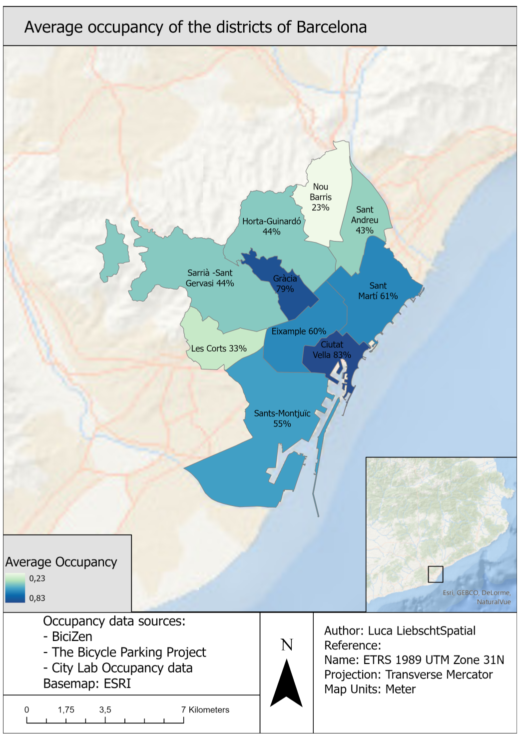

Fig. 11: Average occupancy per district

If we look at the average occupancy per district (Figure 11) derived from the previous data, we see that Gràcia and Ciutat Vella are the districts with a higher occupancy, while Sant Martí and Sant Andreu are the ones with a lower occupancy. Unfortunately, the student lacked the time to calculate and explore the results of calculating the ODM matrix using the public facilitites as origins and the parking facilities with occupancy data associated as destinations. Doing so, would have allowed to study the relation between occupancy and the typology of public facilities.

5 Future work

During the study, various spatial analysis have been made, nonetheless, there are many interesting things that would be interesting to explore, but has not been possible to do so during the current study.

- Perform a comparative study between various cities to explore if the values in Barcelona are different to the ones of the selected cities. It would also be interesting to redo the analysis on a metropolitan level.
- Perform a similar study using overpass-turbo to get data about the shops and municipal facilities on various cities. This would allow to perform the study in cities with less complete open data portals.
- Estimate the number of people in each address using census data with the goal of quantifying the people who have a higher or lower distance to bicycle parking facilities.
- Estimate the hilliness of the various administrative boundaries and correlate it with the distribution of bicycle parking facilities.
- Create profiles of the bicycle parking locations and study their occupancy over the day.

6 Conclusions

The project has satisfactory fulfilled the planned objectives, and has extracted the following ideas from the various analysis performed:

- The distribution of bicycle parking in Barcelona is not uniform. Almost half of the facilities (48.2%) are located in the districts of Eixample and Sant Martí, while the remaining districts account for between 11% and 3% of the bicycle parking locations, with Horta-Guinardó and Nou Barris having the lowest number of parking facilities.
- There are no strong correlations between the number of parking facilities and the area of the evaluated administrative divisions, as well as population and income per person. It has to be noted that there is a moderate correlation between the number of facilities and the population in larger administrative areas.
- Approximately 50% of the addresses in Barcelona have a bicycle parking facility within 100 meters, while 20% do not have any facility within a reasonable proximity. Overall, the north-west and south areas of Barcelona have a higher average distance to bicycle parking facilities, while the city center demonstrates a shorter average distance.
- Approximately 56% of shops in Barcelona have a bicycle parking in less than 75m. The ideal would be

in less than 25 meters, but only a 20% fulfills that situation. With the used categorization of shops, no major differences were found between the categories.

- Similarly to shops, a 55% of public facilities have a parking in less than 75 meters. In this case, the number of facilities with a parking in less than 25 meters is 25%, and the number of parking in more than 250 meters a 12%. The results of studying the differences in the percentage of public facilities in each interval by category shows that the different categories have considerable differences, with education and transport having a considerably higher percentage of facilities in less than 25 meters than leisure or care facilities.

- The occupancy data shows polarized results when comparing the number of facilities against the average number of observations per facility. This is caused due to the fact that the data from BiciZen and the Bicycle Parking projects data concentrates in the central districts of Barcelona and due to the fact that their general low number of observations, lowers the average number of observations per facility.

- The results of exploring the occupancy data show that around 40% of high use, while 33% have healthy use. However, 26% of the facilities have either low occupancy or are saturated. The results are considerably different to the ones found in [5]. The averages per district have also varied in contrast with [5].

In conclusion, bicycle parking is not evenly distributed over the city of Barcelona. The distance to parking facilities is higher the more distant one is from the epicenter of Barcelona. Occupancy data provides valuable insights into the use of parking facilities, which can help in making informed decisions for improving bicycle parking infrastructure in the city, and thus, more occupancy data should be collected in an organized way to avoid biases.

