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Evidence of Green Areas, Cycle Infrastructure and Attractive Destinations Working Together in Development on Urban Cycling

Francisco Sergio Campos-Sánchez *, Luis Miguel Valenzuela-Montes and Francisco Javier Abarca-Álvarez

Department of Urban and Spatial Planning, University of Granada, 18002 Granada, Spain
* Correspondence: scampos@ugr.es

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Abstract: The built environment influences and promotes cycling that has now become a challenge for sustainable urban mobility in many cities where this mode of transport carries little weight. This is the case for Granada (Spain), a medium-sized city in southern Europe, which as a university city and with lots of green areas, could find potential supportive factors to promote cycling. Website-apps with a Global Positioning System (GPS), such as Ciclogreen that encourage active accessibility try to promote cycling and are supported by the University of Granada. The aim of this work is to assess the capacity of green areas and some influential factors of their built environment to attract cycling routes. To this end, a spatial analysis was made and interpreted by a statistical model to check the correlation between these factors and a high number of cycling routes through or near the green areas. The results show a high number of cycling routes within urban surroundings that include green areas, cycle lanes, university facilities, and public car parks in proximity relationships. Identifying synergies among these urban factors and the information and incentive coming from a digital catalyst in shape on an app could be useful in urban planning for cycling.

Keywords: cycling; green areas; decision-making; urban planning; sustainability; university; transport; GIS; GPS; logistic regression

1. Introduction

The influence of certain factors of the built environment on cycling can be interpreted by analysing data from GPS-based apps aiming to promote the use of this mode of transport, such as the www.ciclogreen.com website and app. This platform was created in 2015, and later initiated a commitment with the University of Granada (UGR) to encourage active accessibility to contribute to more sustainable urban mobility in Granada (Spain). This is a medium-sized city with over 60,000 university members (students, lecturers, researchers, administrative, and services staff)—UGR, 2019—and a total city population of 233,764 (Spanish Statistical Office—known in Spanish as INE —2018). The UGR profile on the app shows that there are currently 765 users belonging to the university community, with the largest percentage being young students who, from the beginning of the commitment until now (June 2019), have cycled a total of 88,335.4 km, and saved a total of 18,423.7 kg of CO2 emissions to the atmosphere.

1.1. The Relationship between Cycling and the Urban Built Environment

A large part of the paper deals with the beneficial relationship between green areas and cycling, based on a literature review showing that cycling routes that avoided roads and went through neighbouring parks were sometimes preferred. It could lead to a demand for a more direct and better-connected network of routes among neighbourhoods based on parks (e.g., as in Ontario [1]), as our work aims to identify. In line with this, the potential of green areas to attract might be included for cycling routes that, to a certain extent, prefer to avoid busy zones and the deviation of direct routes to attractive destinations (e.g., as in Graz [2]).

Therefore, there seems to be a potential for promoting cycling by encouraging synergies between the cycling infrastructure, open public spaces, attractive destinations, and young cyclists. Assessing this potential is based on dimensions that, a priori, could be supportive factors in implementing sustainable urban mobility policies by fostering cycling [3]. First, there is a young and educated population more aware of the benefits of active accessibility, which could act as a catalyst for urban sustainability through technological and sustainable incentives, such as those put forward by Ciclogreen [4]. Second, the green areas constitute a variable of the built environment that could have a positive influence on an active mode of transport, such as bicycles [5]. In addition, it is essential to include the layout of university buildings [6] in attracting and generating cycling routes [7], marked out by students, and other potential users of the app. Lastly, the supportive factors of the strategy to be implemented would be the cycling infrastructure per se, whose layout should address any potential that can be deduced and applied by relating the dimensions considered.

1.2. Objective Measures of Cycling in Medium-Sized Cities

The combined application of GPS [8], as an objective tool for measuring cycling routes, and geographical information systems (GIS), to analyse environmental characteristics along the routes, is useful for identifying variables in the built environment that aid or hinder cycling [9,10]. This would happen not only in large cities [11], but also in medium-sized ones, as Pereira and Penha–Sanches [12] found in their recent studies in São Carlos (Brazil), and Krenn et al. [2] in Graz (Austria), among others. In the medium-sized cities, distances are generally shorter than in the large ones, which could encourage the use of bicycles [11], with evidence of it found in some studies on medium-sized cities in the Netherlands [13]. These cities, as with Granada, have other attractions since they often have the potential for tourism and can, therefore, gain an added benefit from cycling because of the opportunity for 'slow tourism' that allows a more significant and sustainable contact with the city [14]. Likewise, another quality in this and similar case studies lies in their strong university profile. Some reasons for this are the large population of young people more likely to cycle, as well as policies from the universities implementing bicycle sharing programmes [15].

