Planning for sustainable urban mobility: demand estimation of on-street vertical walking facilities

The improvement of pedestrian mobility through the use of on-street vertical facilities, i.e. escalators, moving sidewalks, lifts, funiculars and gondola lifts, is becoming increasingly important in many cities with steep slopes that hinder walkers' transit. However, studies on the acceptance, profitability and demand for these facilities are still scarce. The present paper proposes an assessment methodology to evaluate the demand for vertical pedestrian routes and facilities based on diverse accessibility indicators. This methodology was applied to the city of Santander (Spain), where flow measurements and surveys among users of existing vertical walking systems were carried out. These data were modelled using Poisson and Binomial Negative regressions, considering the truncated and discrete character of the dependent variable. The results obtained confirm that vertical walking facilities are highly valued by users. Contrary to expectations, accessibility from these facilities to public services or commercial areas was not relevant to estimate the demand of the existing routes and only accessibility to population proved to be significant. Therefore, it is advisable to install this type of walking facilities in those pedestrian routes located in areas with enough population density over well-equipped central areas, so that the number of potential users justifies their investment and maintenance costs.

Keywords: Vertical walking facilities; Accessibility; Travel behavior, Demand models; Urban planning

1. Introduction and goals

Active mobility promotion is one of the major goals of any transport policy aiming at the improvement of urban quality (Forsyth & Southworth, 2008; Moura et al., 2017) and a key contribution to achieve inclusive and sustainable cities, in line with the 11th goal of the United Nations' Sustainable Development agenda (United Nations, 2015). The pedestrian mobility mode implies, as opposed to motorized modes, strong positive externalities such as the improvement of public health (Ewing et al., 2008; Mueller et al., 2015; Pucher et al., 2010; Saunders et al., 2013), the promotion of social integration and sense of community (Wang et al., 2016) and the creation of safer and more livable and vibrant urban environments

(International Transport Forum, 2012; Leyden, 2003; Soni & Soni, 2016). However, the shorter trip times offered by other modes, among other factors, have caused it to progressively lose relevance in the modal split of many urban areas (Forsyth & Southworth, 2008).

In order to reverse this situation, various cities have progressively incorporated sustainable and inclusive mobility policies and plans including the promotion of pedestrian mobility (Castillo-Manzano et al., 2014; Commonwealth of Australia, 2013; Gardner et al., 1996; Shafray & Kim, 2017; Southworth, 2005), which directly affects the ways in which cities are planned and designed today. The pedestrian character of traditional cities, which was forgotten and replaced during the second half of the last century, by an excessive occupation of urban spaces by automobiles (Jou, 2011), is now recovering its relevance.

In today's city, it is expected that urban spaces encourage pedestrian mobility by improving their walkability. Walkability is defined as a combination of street design and urban environment characteristics that support and encourage walking by ensuring land-use diversity, functionality, safety and convenience, as well as connectivity and accessibility (Moura et al., 2017; Peiravian et al., 2014; Southworth, 2005; Su et al., 2019; Turoń et al., 2017). In this context, connectivity refers to the existence of continuous grids or networks without barriers, such as topographic ones, to pedestrians, while accessibility, besides referring to proximity (i.e. the easiness to reach a variety of destinations), also implies a universal access for all citizens, especially considering the most disadvantaged ones (Moura et al., 2017). In attention to these criteria, some areas are identified as less favorable for walking due to the presence of steep slopes, their peripheral location (as in many informal settlements), or the ageing rate of the population (e.g. historical urban centers).

One of the actions that some cities around the world are increasingly taking to improve universal accessibility and connectivity of these areas is the implementation of vertical walking systems or facilities such as escalators, moving sidewalks and lifts. This type of facilities, which were first implemented as touristic attractions and iconic symbols of many cities in urban environments with steep gradients, have become successful transportation alternatives in several cases. These facilities can play a key role in promoting mobility for all age groups, including elderly pedestrians and people with reduced mobility, encourage them to walk and extend the range of distances they can reach by foot, and also in integrating isolated neighborhoods, especially in cities with certain difficulties to enable active mobility, due to topography or man-made obstacles.

However, despite the increasing implementation of these outdoor vertical walkways and infrastructures throughout the world, their actual efficiency and demand have scarcely been studied in the academic literature. Only a few studies focusing on the engineering requirements necessary to improve the potential of variable-speed or accelerating moving walkways to compete with, or complement, public transport such as bus or underground exist (Kusumaningtyas & Lodewijks, 2008; Rockwood & Garmire, 2015).

This paper seeks to estimate demand models of pedestrian routes which involve the presence of diverse vertical facilities. These models include accessibility to neighboring urban opportunities as one of the factors that can influence demand, thus allowing to analyze whether, and to what extent, facilities with higher levels of accessibility to opportunities attract a larger number of users. In this way, new mobility plans could assess and determine where to locate new routes in order to attract enough users to justify their profitability in social terms, given their construction and maintenance costs.

The used methodology is based on the estimation of linear, Poisson and Binomial Negative (NB) regression models, considering, in the latter two cases, the discrete and truncated nature of the dependent variable. The evaluated routes are located in the city of Santander (Cantabria, Spain), where a firm investment commitment on vertical walking facilities has recently been made, as a part of its Sustainable Urban Mobility Plan (SUMP).

Pedestrian flow measurements and surveys among current users of each route were carried out to characterize mobility demand and evaluate user's satisfaction with the system.

The following section reviews the evolution and characteristics of these facilities as well as the state of the art of previous studies estimating the demand for urban transport modes involving a walking access. Section 3 describes the methodology used, comprising the formulation of accessibility indicators and demand models applied to the city of Santander. The last section presents the final conclusions obtained from the study.

2. Vertical walking facilities and estimation models

2.1 Evolution and characteristics of vertical walking facilities

Chronologically, funiculars were the first facilities to be implemented as touristic attractions. The Montmartre funicular, in Paris, or the Montjuic funicular, in Barcelona, are representative examples of this type of infrastructure that can bridge slopes between 8˚ and 30˚, and are particularly suitable for short urban routes of up to 1.5 km (Hoffmann, 2006). Lifts, which allow pedestrians to overcome vertical unevenness, also became iconic symbols of many cities, as the historic Elevador Lacerda (inaugurated in 1873 in Salvador de Bahía, Brazil (Rezende & Ribeiro, 2012)), and Elevador Santa Justa (inaugurated in Lisbon in 1902 (Byrne, 1985)), but also successful mobility alternatives, moving almost 900,000 passengers per month in the Brazilian case.

Moving sidewalks or walkways, whose first implementations - associated to exhibition events - date back to the beginning of the 20th century, are also present in a few cities or elevated areas such as Medellin (Colombia) and Perugia (Italy) (Scarinci et al., 2017).

Escalators have also been more recently incorporated in outer urban environments with slopes of up to 30˚ (Table 1). A good example is the Hong Kong Central and Mid-Level

Escalator and walkway system (introduced in 1993), whose ladder system, the longest outdoor covered one in the world, is used by tens of thousands of users daily to climb and descend a steeply sloping neighborhood in Hong Kong Island (Cullinane, 2002).

Finally, gondola lifts or cable cars, which are useful for long routes with steeper gradients have been considered a successful urban transport alternative. This is the case of The Metrocable system of Medellín (Colombia), opened in 2004, that has contributed to integrate the population of peripheral informal settlements into the city's structure (Brand & Dávila, 2011a, 2011b), being later imitated by other cities in the world and particularly in Latin America (Garsouset al., 2019).

