Pedestrian Accessibility Characterization in a University Urban Environment for GIS Integration

Noelia Amores-Muñoz*, Manuel D Marín-Granados, Francisco J Ortiz-Zamora, Jose L Martínez-Torres, and Jorge Pérez-García

Department of Graphic engineering, design and projects, University of Malaga, Malaga, Spain.

Corresponding Author: Noelia Amores-Muñoz, Department of Graphic engineering, design and projects, University of Malaga, Malaga, Spain.

Abstract

Cities face environmental challenges requiring effective mobility and urban planning. Mobility is crucial for connecting urban spaces and shaping city form. Malaga has expanded, particularly with its university campus development. Promoting sustainable mobility, especially pedestrian options, is essential for connecting these areas.

Evaluating pedestrian environments necessitates an understanding of pedestrian behavior, which is influenced by sensory interactions with the city, other pedestrians, and the environment.

Factors affecting pedestrian mobility are categorized into accessibility, safety, comfort, and attractiveness. Accessibility pertains to infrastructure, safety concerns traffic dynamics, comfort, is subjective, and attractiveness relates to pedestrian engagement with surroundings.

The Pedestrian Characterization in Mobility Environments (PCME) method, developed by Talavera-García, Soria, and Valenzuela, quantifies these factors and assigns a quality level from one to five. Accessibility is gauged by pedestrian section width; safety is assessed via speed and traffic lanes; comfort considers noise and greenery; and attractiveness examines complexity.

Using this methodology, evaluations were conducted for each faculty on the University of Malaga campus. Measurements included pedestrian passage width, obstacles, car lanes, and permitted speeds, along with the influence of bike lanes and metro tracks on safety perception.

Measurements also assessed tree density, shade provision, ambient noise levels, and the presence of urban elements enhancing quality, such as benches and trash bins. Additionally, faculties were evaluated based on their interaction levels and complexity versus isolation.

Some faculties, like the Faculty of Philosophy and the Faculty of Medicine, achieved high urban quality levels, while others, such as the Faculty of Fine Arts and the School of Computer Engineering, received lower scores.

Keywords: Mobility, GIS, Pedestrian, Accessibility

1. Introduction

Pedestrian mobility is a crucial aspect in cities, as it is a basic civic need which promotes social and cultural interactions, as well as providing economic benefits. According to data from the National Statistics Institute (INE), in Spain nearly 40% of all trips are made on foot. Pedestrian mobility is fundamental to sustainable cities: it encourages essential social and cultural interactions for urban prosperity, yields economic benefits, and is the most environmentally sustainable mode of transport. Its advantages include reduced pollutant emissions with improved air quality, lower noise levels, and enhanced road safety [1]. All of this increases habitability, thereby raising land values—both commercial and residential. Cities that adopt car-reduction policies experience a significant increase in foot traffic and use of public transport and bicycles, compensating for customers who would have arrived by car. Moreover, these new customers tend to visit stores more calmly and more frequently. This is supported by a 2016 study involving over 100 European cities [2], which showed an increase in the number of commercial spaces in pedestrianized areas, benefiting retail businesses.

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Public transport, as an alternative to private transportation, also requires territorial studies to help plan new stops (for buses or taxis), making multimodal travel more accessible for pedestrians [3].

The city of Málaga has grown through the development of new urban configurations, including the expansion of its university campus. To connect these spaces, it is essential to promote sustainable modes of mobility such as walking. The Mediterranean climate encourages walking, particularly where there is proximity, shade, and continuous sidewalks. In this regard, GIS-based accessibility studies have been conducted for planning and monitoring cities on the basis of the "15-minute city" concept [4].

In this article, we propose evaluating pedestrian environments for campus sectors predominantly occupied by educational land uses, taking into account pedestrian behavior. We have evaluated five university centers belonging to the different campuses of the University of Málaga (El Ejido Campus, Teatinos Campus, and the Teatinos Extension Campus).

2. Methodology
2.1. PCME Method
The methodology employed is based on the Pedestrian Characterization in Mobility Environments (PCME) method, which consists of conducting a detailed study of the environment and its characteristics to assess the pedestrian quality of public roads [5].