Therefore, based on the geo-statistical source of information provided by Ciclogreen, the opportunity arises to explore the potential synergies among the cycling infrastructure, the built environment, and the university education land use. The strategic interest of this reading is due to the scant information on cycling in the case study, as well as to the usual poor adoption of policies to promote it.

Some Limits and Intentions

The potential context, variables included, and spatial interpretation answer to the general overview proposed for the geostatistical analysis, whose focal point is to help urban planning to design routes connecting elements supporting cyclists' supply and demand [16,17]. Hence, this research does not follow the routes of the Ciclogreen app users in order to contrast preferences between the chosen and the shortest routes, the same as with other studies on cycling [18]. Instead, one goal of this paper is to find key urban places where the cycling infrastructure might be marked out [19], in order to more successfully support urban policies with positive feedback from (i) the built environment, (ii) the university context is understood to be a supportive factor, and (iii) the catalyst of incentives from ICTs (Information and Communication Technologies), i.e., websites and apps based on GPS.

1.3. Starting Point

This paper is based on certain hypotheses, such as (i) how the use of bicycles relates to the location of cycling infrastructure in quality environments and the convenience of the open public space (e.g., comfortable green areas, light traffic) and in relation to the scope of the study, and (ii) how the interaction of green areas and university facilities encourages the presence and continuity of a flow of cyclists [20]. The work is guided by two research questions that shape the structure of the content, as well as the methodological process followed and interpretation of the results. The first, from an analytical approach, was: how does the built environment of the green areas and their urban configuration influence the frequency of cycling routes? Next, on a second strategic level of the research: to what extent can the layout of cycling infrastructure be based favourably on spatial continuity between university facilities and green areas? These two questions give a global perspective of the research focus to contribute to urban planning with greater decision-making capability in designing out and encouraging active accessibility [21] combined with information and incentives from GPS-based apps.

Thus, the main aim of this work is to know to what extent green areas and their built environment attract urban cycling routes. The former being understood as strategic nodes encouraging cycling and connecting the bicycle infrastructure. This might provide reliable reading on the possible development of more effective cycling routes that make use of the built environment by increasing access for bicycles through the continuity and cohesion of cycling infrastructure [16].

With this aim in mind, spatial analysis of environmental factors and variables with a possible influence on cycling is proposed, in addition to the design and application of a statistical regression model to determine the probability of each variable to exert that influence. For this analysis, the dependent variable consists of the flow of cyclists (i.e., cycling routes) that pass through or near the green areas. The predictive variables, such as the size of these green areas, among others, are identified and grouped around six key factors: cyclist's behaviour, green areas, urban network, built environment of the green areas, traffic, and cycling infrastructure (see Table 1).

Table 1. Factors and variables influencing the presence of cyclists in or close to green areas.

Factors	Variables (Unit)	References	Measurements
Cyclist's behaviour	1. Flow (n)	[11,12,22]	nº of cycling routes (GPS) passing through the green area plus a 100 m buffer zone surrounding it.
Green area	2. Size (ha)	[2,23–26]	Surface area of the green area.
Environment	3. Residents (n)		nº of inhabitants within a 1 km buffer around thegreen area.
Environment	4. Commerce (m2)	[21,26,27]	Built area for commercial use within a 1 km buffer around the green area.
Network	5. Global intermediation (n)	[27,28]	Intermediation (i.e., the potential for intersections) of the access street to each green area at the city level.

Source: Compiled by the authors.