Characteristic	**Lift**	**Escalator**	**Moving sidewalk**	**Funicular**	**Gondola lift**
Slope	Close to verticality	Between 27˚-30˚	Low, between 6˚ - 12˚	Between 8˚ - 30˚	High, usually over 20˚
Capacity	480 passengers/hour /direction (PPHPD)*	4500 - 11000 PPHPD	4500 -11000 PPHPD	Variable according to cabin size, speed and route	1000 - 3000 PPHPD
Accessibility	No restrictions for pedestrian, bicycles, wheelchairs...	Limitations for wheelchairs, children trolleys, persons with mobility difficulties	Similar to lifts. No limitations	Dependent on location and design of cabins and stops	Dependent on location and design of cabins
Implementation and maintenance costs	Relatively low	Relatively high (can triple that of a lift)	Relatively high (can triple that of a lift)	Relatively high	Relatively low
Reliability	High	Medium	Medium	High	High

*Assuming an 8-passenger cabin, a difference in height of 25 meters and a 1.6 meters/second speed.

Table 1. Main characteristics of different vertical walking facilities. Source: own elaboration from City Council of Donostia - San Sebastian (2006), Gómez Núñez (2018), Orro Arcay et al. (2003) and Sanz Alduán (2016).

As can be seen, there are several elements that can configure vertical pedestrian mobility and their selection has to consider specific criteria such as capacity, accessibility, topography, implementation/maintenance cost and reliability (Table 1). Urban and transport planners can select the proper facility to solve each specific problem, or they can opt for a comprehensive analysis of mobility that allows for the configuration and development of continuous pedestrian routes that integrate various facilities, as is beginning to be common in several Spanish cities, such as Barcelona, Bilbao, San Sebastián or Santander (City Council of Bilbao, 2018; City Council of Donostia, 2017; City Council of Santander, 2010; Guerrero, 2019).

There are approximately one thousand vertical infrastructures in operation in Spain (Pons, 2017). Barcelona is the city with the highest number, 129, involving 88 escalators, 41 lifts and 5 inclined lifts that are used by *ca.* 27 million passengers per year (ppy) (Guerrero, 2019), making it another efficient mode of urban transportation. In the second position is Bilbao, with 55 facilities including lifts (36), escalators (13) and moving sidewalks (5) also serving to more than 23 million ppy (City Council of Bilbao, 2018). In the case of San Sebastian, whose first vertical facility was implemented in 2006 thanks to the development of a specific vertical mobility plan, there were 22 routes comprising vertical elements, mostly lifts, in 2017 and the new plan proposes the implementation of 26 additional itineraries with 42 new lifts (City Council of Donostia, 2017). Santander has also clearly committed to the implementation of new vertical facilities since 2007 and still plans for more facilities. Its 13 routes with almost 50 facilities, mostly moving sidewalks, are used by *ca.* 8 million ppy (City Council of Santander, 2020), a considerable number for a population smaller than the previous cities.

Taking these examples into consideration, the greater or lesser success of the planning, implementation and use of these facilities depends, besides the technical factors indicated before, on other relevant factors such as a good location in response to citizens' demand.

2.2 Demand and accessibility estimation models

As mentioned before, little research has focused on vertical walking facilities. As regards demand estimation, studies focus on indoor infrastructures, considering issues such as users' choice between escalators and conventional stairways at metro or rail stations using random utility models (Srikukenthiran et al., 2013, 2014; Zhang et al., 2015) or more recently supervised learning models (Li et al., 2020). However, there is hardly any study specifically addressing demand for outdoor or on-street systems.

Studies on demand of urban transport facilities that can be replicated to analyze vertical walking facilities are those related to public transport stops and stations (see for example Olszewski & Wibowo (2005)). Traditionally, these studies have focused on determining their service area, which enables to estimate the population affected by a stop or station, in order to estimate its potential demand. In the United States, a general rule of a 0.25 miles radius (ca. 400m) has been taken as a guideline to determine the service area of bus stops, and 0.5 miles (ca. 800m) as a standard value for the service area of rail stations (Delmelle et al., 2012). These standards have proven to work well as a general criterion, notwithstanding the fact that there is evidence that demand estimation depends largely on the opportunity (i.e. population, jobs) variable, the spatial distribution hypothesis considered, and other factors related to the cost function selected to build the model (Guerra et al., 2012).

A relevant study in this line of research is the one carried out by Zhao et al. (2003), who propose a novel methodology to overcome traditional methods such as the accessibility estimation of bus stops by generating a service area. This new method considered the unequal distribution of the population, the existence of access barriers to reach stops and the decrease in accessibility with distance. The authors demonstrated that their method estimated a significantly lower total served population than the one estimated using traditional methods.

Similarly, Biba et al. (2014) proposed a method to calculate accessibility to bus stops based on the spatial overlap of parcels/lots that contained demographic and transport network information. The authors proved that this method avoided the overestimation of the served population made by previous methods, such as the direct application of buffers, or the consideration of the ratio between transport network inside the buffer and the population present in each arc under the assumption of a homogeneous distribution. Furthermore, considering the socio-demographic characteristics of transport infrastructure users, Chia et al. (2016) examined differences in accessibility to stops for diverse social groups in Brisbane (Australia). Their results showed that higher income, part-time and elder users were more sensitive to walking times to stops than other users.

However, the selection and use of this type of facilities also depends on their location with respect to the complete pedestrian network, given that route selection is influenced by features of the built environment, such as the configuration and parameters of the urban grid, block and street (Cervero et al., 2009; Gehl, 1987/2011; Krizek et al., 2009; Larrañaga et al., 2016), the land uses and activities present in the vicinity and other variables (Ewing & Handy, 2009; Moura et al., 2017; Shashank & Schuurman, 2019). Indeed, besides residential density, the diversity and location of destinations can also be relevant to promote walking (Xu, 2019). Several studies on walkability have estimated buffers of 400m from centroids of residential neighborhoods to analyze reachable activities that can encourage active transport (Xu, 2019). Therefore, other opportunities accessible from vertical facilities should be considered when analyzing their demand. Thus, service area methods can also be applied to variables that have been identified among the most common travel destinations in the urban environment, besides work or home, such as commerce, educational and health facilities. The population and opportunities present in the service area of one vertical facility can be subsequently related with its demand using various types of regression techniques.

3. Methodology

The methodology applied in this research allows evaluating the demand of different urban routes with vertical walking facilities and predict future demand of new facilities. To this end, the first step of the process was to estimate the number of current users of the existing facilities through a users' count. Additionally, a users' survey was performed to characterize the typology of users, their trip characteristics and their satisfaction with the service, aspects that can be useful to understand their present and future demand. As a second phase, indicators of the accessibility of these vertical walking facilities to population and other opportunities were calculated as variables that can enhance and influence their demand. Finally, a series of models which relates these indicators with the effective user-demand of the facilities were estimated (Figure 1).