In order to effectively characterize pedestrian environments in terms of mobility, it is essential to have a set of indicators to quantify the physical characteristics of the environment. These indicators are aimed at evaluating key aspects of urban design, such as accessibility, road safety, comfort, and attractiveness, which influence the pedestrian experience when moving on public roads.

In the six pedestrian sections under study, we used direct measurements with a tape measure and a digital distance meter. The limits of each zone are defined at the pedestrian section directly in front of the building entrances.
The classification of roads according to speed limits and number of lanes was obtained from the open data portal of the City Council of Malaga [6].

The noise measurement procedure consisted of taking samples at the access to each center, using a sound level meter.

By means of field work, a count of the tree count has been carried out to classify the access according to Table 1. As for furniture and lighting, they are not part of the PCME indicators; however, field observations were included to provide environmental context.

The Indicators will be Classified into Five Standardized Quality Levels as shown in Table 1.

Pedestrian Quality Level	Pedestrian Section (m) (1)	Modal Friction Speed (km/h) and Lanes (2)	Noise Lden (dBA) (3)	Tree Density (trees/km^2) (4)	Width-to-Height Ratio (W/H) (5)	Commercial Complexity (shops/ha) (6)
I	> 3.0	Pedestrian- only	< 60	> 10 000	1:2 – 1:3	≥ 64
II	3.0 – 1.8	20 – 30 km/h	60 – 65	10 000 – 2 500	3:2 – 1:2	40 – 64
III	1.8 – 1.2	50 km/h and 1 lane	65 – 70	2 500 – 1 000	3:2 – 3:1 / 1:3 – 1:4	25 – 40
IV	1.2 – 0.9	50 km/h and 2 lanes	70 – 75	1 000 – 650	> 3:1	9 – 25
V	< 0.9	50 km/h and ≥ 3 lanes	> 75	< 650	< 1:4	< 9

Table 1: Standardization of Results in Pedestrian Quality Levels

Accessibility refers to pedestrian infrastructure, while safety is closely related to traffic, since aspects such as the speed of traffic circulation have an impact on the pedestrian's perceived sense of safety.

Sidewalk width is a key element for accessibility, and requires the necessary and sufficient dimensions for smooth and safe mobility. In this sense, wider sidewalks reduce congestion while increasing safety, as pedestrian flow is not interrupted during maintenance or emergencies [7].

Comfort is a rather difficult factor to quantify due to its subjectivity. Some factors impacting comfort include the presence of trees or noise. High noise levels can negatively affect pedestrians' perception of safety and comfort. Streets with lower noise levels are perceived as more welcoming and safer, encouraging pedestrian use and interaction.

Advances in technology and data analysis are transforming urban planning and noise management. The use of GIS-based indicators to assess noise exposure can help identify areas where pedestrian mobility is most affected by noise pollution [8].

Finally, attractiveness refers to how the pedestrian can interact with the surrounding environment. The built environment plays a crucial role in determining walking attractiveness. Studies have shown that factors such as safety, comfort, and aesthetic appeal of the environment significantly influence walking behavior [9]. For example, well-maintained sidewalks, adequate lighting, and the presence of vegetation are key elements that make walking more attractive [10]. In addition, the availability of street furniture, such as benches and shelters, can enhance the walking experience [11].

To quantify these factors, we use the Pedestrian Characterization in Mobility Environments (PCME) method developed by Talavera-García et al. (2014) [5]. This method consists of developing each of the representative variables of these factors, quantifying them, and giving them an urban quality level from one to five, with one being the highest level. In terms of accessibility, the pedestrian section is quantified. For safety, speed and number of lanes are taken into account, while for comfort, the variables are noise, tree density and the ratio between width and height. Attractiveness will refer to complexity.

2.2 Case Study Data

Following this method, we evaluated each faculty on the University of Malaga, spanning three main campuses: El Ejido, Teatinos, and Teatinos Extension. In this article, we focus on the most significant faculties to identify the busiest sidewalks and their deficiencies. Below is a table with the total number of people who belong to each faculty.