Table 1. *Cont.*

Factors	Variables (Unit)	References	Measurements
Network	6. Global integration (n)	[27,28]	Integration (i.e., potential for a destination) of the access street to each green area at city level.
Green area	7. Altitude (n)	[5,21,29]	Variability in altitude in the green areas.
Cyclist's behaviour	8. Length (km)	[2,12,25,30]	Average length of the routes passing through each green area +100 m buffer.
Cyclist's behaviour	9. Time (h)	[2,12,25,30]	Average time for the routes passing through each green area +100 m buffer.
Cyclist's behaviour	10. Speed (km/h)	[2,12,25,30]	Average speed of the routes passing through each green area +100 m buffer.
Traffic	11. Crossroads (n)	[11,31,32]	n° of crossroads ≥4 roads within a 1 km buffer around the green area.
Traffic	12. Parking (n)	[1,12,21,33,34]	n° of public car parks within a 1 km buffer around the green area.
Cycling infrastructure	13. Bicycle racks (n)	[21,35,36]	Bicycle racks in each green area +100 m buffer.
Cycling infrastructure	14. Bicycle lanes (m)	[2,3,23,36]	Distance from the edge of the park to the nearest bicycle lane (or bus-taxi lane for use by cyclists).
Environment	15. University centres (n)	[21,26,27]	n° of university buildings (faculties, centres, rectorate, etc.) within a 1 km buffer around each green area.

Source: Compiled by the authors.

According to the above, the method to gain a better understanding of how to implement cycling in a university city is structured on the following steps. First, to justify the chosen linking factors and variables through a review of the literature on the subject. Second, a presentation of the case study highlighting spatial features of its urban structure, in addition to presenting previous studies that support the interest of this research. Third, to identify spatially and statistically the most significant variables in respect of the proposed hypotheses of work to find the geostatistical link to green areas, with regard to the cycling routes (frequency) marked out by Ciclogreen users. Finally, to go further into the spatial strategy to aid decision-making to improve the supply and demand for bicycles, by drawing conclusions from the area studied and similar ones, and assessing how the information and models applied to adapt to it.

2. Materials and Methods

2.1. Influential Environmental Factors and Variables

A review of the literature was carried out on objective measuring factors and variables of the built environment that might have an influence on urban cycling. Of particular interest is the recent review by Vale et al. [21] on active accessibility, which gathers several variables of this type. Table 1 shows the majority of the most frequently cited variables, grouped into six environmental factors: (i) cyclist's behaviour (cycling flow and characteristics of the routes); (ii) cycling infrastructure (cycling facilities); (iii) green area (size and altitude, i.e., altimetric elevation); (iv) environment (population and land use); (v) network (topological and geometric measurements of access streets to green areas); and (vi) traffic (characteristics of the road network and public car parks).

2.2. Case Study

The case study focuses on a medium-sized city in southern Europe, which is also a state capital, with an important university role. There is a lack of previous research on cycling in these type of cities. However, increasing knowledge of active commuting in cities where the university community produces high urban mobility is of major relevance. Several strategies and plans to encourage cycling in Granada have fallen by the wayside over the last few decades. Both regional drives, local projects, and others, either from sectoral initiatives (e.g., hospitals—ECO21 Consulting—[37]) or private ones in collaboration with public administration (e.g., bicycle-sharing) have not met with sufficient success or the continuity required. However, recently, some work and certain indicators are showing encouraging signs of a gradual evolution that, in the long-term, could lead to an improvement in supply and demand for cycling in Granada.

In general terms, it can be said that regional plans for financial support [38], as well as municipal planning for urban mobility have failed [39], either in coordinating strategies, commitment from institutions, design of the urban infrastructure or awareness campaigns, the latter being an essential factor for success in a city with a scant cycling culture, but great potential for cycling.

Nevertheless, some positive milestones have been observed recently, both in partial success (e.g., ECO21 Consulting [37]) and the appearance of innovations (Ciclogreen app), and resolutely renewed municipal plans that include proposals much in demand from cyclist groups (e.g., Biciescuela [40]). In addition to the above, there are more recent and reliable municipal data to support decision-making on planning for cycling access, with the latest surveys [41] showing that the average use of bicycles in Granada has increased in recent years (from 4.59% in 2017 to 4.88% in 2018), which may be due to the increasing popularity of e-bikes. Together with the foregoing, initiatives have arisen to promote cycling (University of Granada and ECO21 Consulting [42]) that have recently been developing bicycle-sharing (Obike and Ofo, 2017–2018). Although they largely failed, perhaps have helped to generate some awareness on the opportunity for health, mobility, and the sustainable environment that cycling provides as an alternative form of active transport, rather than vehicles.

In light of this scenario, our research into the attractions of the Ciclogreen strategic incentive from the UGR makes sense. This app provides highly innovative information (GPS data) to study the frequency of use of cycling routes in Granada relating to elements in the built environment, such as green areas, and complementing these, the layout of university facilities, road traffic, and cycling infrastructure.