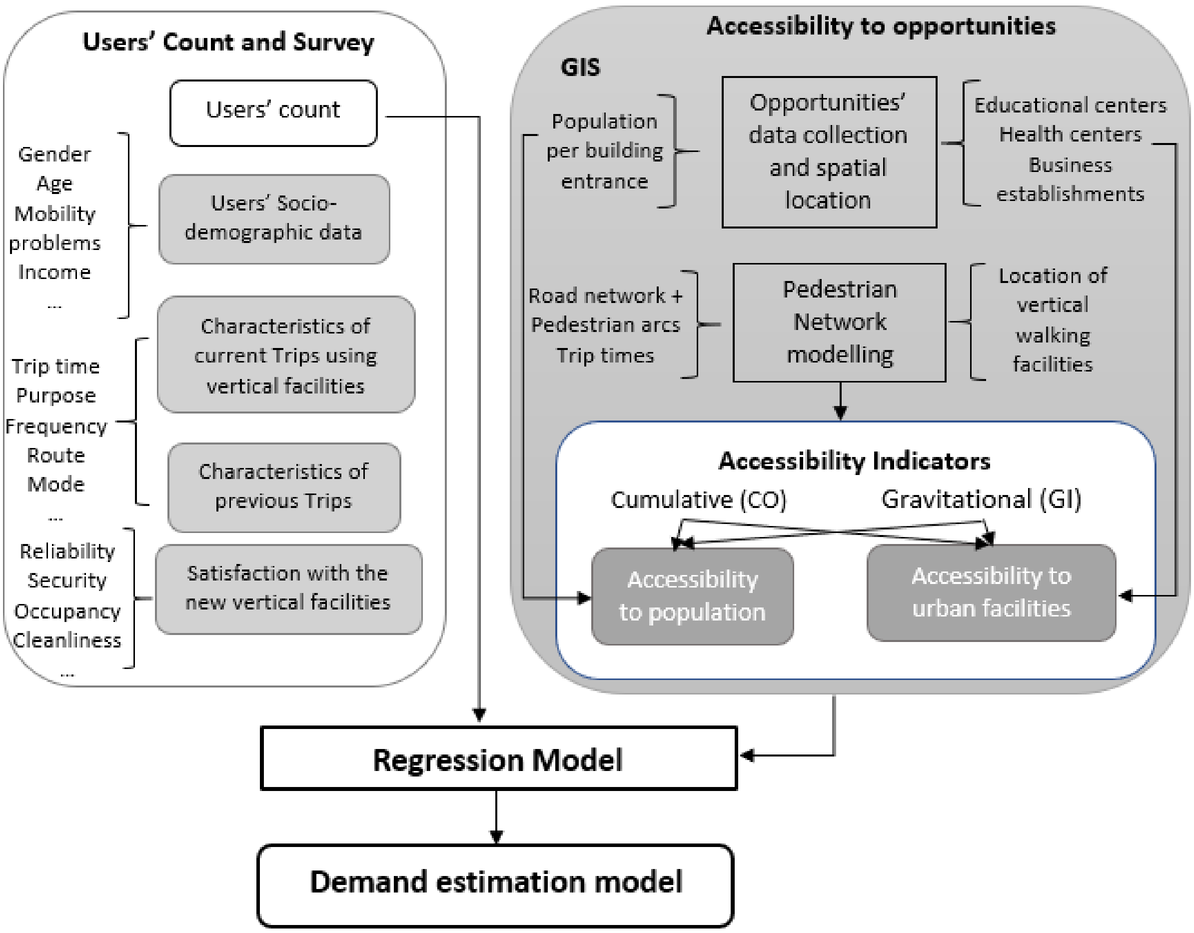

Figure 1. Methodology for estimating the demand for vertical pedestrian routes

3.1 Users' count and survey

Users' counts were planned at the peak hours of several days at the beginning and end of each route to obtain the average number of daily users. It should be considered that some of the routes have several subsections and vertical facilities, so that citizens can leave the route or join it at intermediate points.

Once the count was performed a survey was proposed for which the minimum number of respondents was established according to:

$$n \geq \frac{N \cdot z^2 \cdot \sigma^2}{e^2(N-1)+z^2 \cdot \sigma^2} \quad (1)$$

where, *n* is the minimum number of required responses, *e* is the maximum acceptable standard error as a proportion, *z* is the desired level of confidence, *N* refers to total number of users and σ^2 is the variance in the population of the interest variable.

The proposed survey was structured in attention to four major goals: 1) to identify users' characteristics, 2) to analyze their trips using these vertical facilities, 3) to analyze their trip before these facilities were available and 4) to determine their assessment of the system (see survey form in Figure 2).

DAY		HOUR		LOCATION	

VERTICAL MOBILITY REVEALED PREFERENCE SURVEY

USER CHARACTERISTICS

Sex		
	Woman	
	Man	

Reduced mobility	
YES	
NO	

	Yes	No
Driving License	Yes	No
Car Availability	Yes	No

Age (ind.)	
<= 24	
25 - 34	
35 - 44	
45 - 54	
55 - 64	
>= 65	

Family Income (€)	
<= 900	
900 - 1.500	
1.500 - 2.500	
>= 2.500	
NS/NC	

CHARACTERISTICS CURRENT TRIP

Trip Origin
Trip Destination

Trip Time (min)	

Trip Purpose			
Home		Study	
Work		Health	
Leisure		Shopping	
Other			

Use Frequency escalators/ramps/lifts			
Daily		Trips/day	
Weekly		Trips/week	
Monthly		Trips/month	
Sporadically			

Mode	Available	Frequent
Car		
Motorbike		
Bus		
Taxi		
Bike		
Foot		
Other		

Meteorological conditions	

Will you use the same route to return?	
YES	
NO	

If you are not going to use the same route, choose mode	
Car	
Bus	
Taxi	
Bike	
Foot	

If you choose CAR		
	Parking choice	
	Parking Place	

TRIP CHARACTERISTICS BEFORE INSTALLATION OF VERTICAL MOBILITY INFRASTRUCTURE

Mode	Used mode
Car	
Motorbike	
Bus	
Taxi	
Bike	
Foot	
Other	

Trip Time (min)	

In case of using CAR		
	Parking alternative used	
	Parking Place	

VALUATION OF CURRENT TRIP AND TRIP BEFORE INSTALLATION OF VERTICAL MOBILITY INFRASTRUCTURE

	CURRENT TRIP (VERTICAL MOBILITY INFRASTRUCTURE)					
	VERY BAD	BAD	NORMAL	GOOD	VERY GOOD	NR/DK
Reliability						
Security						
Schedule						
Occupancy						
Cleanliness						
Access Time						
Egress Time						
GLOBAL VALUATION						

	TRIP WITHOUT VERTICAL MOBILITY INFRASTRUCTURE					
	VERY BAD	BAD	NORMAL	GOOD	VERY GOOD	NR/DK
Reliability						
Security						
Schedule						
Occupancy						
Cleanliness						
Access Time						
Egress Time						
Fare						
Parking availability						
Kindness of employees						
GLOBAL VALUATION						

Only apply the variables of each mode

REMARKS AND PROBLEMS DETECTED

Figure 2. Users' survey form

The first section contained questions about gender, age, existing of reduced-mobility conditions, income and availability of car use. Second section included questions regarding current trip using vertical facilities, such as trip time, purpose, frequency, route and mode of transportation. Third section comprised questions about the former trips such as mode of transportation and trip time, in order to establish variations due to the implementation of the vertical facilities. Section four comprised aspects about users' satisfaction with the new facilities. These responses were collected using a five-point Likert scale, ranging from very bad to very good valuation. Finally, there were also space for users to make several comments about the problems they noticed in the new routes implemented.

3.2 Estimation of accessibility to opportunities of vertical pedestrian routes

Prior to calculating the demand models, an accessibility estimation from the vertical routes to both population and representative urban facilities, i.e. health/educational facilities and business establishments, was carried out. This estimation depended on three main factors: the unit used to measure accessibility in each of the selected elements and their spatial distribution, the level of cost and the chosen cost function.

As regards the unit of measurement and its spatial distribution, accessibility is very dependent on the type of opportunity selected, as well as on data availability. In the case of population, data can be totally disaggregated at the dwelling/housing level, somewhat more aggregated at building level or even more aggregated considering the type of zoning, generally at a district census level. Another possibility is counting on population data aggregated at the road/street axis level (O'Neill et al., 1992). The most recommendable alternative to establish the best possible estimates is to consider disaggregated data at dwelling or building level. Otherwise, the second-best option would be to work with data at arc or zone level and complement them with information on population distribution. The simplest case regarding the spatial distribution of the population is to assume a homogenous distribution throughout the arc or zone, although this assumption is the one that can lead to estimates with a higher error. A better alternative is to consider land use data that allows the total existing population to be distributed over those parts of the arc or area with residential uses.