Faculty	Students	Academic	Administrative and Service staff	Total
School of Industrial Engineering	4009	523	58	4590
School of Computer Engineering	2032	280	33	2345
Faculty of Philosophy and Humanities	3680	507	47	4234
Faculty of Medicine	1475	263	62	1800
Faculty of Fine Arts	394	70	21	485

Table 2: Users of Each University Center of the University of Malaga

3. Results

The study area encompasses three university campuses. Figure 1 shows their location, as well as the number of users of each center.

Figure 1: Location and Access to the Buildings on each Campus. Source: Own Elaboration

3.1. School of Industrial Engineering

Two access points to this School are evaluated: the southern access, where the main entrance is located, and the northern access. Firstly, it is worth noting that the southern access has a walkway width of 4.30 meters, which gives it a Level I pedestrian quality according to the PCME method. In terms of safety, it does not have a bike lane, but there are four vehicle lanes (two in each direction), separated in pairs by a median strip.
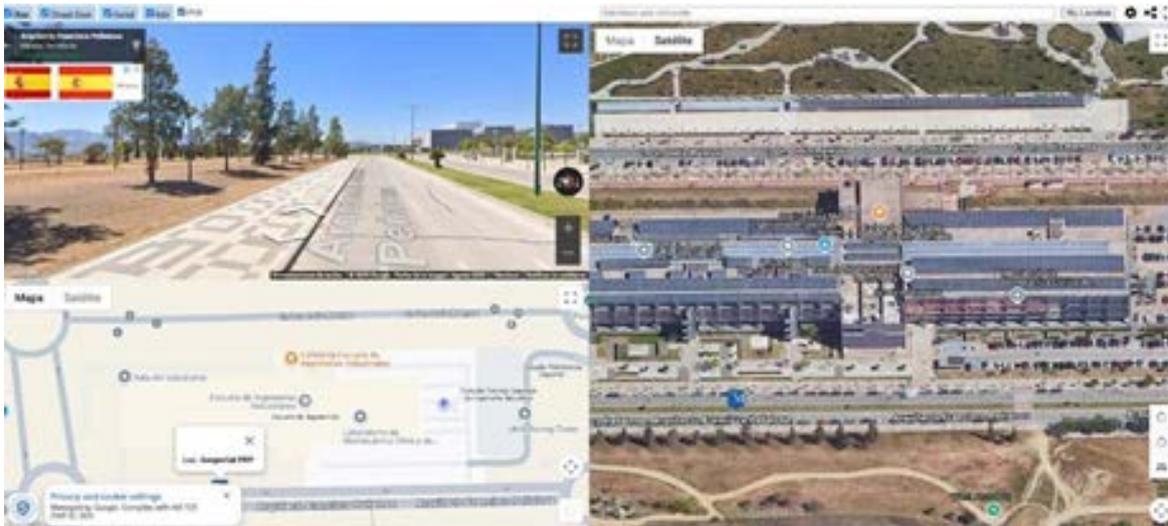
Figure 2: Southern Access to the School of Industrial Engineering, Malaga: Satellite and Street View. Source: Geoportal Malaga [12-14]

However, the speed limit is 30 km/h. The parking zone between sidewalk and roadway enhances perceived safety, yielding a Level II rating. There is a line of trees spaced 5.5 meters apart, giving the tree density a Level II quality rating. These are young trees, so they do not provide much shade. The building has three floors and is separated from the sidewalk by a garden and a parking area, which places the height-to-width ratio at Level II. The final comfort factor, noise, is evaluated based on the area's complexity and traffic: there are four traffic lanes, two on-street parking zones, and one external parking area adjacent to the building, resulting in moderate traffic. No buses pass through this area, and there are no significant destinations except for a garden belonging to the university but open to the public, with benches and lush trees, making it a pleasant area where pedestrians can walk dogs or relax. The noise level is rated as Level II, and complexity is classified as Level III, as the area attracts non-university pedestrians for walking, skating, or cycling.