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A GENERAL ANNEXES

A.1 Bicycle Parking Data in Spanish Cities

City	Madrid	Barcelona	Valencia	Sevilla	Zaragoza	Málaga	Murcia	Palma	Las Palmas	Bilbao
OD	4677	3951	3484	-	234	-	-	-	-	-
OSM	1356	2898	320	410	895	369	197	101	23	95

TAULA 2: City Data

A.2 Data Sources

Reference	Use	Url
D1	Bicycle parking locations. Used in RSQ1/RSQ2	Bicycle parking locations URL
D2	Municipal boundaries of Barcelona. Used in RSQ1/RSQ2/RSQ3	Municipal boundaries URL
D3	Population Barcelona. Used in RSQ1	Population URL
D4	Indicators of income. Used in RSQ1	Indicators of income URL
D5	Addresses from the province of Barcelona. Used in RSQ2	Addresses URL
D6	Shops in Barcelona. Used in RSQ2	Shops URL
D7	Road segments from the province of Barcelona. Used in RSQ2/RSQ3	Road segments URL
D8	BiciZen data. Used in RSQ3	BiciZen data URL

A.2.1 Municipal facilities data

Category	Data	Url
Care	Health centers	Health centers URL
Care	Social services	Social services URL
Care	Day centers	Day centers URL
Education	Preschooler education	Preschooler education URL
Education	Primary education	Primary education URL
Education	Secondary education	Secondary education URL
Education	Universities	Universities URL
Leisure	Spectacles	Spectacles URL
Leisure	Libraries	Libraries URL
Leisure	Spaces of social interaction	Spaces of social interaction URL
Leisure	Playgrounds	Playgrounds URL
Leisure	Sport facilities	Sport facilities URL
Transport	Collective transport	Collective transport URL
Transport	Daily bus	Daily bus URL
Transport	Night bus	Night bus URL
Transport	Bicing stations	Bicing stations URL

TAULA 4: Data URLs by Category

B DISTRIBUTION ANNEXES

B.1 Distribution correlations

Area	Facilities vs Capacity	Facilities vs Area	Facilities vs Pop	Facilities vs Person income
District	0.997414851	-0.18189	0.686421	0.039345699
Neighbourhood	0.992926007	-0.13424	0.677654	-
Statistical units	0.97584833	0.180418	0.054432	-
Census divisions	0.972563082	0.178662	-0.01914	0.043279589

TAULA 5: Comparison of Facilities in Different Areas

B.2 Distribution number of facilities and capacity

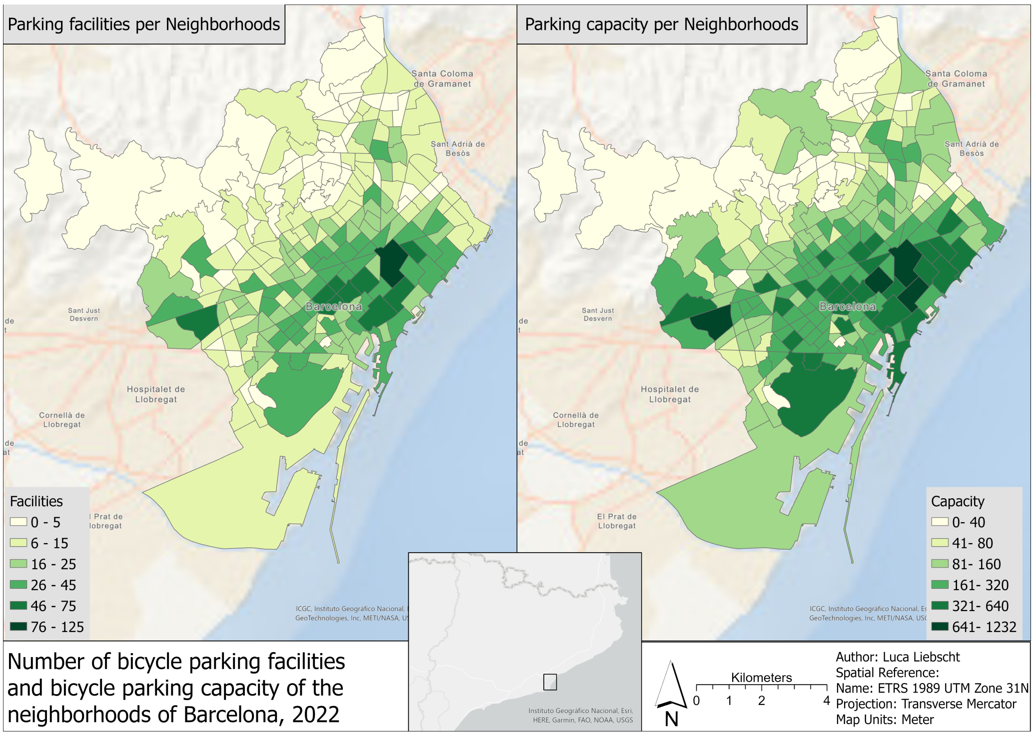

Fig. 12: Distribution of parking facilities and parking capacity per neighborhoods