Pedestrian trip cost can be estimated by the Euclidian or Manhattan distance, or by the distance covered by the pedestrian network. Another alternative would be to consider trip time as the ratio between distance and an average pedestrian speed. The latter option is preferable, especially when distance is estimated across the pedestrian network. This network should consider the existence of barriers (natural or human-designed) that prevent pedestrian mobility between arcs.

The existing pedestrian network, in which each arc accounted for its length, was considered. This pedestrian network was obtained from a previous road network edited to take into account all pedestrian arcs. From these data, pedestrian trip time was calculated assuming the average speeds shown in Table 2. The traveling speed of vertical walking facilities (sidewalks, escalators or lifts) was estimated according to their technical specifications. Walking speeds considering ground slope were estimated using Tobler's hiking function (Tobler, 1993), as follows:

$$w = 6e^{-3.5|S+0.05|} \quad (2)$$

where *w* refers to speed in km/h and *S* to slope in percentage.

Type of pedestrian arc	Speed (m/s)
Slope <=5%	1.28
Slope between >5% y <=10%	1.08
Slope between >10 y <=20%	0.83
Slope >20%	0.5
Pedestrian crossing	1
Stairway	0.35
Sidewalk/Escalator	0.5
Lift	1

Table 2. Speed factors applied according to slope and type of vertical walking facility

Finally, the cost function must be adjusted to the data observed on the actual distances or trip times covered by pedestrians. The most frequently used cost functions are the potential and exponential ones (Iacono et al., 2010), both with a single parameter to estimate.

Therefore, the accessibility estimation relied on two of the most commonly used indicator types found in the literature: cumulative opportunities and gravitational ones, formulated as follows:

$$A_i = \sum_j f(P_j, C_{ij}) \quad (3)$$

where P_j is a measure of the opportunities (population, jobs) offered by destination j (housing, building, arc or zone) and C_{ij} is the cost between zones i and j, measured as a walking trip time or a distance. If the type of chosen indicator is one of cumulative opportunities (Geurs & van Wee, 2004; Handy & Niemeier, 1997) the value of C_{ij} will be =1, if the opportunity can be reached within a predetermined cut-off time, and 0 otherwise. The indicator used may also be of the gravitational type, in which case the opportunities will be weighted by the results of the specified cost function $f(c_{ij})$.

The cumulative opportunity indicators of population, public services and shops were estimated according to previous equation, considering a cut-off value of a 5 minutes walking time through the pedestrian network, from both the beginning and the ending points of the routes. Thus, the result of the indicator for each route corresponds to the sum of opportunities reachable in a detailed 5-minute service area from both reference points. This trip time was established by analogy with the 400 meters distance normally considered in bus-stop accessibility studies (see for example Kaszczyszyn & Sypion-Dutkowska (2019)).

Gravitational indicators were also estimated using equation (1), considering an exponential cost function where its parameter was calibrated from the trip time provided by the users in the survey.

3.3 Models of trip demand estimation in vertical pedestrian routes

We proposed a regression model to estimate the demand of vertical pedestrian routes. Among the models that consider the truncated and discrete nature of pedestrian trip demand, one of the best known is Poisson's non-linear regression model (Lim & Srinivasan, 2011). In this model the probability of trip demand is given by (Greene, 2012):

$$P(y_i) = \frac{\lambda_i^{y_i} e^{-\lambda_i}}{y_i!} \tag{4}$$

The Poisson model assumes that the dependent variable y_i (trip demand) is extracted from a Poisson distribution with parameter λ_i, which depends on a linear combination of independent variables (e.g. population in the service area):

$$ln(\lambda_i) = x_i' \beta \tag{5}$$

This model has the limitation of considering that the mean and variance of the Poisson distribution are equal, which may not be true in those cases in which y_i is over- or underdispersed. This hypothesis can be relaxed by using more general models that allow unequal mean and variances, such as quasi-Poisson regression models (Zeileis et al. 2007) and NB regression models. NB models shows the following probability for a given trip demand:

$$P(y_i) = \frac{\Gamma(y_i+\theta)}{\Gamma(\theta) y_i!} \frac{\lambda_i^{y_i} \theta^{\theta}}{(\lambda+\theta)^{y_i+\theta}} \tag{6}$$

where λ_i is the mean, Γ corresponds to the gamma distribution and θ is the inverse of the gamma distribution scale parameter. In the NB model, variance is conditioned by $\lambda_i(1+(1/\theta)\lambda_i)$. It is possible to perform a test with a null hypothesis (1/θ)=0 to check whether the distribution that better fits the data is really the Poisson type, or it should be discarded in favour of a more general form with different variance and mean values.

4. Application to the case study of Santander

4.1 Study area and available data

The proposed methodology was applied to the case study of the city of Santander (Cantabria, Spain). Santander is a middle-sized city located in northern Spain, with *ca*. 172,000 inhabitants. Given its complex orography, formed by a north-south succession of significant ground elevations and depressions, some of the neighborhoods have problems of pedestrian mobility, especially those that concentrate elderly or dependent populations.

The Santander SUMP (City Council of Santander, 2010) proposed, as a part of the promotion of non-motorized or active mobility, the creation of 10 itineraries of on-street vertical pedestrian mobility by introducing facilities to help improve the mobility of its citizens. Six of these routes were completed by the time this research was carried out, i.e. routes 1, 2, 3, 6, 7 and 8 (Figure 3). It is worth mentioning that route 1 will not be connected to route 2 until a small intermediate section is completed (future route 11). Route 5 was also operational at the time of study, although it had undergone strong modifications with respect to the SUMP's initial proposal. Moreover, route 4, which was not initially proposed by the plan, was also implemented. Therefore, there were 8 fully operational routes with vertical walking facilities in the city when this study took place. They all have a north-south orientation to promote pedestrian mobility between the central axis of the city and the highest residential neighborhoods (Figure 3, Figure 4).