Survey Plan

According to the Granada Bicycle Survey Plan (GBSP) [43] carried out at 19 indicative points in the city, through 10 min periods at different times of the day, the average use of the bicycle is 4.59% (2017) of the total traffic observed. The four measurement points of the GBSP where the percentages of bicycle use reached the most significant average values (data from Granada City Council [43]) were generally next to green areas (GAs) with a high number of cycling routes (n minimum = 0; n maximum = 96;

statistical mean of n = 13.50—reference value—), taking into account Ciclogreen data for the '30 days by bike challenge 2019': (1) GA nº 44 (13.7%—percentage of average use of bicycle according to GBSP—; n = 66—number of cycling routes in or close to green areas according to Ciclogreen—); (2) GA nº 21 (12.5%; n = 41); (3) GA nº 26 (9.6%; n = 79); (4) GA nº 29 (7.7%; n = 72). This information is seen as a general coherence indicator between measurements taken by Granada City Council (available on www.movilidadgranada.com) and those provided by the Ciclogreen app for the challenge mentioned, which raises the degree of reliability of the model.

2.3. Data Sources and Processing

The cycling route database was compiled by an initiative from the Secretariado de Campus Saludable (Healthy Campus Secretariat) at the UGR (University of Granada, Spain) through the www.ciclogreen.com project (financed by the Horizon 2020 program from the EU). It is an online platform (website and app using GPS) through which users can obtain rewards (e.g., discounts and gifts in bicycle and ecological shops) if they use sustainable mobility of various types (bicycle, walking, running, etc.). Users can register and check their routes, distances, and movements, as well as taking part in challenges of their choosing.

This study is based on the challenge '30 days by bike 2019' (n = 560—number of active users—) promoted by the UGR and aimed at the university community. That was a global campaign for cycling throughout the month of April 2019. Users (cyclists) registered for the challenge in several steps: (i) registering on the platform, (ii) downloading the app to their mobile device, (iii) starting the session with their access identity, (iv) using the app to register their movements by bicycle. Lastly, users' data (sex, age) and the routes they covered (heat map of the journeys, length, average speed, duration) were recorded on the platform accessed.

Once the routes and associated data were obtained, a geographical working map was drafted using a geographical information system (QGIS v 3.4), in order to identify and spatially analyse the cycling routes, green areas, and influential environmental variables. Green areas of ≥0.5 ha were selected from the Reference Spatial Data of Andalusia (known in Spanish as DERA) database (Reference Spatial Data of Andalusia). These green areas are for leisure activities, which include parks, gardens, playgrounds, sports fields, and other open spaces. The road/street network is provided by the Unified Digital Street Map of Andalusia (known in Spanish as CDAU). Transforming the road network to a segment map, also processing the crossroads at a different level, was done by PST (Place Syntax Tool) [44]. The spatial distribution of the number of inhabitants and commercial land use were obtained from the ATOM Inspire cadastral service, via unbundling and bundling operations based on the available information on the number of dwellings per building, types of land use and data on the population of residents. The latter came from census sections at the IECA (Institute of Statistics and Mapping of Andalusia). The information on cycling lanes, bus-taxi lanes suitable for cyclists, bicycle racks and public car parks was obtained from vectorial layers on the www.movilidadgranada.com website from Granada City Council. Addresses of university centres and facilities were obtained from the UGR website and geo-coded using Google's API Key. The analysis of street network variables (global integration and intermediation) was carried out using Depthmap and the SS-Toolkit software implemented in QGIS.

The flow of cyclists in/close to each green area, also the number of bicycle racks, were captured with help from a 100 m radius buffer around each green area. On the other hand, the built environment variables (nº of residents, commercial land use, nº of crossroads, etc.) were captured via a 1 km buffer catchment area around each green area (approximately 10 min walking distance). Both distances consist of measuring close proximity in the first case and analysing the neighbourhood in the second, commonly used in studies of active commuting influenced by the presence of green areas for leisure use [31,45–48]. The distance captured by the buffer catchment area (isochronous) took into account the road/street network. The isochrones were calculated from functions in www.openrouteservice.org, based on the OpenStreetMap database. The methodology is shown schematically in Figure 1.