C WALKING DISTANCE ANNEXES

C.1 Average distance to the shops by shop category

Category	Facilities	In range	%	Avg. Distance	T. parkings	Max	Avg Facilities
Fresh food	4431	824	19%	14.3207	1501	4	1.31
Daily needs	10891	2179	20%	12.7452	3531	7	1.29
Supermarkets	2356	483	21%	12.9569	724	4	1.23
Bars	11119	2536	23%	13.0354	4021	6	1.26
Various	16290	3226	20%	12.6663	4853	4	1.23
Other	16442	2851	17%	12.9654	4379	4	1.24

TAULA 6: Facilities Statistics by Category

C.2 Average distance to the shops by shop category

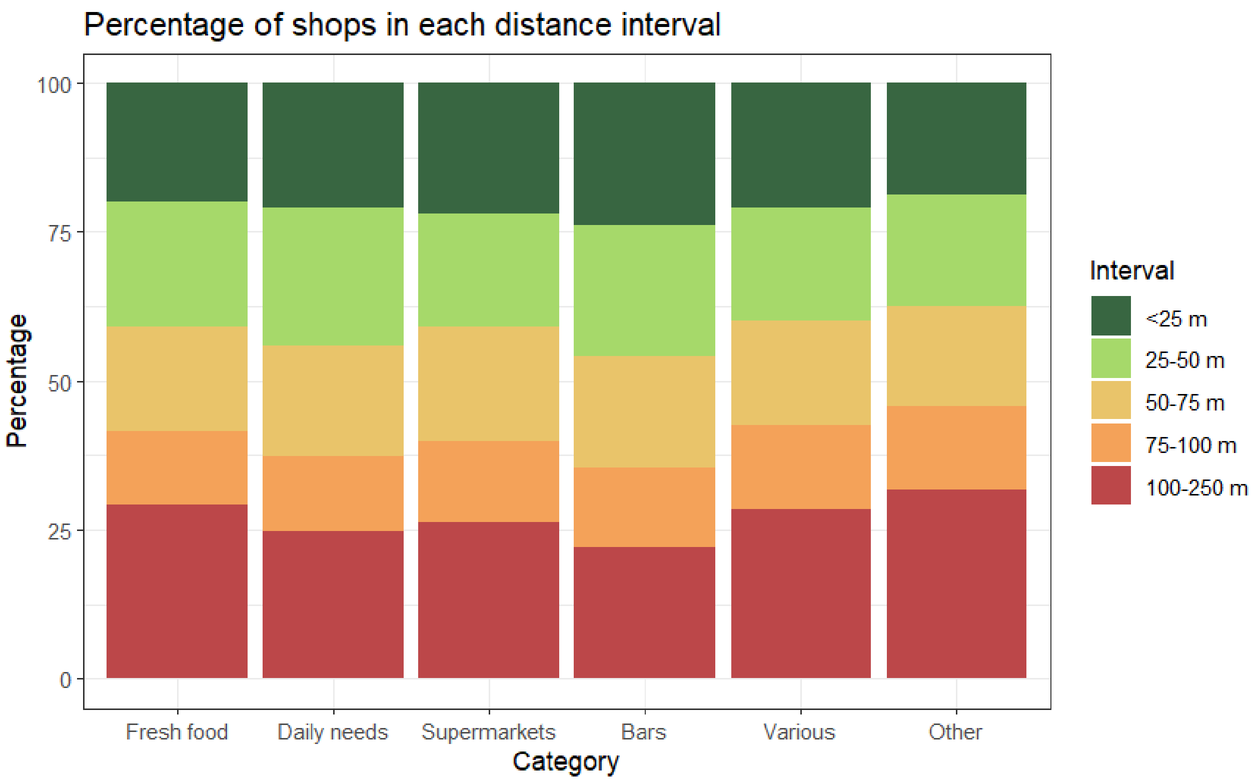

Fig. 13: Proportion of addresses in each distance category by shop category

C.3 Average distance to the public facilities by facility category

Category	Facilities	In range	%	Avg. Distance	T. parkings	Max	Avg Facilities
Care	435	61	14%	13.7755	109	3	1.31
Education	1567	481	31%	13.0164	911	5	1.37
Leisure	1879	410	22%	12.0384	734	6	1.35
Transport	1081	294	27%	11.8575	471	5	1.27

TAULA 7: Facilities Statistics by Category