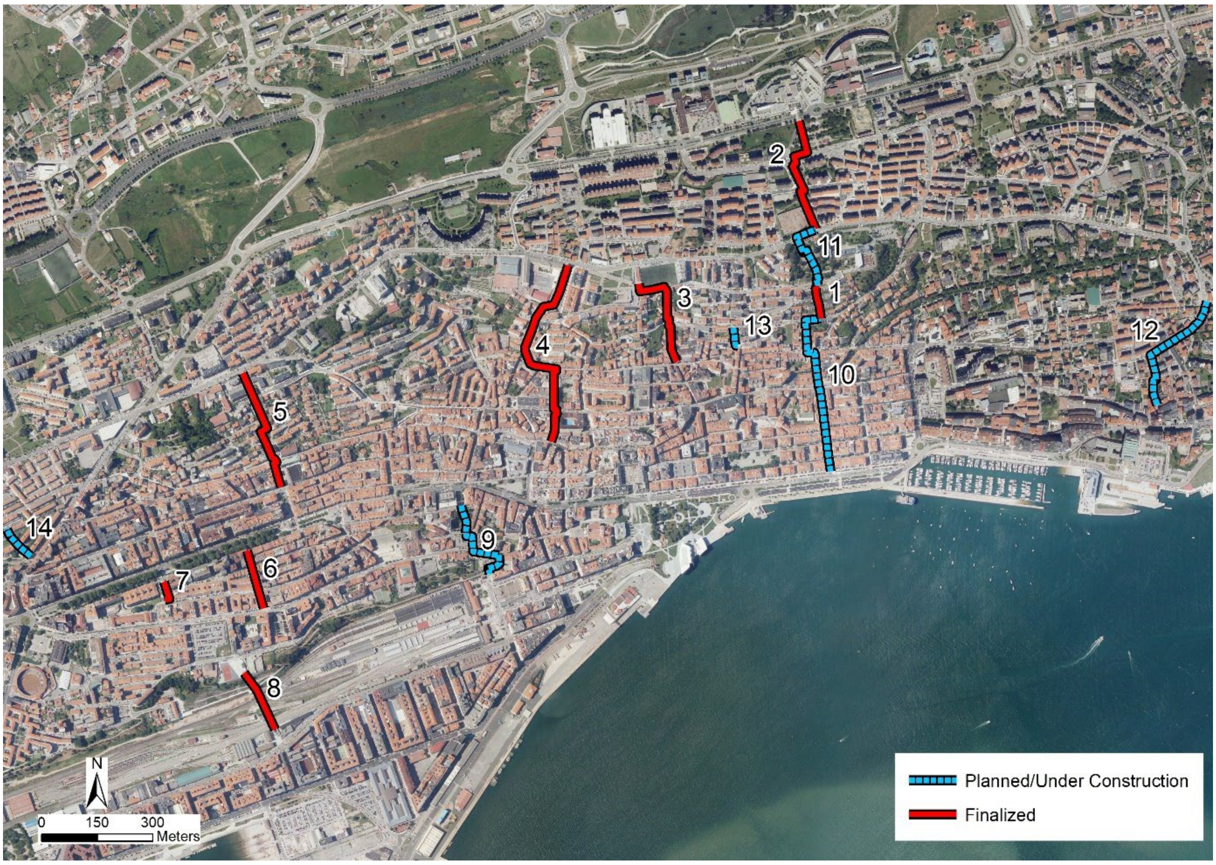

Figure 3. Completed, planned and under construction vertical pedestrian routes in Santander (2018)

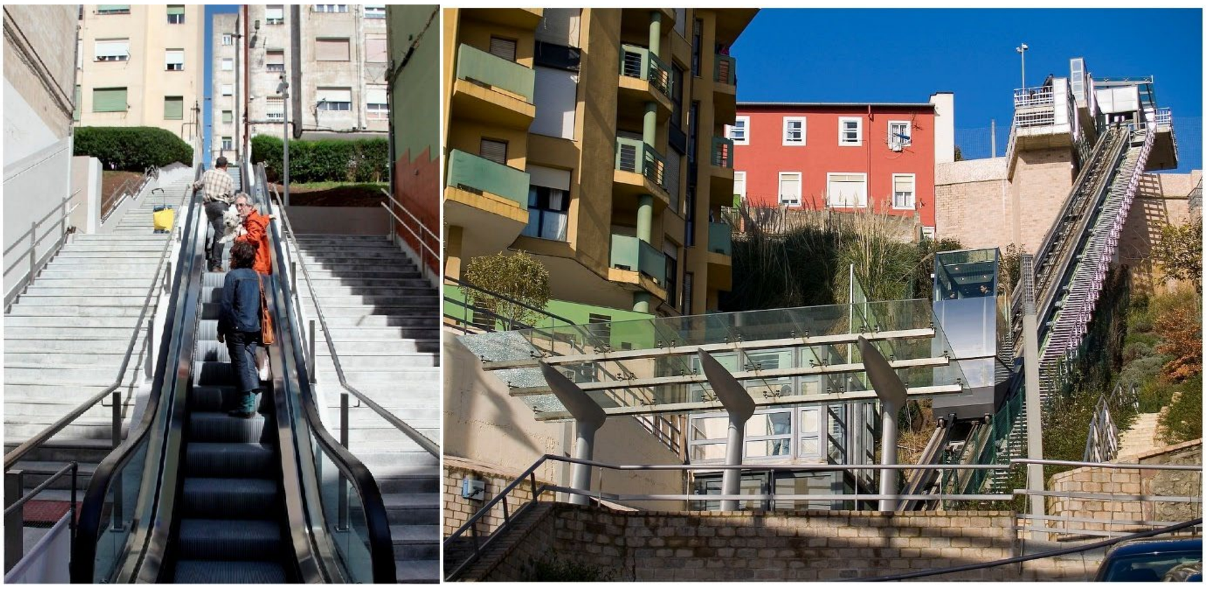

Figure 4. Example of vertical walking facilities in Santander. Route 1 (Left) and Route 3 (Right).

These routes include a total of 6 lifts, 22 moving sidewalks and 19 sections of escalators, in areas with slopes that can range from 2 to 31.5 degrees, with lengths ranging between 54 meters, in the shortest route, and up to 592 m. in the longest one (Table 3). Of the three routes initially planned in the SUMP that have not been completed, one has been finally discarded, as it has lost its initial expected functionality, while two more are expected to be completed in the future (routes 9 and 12). Besides, local demands have led the city council to commit to the construction of three additional itineraries which were not originally contemplated by the SUMP (routes 10, 13 and 14). Therefore, it is expected that in the near future, the system will have a total of 14 routes.

The first facilities were inaugurated in 2007, while the last one included in this study was opened in 2018. The creation of these pedestrian routes meant a municipal investment of nearly 19 million euros and maintenance costs of approximately 430,000 euros per year. This is a considerable outlay, although the use of these facilities is quite high, with an average of 21,272 daily users (*ca*. 647,000 monthly users) in all the facilities according to local government data for 2018, which means a maintenance cost of 0.055€ per user. The total disbursement justifies the need to plan new possible vertical pedestrian routes considering their accessibility to opportunities and their potential demand, in order to conduct a subsequent cost-benefit analysis that ensures their social profitability.

Route	Total number of facilities (moving sidewalks, escalators & lifts)	Height difference O/D (m)	Trip distance (m)	Installation cost (€)
1	5	28	93	2,928,924.09
2	7	40	349	1,801,965.17
3	5	57	302	4,191,211.23
4	9	62	592	2,210,280.61
5	6	45	352	2,020,311.59
6	5	22	161	1,434,249.68
7	6	15	61	1,861,032.89
8	4	36	175	2,188,081.57
9	Planned	16	283	
10	Under Construction	39	472	
11	Under Construction	4	216	
12	Planned	38	363	
13	Planned	17	54	
14	Planned	14	100	
Total				18,636,056.83

Table 3. Characteristics of Santander's vertical pedestrian routes and installation costs in 2018

4.2 Users' count and Survey results

The number of users of these vertical pedestrian routes was measured during three days in mid-November 2018, at the peak hours of urban trips within the city, i.e. between 12:30 to 14:30 hours. An average of 444 daily users was obtained (Table 4). The route number 5 was the one with the highest number of users, followed by route 7, both in the western part of the city and in an area of considerable residential density. In contrast, route 1 had the fewest users, probably due to the fact that it is located in an area of lower residential density and it is part of a wider pedestrian route that does not yet have all the vertical facilities required to be completed. It should be noted that data from route 10 was also included since, although it was only partially operational when the survey was carried out, it will be used to validate the estimated models.

Route	Name of the route	Number of Users counted
1	Grupo Santa Teresa	170
2	Facultad Ciencias - General Dávila	347
3	Rio de la Pila - General Dávila (Funicular – Upward)	369
4	Plaza de los Remedios - General Dávila	590
5	Numancia - General Dávila	707
6	Eulalio Ferrer - Calle Alta	416

7	Calle Alceda - Isaac Peral (Upward)	673
8	Pasarela Calle Castilla - Calle Alta (Upward)	403
10	Paseo Pereda - General Dávila	321
	Mean	444
	Variance	31329

Table 4. Number of users of vertical pedestrian routes (upward direction – 2 hours)

Note: The data represent the average number of users counted between the beginning and the end of the route. In the case of two-way routes only the upward direction was counted.