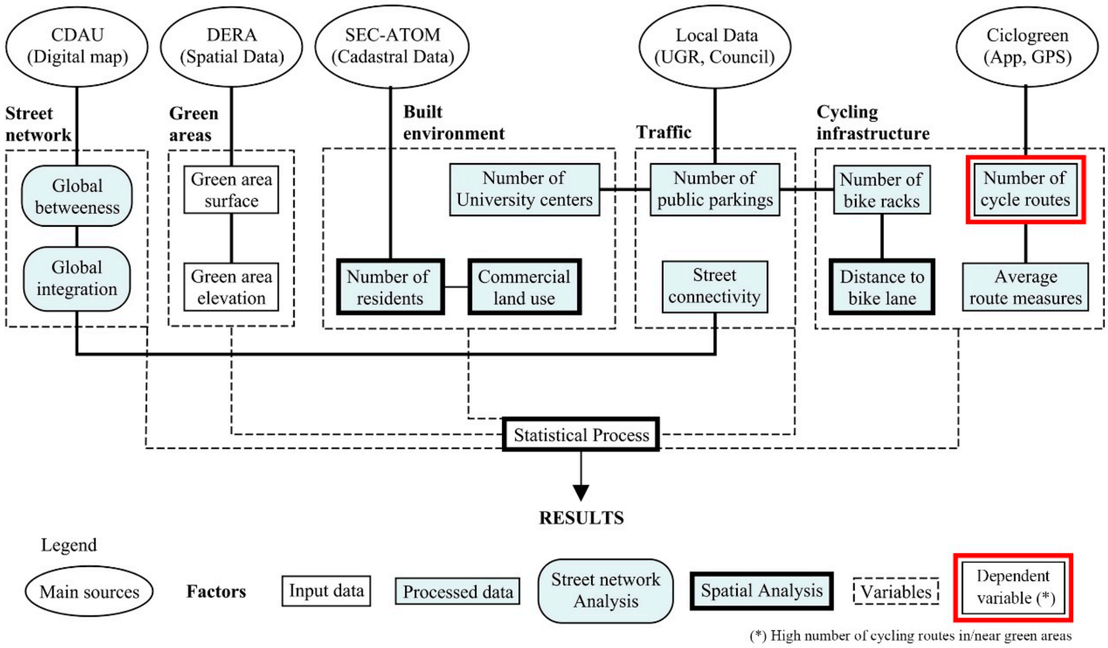

Figure 1. Methodological scheme. Source: Compiled by the authors.

3. Results

3.1. Spatial Analysis

Once the spatial and proximity analysis were carried out, quantitative data was obtained on the variables studied for the green areas identified through the road/street network. Figure 2 shows the heat map of the cycling routes, also the urban green areas studied (≥0.5 ha), highlighting those with a higher number of cyclist routes in/close to them (100 m buffer), and indicated on the map by the value 'n'. It could be seen how these latter green areas are mainly found around the central district of the city, that includes a part of the historic centre. These surrounding urban areas, featuring a more regular street layout and a larger block size than those within the historic centre of the city that generally has narrower, more haphazard streets and few green areas. The largest green areas are in an outer arc round the north-west-south of the city, where more space is available, and the land is flatter. Cyclists are mostly found on the radial roads leading north to south, and north-west to south-east, in a fairly straight line, occasionally equipped with cycle lanes. It should be noted that there is a high number of cycling routes going through the green areas on the central-western edge of the city, along a very long cycle lane running parallel to the outer motorway. This type of cycle lane is the one with fewest intersections (mainly links between the motorway and urban roads), so it is presumably the fastest and safest in this respect. These conditions might be a factor attracting cyclists more than to other cycle lanes, even though they are shorter routes to their destinations. In line with the above, a statistical assessment of the spatial results obtained is given below.

3.2. Statistical Analysis

The IBM SPSS Statistics V.23 software was used in the statistical analysis. All the variables analysed are quantitative. The dependent variable (cyclist flow or the number of cycling routes in/close to green areas) is the discrete type. Normality was compared by a Kolmogorov–Smirnov test, with most of the variables, found to have a non-normal distribution (bilateral asymptotic significance <0.05). A non-parametric model of statistical analysis was chosen of the binary logistic regression (BLR) type, which explains the dependent variable. This aims to predict the probability of a successful event occurring (high number of cycling routes in/close to green areas) depending on the level of predictive variables selected (Table 1). All the variables were recoded to dichotomous categorical variables (1–0).