The north access point extends from the rear street of the Faculty of Marketing, so its characteristics are similar. The pedestrian walkway is 5 meters wide, which is well above the recommended minimum of 3 meters and thus guaranteeing optimal pedestrian flow. Therefore, according to the PCME method, its pedestrian quality level is I. The tree density is higher than on the southern side, with two rows of trees: one row spaced 5 to 6 meters apart, and the other about 10 meters apart, giving it a pedestrian quality level of I. Regarding safety, the street has two lanes of traffic in both directions with a speed limit of 30 km/h, separated from the sidewalk by a parking zone and a 3meter bike lane. As in previously analyzed cases, its pedestrian quality level in this category is II. The building has three floors, but it is located

below the sidewalk level, requiring stairs to access it, and the sidewalk is further separated from the building by open space. Therefore, the height-to-width ratio is classified as level I. This is not a high-traffic area, so its noise level can also be classified as level I. In terms of attraction or complexity, in this street, less than 300 meters away, there are two city bus stops (Line L) and a stop where five regional bus lines pass, connecting different municipalities in Málaga: Mijas (M114), Benalmádena (M116), Cártama (M118), Alhaurín de la Torre (M143), and Rincón de la Victoria (M166). It also connects to two metro stations at a distance less than 500 meters: Paraninfo and Andalucía Tech. Its complexity is greater than in other areas of the campus, making this the best pedestrian option on campus. However, this campus is still quite distant from non-academic activities. Other aspects to consider include shade—these trees are leafy but young, so much of the sidewalk remains sunny; landscaping and natural design, with a lush garden across the street; and urban planning elements, such as the presence of benches, trash bins, and a wide sidewalk.

3.2. School of Computer Engineering
First, accessibility is analyzed, as it is the most basic condition for mobility. The indicator that refers to accessibility according to the PCME method is the pedestrian section, which in this case is 2 meters wide, placing it at pedestrian quality level II. On the other hand, in terms of safety, the area has two bike lanes and two vehicular lanes with a maximum speed limit of 50 km/h. However, as it is located at an intersection, it also has three side lanes with heavy traffic at 50 km/h. Therefore, its safety rating is V. Regarding comfort, three variables determine its quality level: noise, tree density, and the width-to-height ratio.

Figure 3: School of Computer Engineering: Satellite View and Street View. Source: Geoportal Malaga [12-14]

Due to the heavy traffic (the side streets at the intersection are roads that lead to the highway), the noise level is high, classified as level V in terms of quality. Although there is a garden, it is fenced with a single entrance and to access it one must cross both bike lanes, making it not very accessible. The fencing of the garden also disrupts the landscape and natural aesthetics. On the same sidewalk used by pedestrians, there are no trees, and the area is fenced off to separate the faculty's parking lot from the street itself, which fails to create a pleasant landscaped atmosphere. Weeds are abundant, giving the impression of a neglected area. Additionally, no urban furniture is observed, indicating a lack of pedestrian-focused urban planning. On the other hand, the area is more complex than the Ampliación campus, as it includes the Virgen de la Victoria University Hospital (El Clínico) where several restaurants are located on a vacant lot across from the hospital, although they are located some distance from the faculty building. It also features a metro stop at a distance less than 200 meters and two stops of the L urban

bus line (one of them at a distance less than 300 meters, and the other at a distance less than 500 meters). Despite this, it is the most remote and isolated faculty within the Teatinos campus, giving it a complexity level of quality III. The School of Computer Engineering has three floors; however, there is a large distance between the sidewalk and the building itself, resulting in a level III quality rating in terms of the width-to-height ratio.