Users' survey was conducted at the end of the month. Since the aim of the survey was to characterize the actual users of the vertical facilities instead of obtaining a sample of the city population, a random selection of users was chosen trying not to incur any selection bias. Considering the total user demand obtained, the minimum sample estimated according to (1) was 128 people, for z=1,645 (90% confidence level), error 10% and variance of valuations equal to 0.5. Finally, a total of 168 users were selected and interviewed. Most survey respondents were women (59%), in line with the general gender population distribution (54%). The distribution by age was fairly homogeneous, although older users predominated (respondents over 55 accounted for 44% of the surveyed sample, whereas they only were 40% of the population). A large proportion of users presented a driver's license, although almost half of them did not have a vehicle available (Table 5). The average pedestrian self-reported trip time of vertical facility users was close to 18 minutes, the majority travelling to their home (27%), work (20%) or shops (14%). The majority of users stated that they used vertical walking facilities on a daily basis with an average of two trips per day.

		Value
Gender	Male	41.1%
	Female	58.9%
Age	24 or younger	11.9%
	25 to 34 years old	11.3%
	35 to 44 years old	17.9%
	45 to 54 years old	14.9%
	55 to 64 years old	20.2%
	65 or older	23.8%
Monthly household income	< 900 €	13.7%

	900 - 1500 €	29.8%
	1500 - 2500 €	31.5%
	> 2500 €	11.9%
	NR / DK*	13.1%
Reduced mobility	Yes	6.5%
	No	93.5%
Driving license	Yes	61.3%
	No	38.7%
Car Availability	Yes	54.2%
	No	45.8%
Trip time	-	18.23 min
Trip purpose	House	27.38%
	Work	20.24%
	Study	10.12%
	Health	4.76%
	Shopping	13.69%
	Leisure	12.50%
	Other	11.31%
Use Frequency	Daily	58.33%
	Weekly	26.19%
	Monthly	4.76%
	Sporadically	10.71%
	Trips / day	2.03
	Trips / week	2.75
	Trips / month	2.87
Perceived Quality	Reliability	3.89
	Security	4.25
	Schedule	4.29
	Occupancy	4.04
	Cleanliness	3.95
	Access Time	4.29
	Time to destination	4.34
	Overall Evaluation	4.35
* No Response / Don't Know		

Table 5. Characteristics of the users of vertical pedestrian routes obtained from the survey sample

The aspects most highly valued by users were accessibility to vertical pedestrian facilities from their origin and from these facilities to their destinations. In other words, users found the location of these facilities highly convenient, although in these results there may be a selection bias derived from the fact that only actual facility users were surveyed. The next most valued factor was the operation hours of the facilities, between 06:00 am to 00:00. This indicates that only a few users considered the fact that vertical facilities are not operational at night inconvenient. The least valued aspect was reliability, an aspect that was also noted in the observations made by users, since many of them perceived that the facilities are not working properly too often, a phenomenon that is also related to the vandalism problems reported by some respondents. Even so, the overall valuation of the service was very high, with a score of 4.35 out of 5, indicating that users are very satisfied with these facilities. This valuation was not significantly different (Mann-Whitney, p-value>0.05), for men (4.37) and women (4.33), and neither considering age and income group according to the Kruskal-Wallis test (p-value>0.05).

If the frequency of use is taken into account, the users who best rated the routes were daily users (4.42) while monthly and sporadic users (4.20) did so to a minor extent. However, the Kruskal-Wallis test between the scores given for the diverse frequencies of use did not show significant differences either (p-value>0.05).

If we consider the same origin – destination trip before the existence of the vertical facilities, most of the users (81%) answered that they did the route also on foot. However, 13% of them claimed that they had previously chosen other transport modes, mainly the bus (11%) or private motorized transport (2%). In addition, other 6% did not know or did not take that route previously. Furthermore, the users who previously took the routes perceived in general that, with the new vertical facilities, their trips were shorter by an average saving of 3.85 minutes.

4.3 Estimated accessibility to population, facilities and business establishments on vertical pedestrian routes

For the calculation of the accessibility indicators, population data were available at census district level with a maximum population of 2,200 inhabitants per zone. In order to improve the disaggregation of the data, a layer containing a point per each street entrance of the residential buildings of the city was also used. In this way, the location of the population could be more accurately analyzed, by distributing the total population homogenously among all the buildings entrances comprised in each zone, as follows:

$$P_{in} = \frac{P_n}{V_n} \tag{7}$$

where P_{in} is the population in a residential building i in zone n, P_n is the population in zone n, and V_n is the total number of buildings entrances present in zone n. In Figure 5, residential buildings entrances are located as points along with the pedestrian network and the vertical routes analyzed. Prior to the application of (7) the buildings layer was amended in order to eliminate all those points not having a real residential purpose.

Other types of opportunities such as health and educational facilities as well as business establishments present in the study area, were also located and represented as points (Figure 5). As health facilities (24) we considered local primary care centers (10), clinics (2), hospitals (4) and special medical centers (8). As educational facilities (130) we identified public and private nursery-primary schools (36), secondary schools (19), schools from nursery to sixth form or further education (47), professional training (further education) schools (9) and the university faculties (16). As business establishments (5,517) we considered shops, restaurants, consultancy offices, etc.

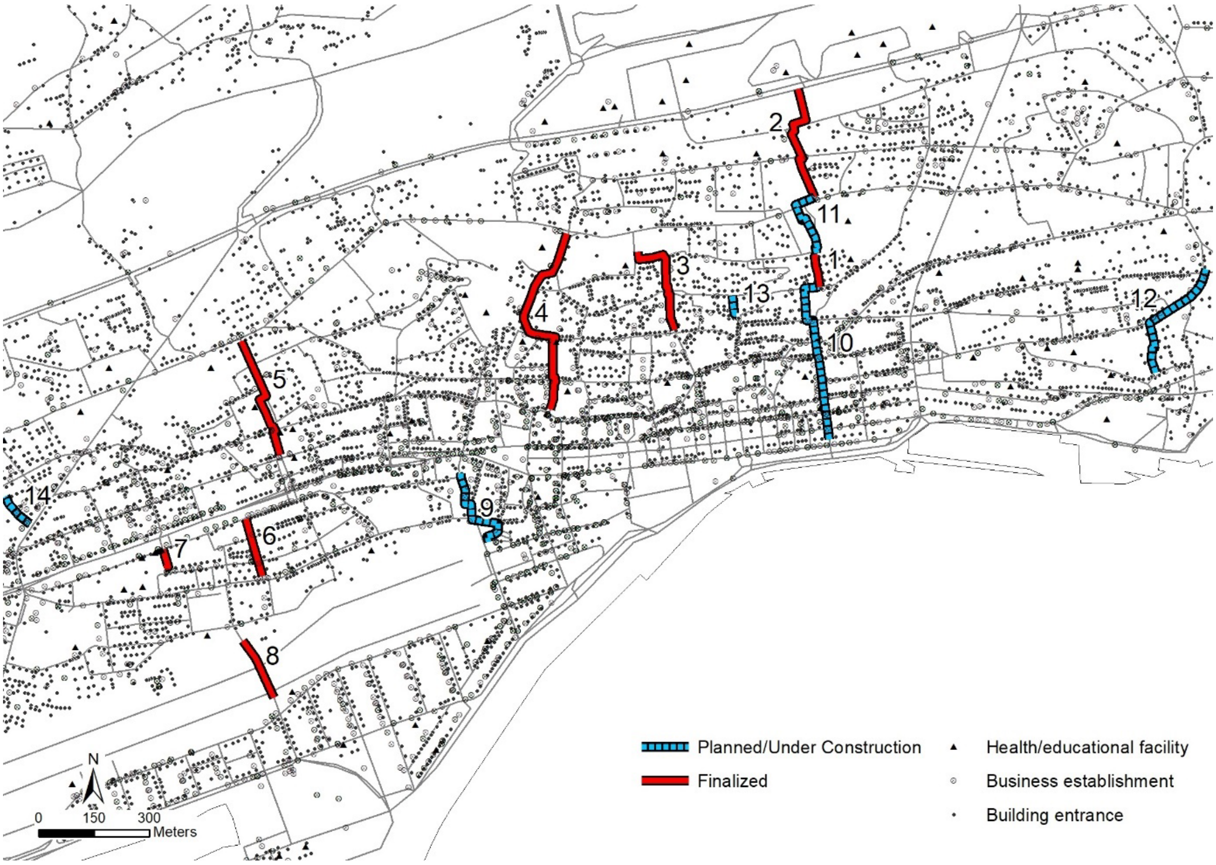

Figure 5. Vertical pedestrian routes, street network and location of residential buildings, health and educational facilities and business establishments