The probabilities describing possible results from the dependent variable were modelled using a logistic function based on the explanatory variables. Table 2 shows the descriptive statistics for the calculation variables. The mean of the source data (i.e., median: a value representing the central position of the source data set) was chosen as the reference value for the cut-off points among dichotomous values (1–0), except for (a) variable nº 13. Bicycle racks, where: 1 = bicycle racks within the corresponding buffer catchment area, 0 = no bicycle racks; and (b) for variable nº 7. Altitude, where: 1 = altitude within 663–713 m (Percentiles 25 and 75), and 0 = the remaining values. The latter classification was made on the assumption that cyclists prefer to travel at medium altitudes (interval P25–P75), and not at extreme ones (intervals min.–P25 and P75–max.), which implies a higher physical cost.

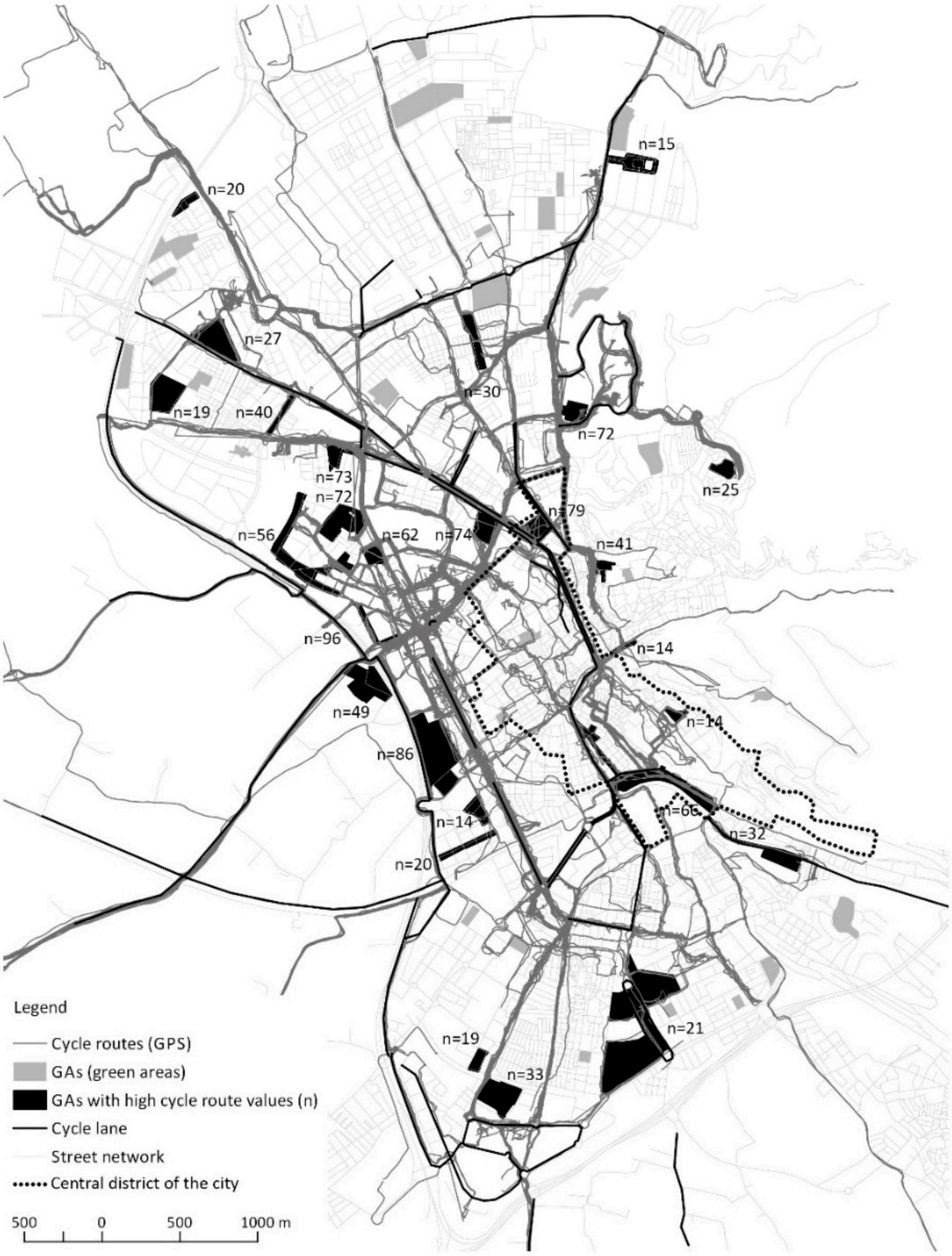

Figure 2. Cycling routes and green areas. Source: Compiled by the authors.