3.3. Faculty of Philosophy and Humanities
The main difference between this faculty and the previous one is the presence of trees in one row spaced 6.5 m apart, which results in a pedestrian quality level of III. These are young trees and do not provide much shade. The walking section is still 4.70 meters wide with a 2.10-meter bike lane; however, obstacles for pedestrians are observed due to the presence of bus stops that reduce the effective sidewalk width to 2.08 m.
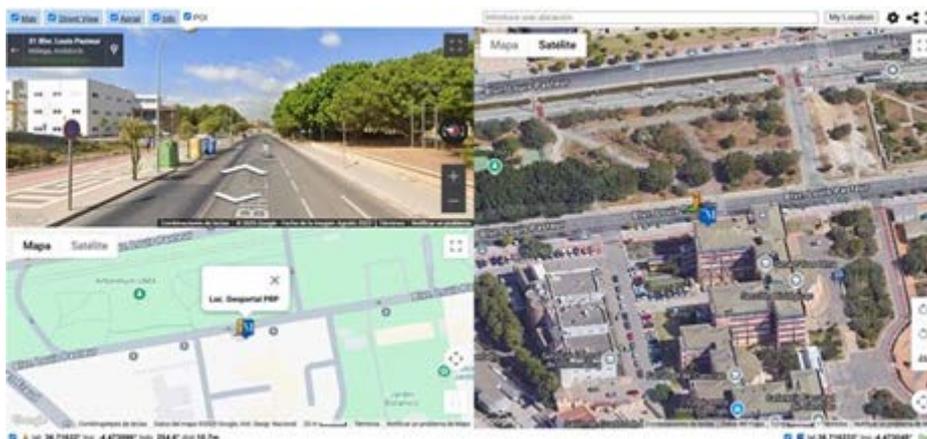

Figure 4: Faculty of Philosophy and Humanities of Malaga: Satellite View and Street View. Source: Geoportal Malaga [12-14]

The biggest advantage of this street is the presence of features that engage pedestrians. It has two bus stops served by busy lines such as 11, 18, and 22, and intercity buses to several municipalities, specifically Mijas (M114), Benalmádena (M116), Alhaurín de la Torre (M143), and Rincón de la Victoria (M166), as well as a nearby metro stop. These stops

are located at a distance less than 300 m away. Additionally, it is adjacent to the botanical garden and a recycling point building, and there is a parking lot across the street. Its quality level in terms of attraction is II. Due to the presence of speed bumps, the speed is reduced to 30 km/h, which improves safety, although noise levels remain the same,

at level III. The faculty building has only two floors and is separated from the sidewalk by a garden, so the width-to-height ratio can be considered level I.

3.4. Faculty of Medicine

In order to apply the PCME method, the first step is to analyze the accessibility factor by evaluating the street's walking section. This was physically measured on site, determining that the pedestrian section is 2.70 m wide in the center of the block, corresponding to a pedestrian quality level of II, and 5 meters wide in the other half, corresponding to level I. This variation is due to the bicycle lane being interrupted in the middle of the faculty. Regarding safety, the street has

two bicycle lanes, 3 meters wide, although one is interrupted halfway along the sidewalk and is only one-way. There are also three vehicle lanes, one reserved for buses, in a 40 km/h zone. As for its attraction or complexity, in this street less than 300 meters away there are two city bus stops (8, 11, 23 and C5) and a stop where five regional bus lines pass that go to different municipalities of Málaga, specifically to Mijas (M114), Benalmádena (M116), Cártama (M118), Alhaurín de la Torre (M143) and Rincón de la Victoria (M166). There is also a metro stop within 300 m. The presence of the nearby metro stops can raise safety concerns—there are no elevated fences, so pedestrians can easily access the tracks. We classify the perceived safety level as V.

Figure 5: Faculty of Medicine: Satellite View and Street View. Source: Geoportal Malaga [12-14]

Traffic in this area is high, as this is one of the most prominent faculties of the University of Malaga and the street connects to a 3-lane highway. Moreover, it is adjacent to a highly frequented location which is the El Clínico Hospital, and thus resulting in a very noisy environment with a quality level of V. There is a single row of fairly dense trees, but no additional greenery from a garden, resulting in a vegetation quality level of V. The height-to-width ratio of the building is estimated at level III, since it is a three-story building on a five-meter-wide street, although the exact building height could not be measured. There is no commercial complexity in the university zone, but the area's pedestrian appeal can be estimated due to the presence of the faculty and nearby points of interest. In this case, it is a prominent building with many students, located next to the library and hospital, making it fairly attractive to pedestrians. Other

factors not considered in the PCME method but still affecting walkability are also analyzed, such as shade from the trees, which provides sun protection. In this street, there are leafy trees that provide some shade. In front of the faculty, there is a park with a large number of trees, shaded areas, benches, and trash bins, creating a sense of nature and landscaping. On the other hand, the area has some basic urban planning elements, though these are mostly limited to trash bins.