As regards the estimation of accessibility, the exponential cost function presented the best fit to the data, with an R^2 value of 0.96 versus an adjustment of 0.91 of the linear function and 0.71 of the potential function (Figure 6). The estimated parameter resulted in a value of -0.052 in trip frequency to vertical walking facilities for each additional minute of trip time.

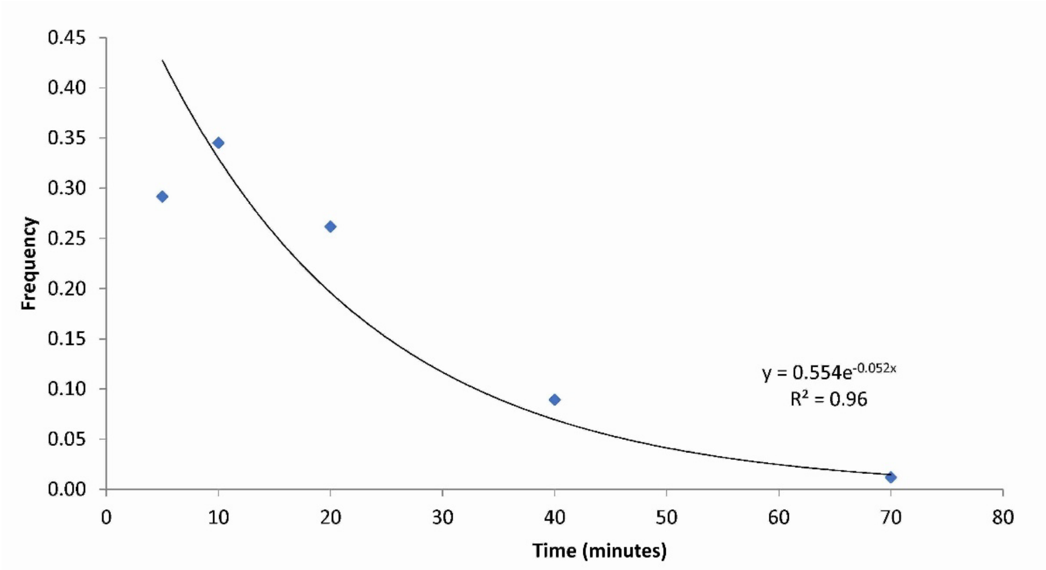

Figure 6. Adjustment of the cost function according to the proportion of trips for different trip times

Accessibility estimates using the gravitational indicator were much higher than cumulative ones because they do not impose a strict cut-off point in access to different opportunities (Table 6). Even so, cumulative opportunities and gravitational indicators showed a certain degree of correlation, with values of 0.25 for the population and health/educational services and 0.4 for commerce.

	Accessibility to population		Accessibility to public services		Accessibility to shops	
Route	CO*	GI**	CO*	GI**	CO*	GI**
1	1812	47927	3	45	17	1779
2	2407	37783	2	39	65	1210
3	6507	51760	3	46	163	2009
4	7240	55968	8	47	506	2281
5	7603	57248	7	46	192	2076
6	5429	56958	0	45	193	2069
7	2922	54900	7	45	91	1938
8	3694	47919	2	37	71	1731

Table 6. Comparison of accessibility to population, public services and shops according to two types of indicators

*CO: Cumulative opportunities indicator. ** GI: Gravitational indicator

4.4 Results provided by demand models

Accessibility indicators, together with the distance travelled along vertical pedestrian routes, were included in the specifications of the models to examine their relationship with the trip demand appraised from users counts. The existing correlation between the specified variables, as well as their variance inflation factor (VIF) values, were checked to avoid a situation of high collinearity between the independent variables. In the case of gravitational accessibility to population and commerce indicators both were highly correlated and presented VIF values above 10.

As a result, two types of models, according to the accessibility indicators selected, were estimated for each type of demand model, i.e. linear regression (MLR1 and MLR2), Poisson (PR1 and PR2) and NB (NBR1 and NBR2) (Table 7). The models numbered as 1, correspond to models specified with accessibility to population indicators (AccPop), to health and educational facilities (AccPubFac) and to commerce (AccCom) ones, while models numbered as 2 were specified with gravitational indicators, but excluding the indicator of accessibility to commerce due to its strong correlation with accessibility to population.

Variable	MLR1	MLR2	PR1	PR2	NBR1	NBR2
Intercept	187.300 (.321)	-37.300 (.964)	5.512 (.000)	4.927 (.000)	5.497 (.000)	5.389 (.000)
Distance	-0.333 (.603)	0.346 (.410)	-0.001 (.000)	0.001 (.000)	-0.001 (.481)	0.001 (.175)
AccPop	0.040 (.384)	0.024 (.163)	0.000 (.000)	0.000 (.000)	0.000 (.183)	0.000 (.010)
AccPubFac	42.920 (.164)	-19.070 (.508)	0.090 (.000)	-0.048 (.000)	0.080 (.046)	-0.062 (.164)
AccCom	-0.000 (.999)	-	0.000 (.261)	-	0.000 (.899)	-
R^2/Pseudo R^2	0.70	0.52	0.13	0.13	0.65	0.65
Log-Likelihood	-	-	-122.90	-161.08	-49.24	-49.86
AIC	-	-	255.80	330.16	110.48	109.71

Table 7. Estimated Models (p-value in brackets)

While the linear regression models did not present any clearly significant parameter, several of the Poisson and NB models did. In addition, the goodness of fit to NB model data was better than that of the Poisson models (see Log-Likelihood and AIC in Table 7).

To check if there was overdispersion in the Poisson models, the test developed by Cameron and Trivedi (1990) in which the null hypothesis is equidispersion and the alternative hypothesis is over- or underdispersion of the dependent variable, was estimated. In the PR1 model, considering a function of quadratic variance, the test yielded a value of 1.24 (0.11) so that the equidispersion hypothesis could be rejected at a confidence level close to 10%. In the case of PR2, the test yielded a value of 2.02 (0.02) so that the equidispersion hypothesis could be rejected with a confidence level close to 98%. In both cases, the estimated dispersion parameter was positive, so there is evidence that the Poisson models may present a higher than the mean conditioned variance. Therefore, NB regression would be more appropriate to model the usage data of the vertical pedestrian routes.

The route distance variable (Distance) had a significant parameter in the Poisson models, although with a negative sign in the case of the model specified with the accumulated opportunities type of accessibility indicators. As for the NB models, the parameter ceased to be clearly significant, presenting an estimated 0.1% of additional users for each extra meter of the route in the NBR2 model.