3.5. Faculty of Fine Arts

The pedestrian section is 1.60 meters wide, which corresponds to a quality level III in terms of accessibility. Regarding safety, the street has a single vehicle lane in a 30 km/h zone, yielding a safety level of II. Additionally, the presence of parking spaces between the sidewalk and the road enhances the perceived sense of safety.

Figure 6: Faculty of Fine Arts of Malaga: Satellite View and Street View. Source: Geoportal Malaga [12-14]

Traffic is moderate, as reflected in the number of parked cars, and noise levels are low, resulting in a quality level of II. The street has no trees. It is narrow, and the pedestrian section narrows further to 1.25 m where utility poles are placed. Therefore, tree density is classified as level IV. Although there are no trees on the street itself, there are trees in the park across the road, which contributes to the overall landscape quality. The proportion between the building's height (3 stories) and the street width (1.60 meters) leads to a quality level of V. Other factors not included in the PCME method but which affect pedestrian mobility include shade; in this case, the street is fully shaded due to the height of surrounding buildings. A bus stop for Line 37 is located within 300 m. The street itself lacks any urban furniture, but across the road there is a well-designed space for pleasant walking. Overall, the street gives off a neglected feel, with graffiti on the walls and cars dominating the entire area.

3.6. Summary of Indicators
Below is a summary of the ratings obtained using the PCME method for the set of university access points evaluated:

Centers	Pedestrian Section	Modal Friction	Noise	Tree Cover	Height/Width Ratio	Complexi ty
School of Industrial Engineering – South Entrance	I	II	II	II	II	IV
School of Industrial Engineering – North Entrance	I	II	I	I	I	IV
School of Computer Engineering	II	V	V	V	III	III
Faculty of Philosophy and Humanities	I/II	III	III	III	I	II
Faculty of Medicine	I/II	V	IV	IV	III	I
Faculty of Fine Arts	III	II	II	IV	V	IV

Table 3: Summary of Ratings by University Center

The results show that distance to destination, land uses, type of sidewalk, and trees are key when evaluating pedestrian quality. Other factors that also gain importance are the slope, street type, street continuity and distance to intersections.

4. Conclusions
One of the most important aspects for understanding the factors that encourage or discourage pedestrian mobility is accessibility.

The first factor is the space allocated to sidewalks compared to the space allocated to roadways (for vehicles). This also includes the quality of the sidewalks, which depends largely on their width.

Sidewalk width is a basic factor, as streets must allow for an appropriate flow of pedestrians. Similarly, it is important to consider obstacles that reduce the minimum walking space, such as bus stops, waste containers, or streetlights. Safety is also key. In university areas, it is recommended to reduce vehicle speed to 30 km/h, so pedestrians do not feel threatened. Alternatively, a buffer zone, such as a parking strip, can be placed between the sidewalk and the roadway. Shade, trees, and landscaping are essential for protecting pedestrians from weather conditions and enhancing comfort. Similarly, noise levels influence whether pedestrians can move in a pleasant and comfortable way. Urban design must support pedestrian presence by including elements such as trash bins, benches, and pedestrian signage. Finally, the environment should engage pedestrians.

Overall, areas such as the School of Industrial Engineering, the Faculty of Medicine, and the Faculty of Philosophy and Humanities, each with their own specific characteristics, provide pleasant streets for pedestrian circulation. However, other areas like the School of Computer Engineering or the Faculty of Fine Arts do not support pedestrian circulation effectively and therefore require measures to redesign their surroundings.

Currently, based on these indicators, this research team is using GIS tools to model maps of healthy walking routes that promote the concept of the 15-minute city in nonuniversity districts.

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