As regards the accessibility indicators, while access to population and commerce presented a positive parameter in all models, access to health and educational facilities yielded a negative parameter in the case of the NB models with a gravitational indicator (NBR2). This may indicate that routes closer to areas with public services, notably the central zone, are less used than routes closer to residential areas, though the estimated parameters were not significant ($p>0.05$). In the case of accessibility to population, the estimate was of 0.01% more trips per each additional resident. The simulation of growth in the number of users, by increasing route accessibility to the population, can be consulted in Figure 7, assuming average values for the rest of the variables of the NBR2 model.

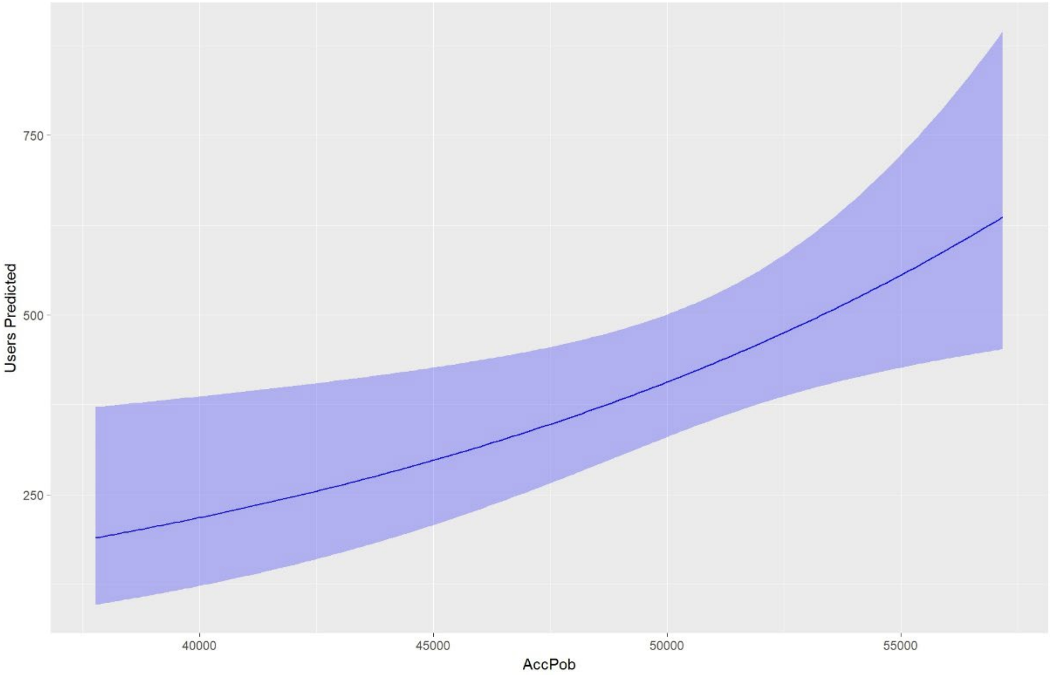

Figure 7. Change in the number of users when, *ceteris paribus*, accessibility to the population varies (shaded surface represents the 95% confidence interval)

4.5 Validation of the estimated models

In order to validate the models obtained, a demand forecast for vertical pedestrian route 10, which was partially opened to use when data collection for this research was carried out, was proposed. Data concerning this route was not used to estimate the previous models. In this case, two indicators were used, the Mean Absolute Error (MAE) and the Root Mean Square Error (RMSE) of the estimates with respect to the value of actual counted users. The estimated errors, both considering the MAE and the RMSE, were clearly lower in the models specified with the gravitational type of accessibility indicators (Table 8). In addition, the lowest errors were presented by the NBR2 model, which, in addition to its good fit to the data and the fact that it can be specified with one parameter less than the NBR1 model, makes it the best of the estimated models.

Indicator	MLR1	MLR2	PR1	PR2	NBR1	NBR2
MAE	123.34	2.65	154.92	3.78	130.80	0.32
RMSE	15211.97	7.03	23999.06	14.32	17109.04	0.10

Table 8. MAE and RMSE of the obtained estimations

5. Discussion and conclusions

On-street vertical pedestrian mobility using different systems has been poorly addressed in the fields of urban and transport research. This is so even considering that these projects encourage active modes of transportation, i.e. pedestrian and cycling, in urban environments with steep slopes, which is undoubtedly positive for the promotion of a more sustainable urban mobility. These types of facilities can also improve the living conditions of certain neighborhoods with accessibility and mobility problems, contributing to a better physical and socio-economic integration of the population of the affected areas (Su et al., 2019), and thus to an improved articulation of the whole urban structure.

In this sense, this paper was mainly aimed at obtaining reliable estimates that allow urban and transport planners and decision makers to promote the implementation of vertical facilities and to determine where, and whether or not, it is convenient to create vertical pedestrian routes. To the best of our knowledge, it is the first study proposing a methodology to evaluate the influence of the location of vertical pedestrian routes and facilities on the estimation of their potential demand.

Specifically, this research examined how the demand for the use of vertical pedestrian routes and facilities can be influenced by their accessibility to different opportunities such as population, health/educational facilities and commerce/shops. The study was carried out with data from surveys and counting of users of vertical pedestrian routes in the city of Santander, allowing the estimation of several demand models, including those with truncated and discrete response variables of the Poisson and NB types. The survey's results showed how user's perception of these services was generally very positive, and that, except for specific problems such as breakdowns, the promotion of the pedestrian mode and inclusive pedestrian facilities in the city is a successful planning policy with a high level of public acceptance.

The models' results, and especially those of the NBR2 model, showed that accessibility to population was a factor that generates a greater demand in these facilities, whereas unexpectedly, in the case of Santander, accessibilities to health and educational facilities and retail were not relevant. This could be related to the fact that most users declared home or work as the main purpose of their trip (57 and 20%), and only a very small percentage related to health or education purposes (10 and 5%). It is also worth to consider that most of the facilities installed in Santander were also located in residential areas that coincide with the city's steeper slopes, while the main commercial areas are located in the flatter parts of the city. In addition, older users were predominant in this study and, as Xu (2019) argues, the elderly tend to carry out their daily activities and walks within the different neighborhoods rather than around the urban centers. These results indicate that this type of facilities must be located in environments with a higher accessibility to the population, i.e. in environments that are demographically denser and physically more compact, rather than well-equipped central areas. In this case, the facilities could be used by a sufficient number of users to justify the costs of installing and maintaining them, a conclusion that has also been pointed out by previous qualitative research (Brand & Dávila, 2011b).

Finally, the models which measured accessibility using a gravity type indicator (GI), with a cost function parameter estimated on the basis of the real trip times answered by the users, performed better and with fewer errors when predicting the demand of users of a vertical pedestrian route whose capacity was not used in the estimation of the models.

These results support the idea of using this type of models to estimate the potential number of users who would use the new planned routes, and therefore whether these routes can give service to a minimum number of users. The construction and maintenance costs of these facilities is not negligible, so their implementation, regardless of good public acceptance, should be based on a reasonable cost-benefit analysis, in which the number of users to be attracted by a given route should be a fundamental source of input data.

This investigation paves the way for further research on new aspects to be considered when planning sustainable urban mobility. For example, mobility studies and surveys for the development of the next SUMPs of urban areas with steep slopes should consider including vertical pedestrian mobility analyses, to estimate users' motivations to choose this mode of transport and how the implementation of vertical facilities may have affected others, especially public transport. In addition, the effectiveness of pedestrian vertical projects or plans could be assessed and monitored by using models that consider demand changes over time, based on time series data on the use of these facilities in relation to accessibility indicators. Finally, it would be relevant to study what effects these types of facilities have on the integration of neighborhoods with accessibility problems, as well as their impact on urban structure as a whole.

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