First, and exploratory in nature, all variables in Table 1 were processed jointly with a BLR using the stepwise Forward Wald method, which starts with a model that includes all the variables. A statistical assessment is made to find and discard the variables that participate least in the model. This process is carried out successively and automatically throughout the various steps until a model is obtained that fits the required conditions ($p \leq 0.05$). The significant variables obtained after two steps were n° 12, parking and n° 14, bicycle lane, and the others were discarded.

Table 2. Descriptive statistics of the calculation variables.

Variables (Unit)	N	Minimum	Maximum	Average	Mean	SD
1. Flow (n)	54	0	96	23.93	13.50	26.92
2. Size (ha)	54	0.50	19.78	2.52	1.48	3.08
3. Residents (n)	54	8165	86,089	36,155	34,833	14,882.26
4. Commerce (m2)	54	8426	532,869	173,217	132,209	149,247.28
5. Global intermediation (n)	54	16	31,919,872	1,656,727	108,857	4,869,757.24
6. Global integration (n)	54	937	1833	1425	1414	225.31
7. Altitude (n)	54	647	827	695	682	39.21
8. Longitude (km)	54	0	12.50	4.25	3.55	2.75
9. Time (h)	54	0	4,90	0.57	0.39	0.73
10. Speed (km/h)	54	0	25.66	10.53	11.02	5.04
11. Crossroads (n)	54	57	377	160.59	148.50	66.46
12. Parking (n)	54	0	33	9.76	7	9.75
13. Bicycle racks (n)	54	0	8	0.98	0	1.71
14. Bicycle lanes (m)	54	0	665	192.59	137.50	198.13
15. University centres (n)	54	0	36	9.72	4	10.22

Notes: Average = a number calculated by dividing the sum of the values in the set by their number; SD = Standard Deviation. Source: Compiled by the authors.

Second, the analysis was refined by performing the BLR in two stages. First, a bivariate analysis was made to compare the independent variables one by one with the dependent variable (variable n° 1. The flow of cyclists) and find which variables would be, in the first instance, the explanatory ones for the model ($p \leq 0.05$), and which would not ($p > 0.05$). The results from the bivariate analysis show that variables n° 5, 7, 8, 9, and 10 do not individually explain the model, while variables n° 2 and 11 explain it at a low level ($p \leq 0.1$). Second, a multivariate analysis was made by entering the dependent variable with the significant independent variables, according to the results of the previous bivariate analysis (variables n° 2, 3, 4, 6, 11, 12, 13, 14, and 15). The process was performed by the Enter method (non-automatic) in a single step. Table 3 shows the results from the BLR (72.2% of the cases explained. Omnibus significance test = 0.003). In addition, from the point of view of sexes, more male than female cyclists passed through green areas, with a ≤ 10% difference across all measurements (see Table 4).

The results from Table 3 show that the statistically significant predictive variables are n° 12 (the number of public car parks in the 1 km buffer catchment area around the green area), n° 14 (distance from the green area to the cycle lane/bus-taxi lane designated for bicycles), and n° 15 (number of university facilities in a 1 km buffer catchment area around the green area). The statistical analysis results mean that the green areas with a nearby cycle lane and an urban built environment around them with a high number of public car parks and university facilities are more likely to have cyclists in/close to them. The significance must be mentioned, although very low, of variable n° 11 (crossroads ≥4 streets) and its (B) negative sign, i.e., the larger the number of this type of intersection (indicating traffic flow), the fewer the number of cycling routes, which a priori supports the significance level of variable n° 12 (public car park) encouraging cycling. Therefore, the model shows the potential for a model of a university city with clusters of cycling routes in the close proximity of the university campuses provided with cycle lanes, green areas, and where traffic flow is controlled.

Table 3. Significant predictive variables as a result of the multivariate binary logistic regression performed.

Variables	B	ORs	*p*	95% CI
2. Size (ha)	0.674	1.962	0.424	0.376–10.247
3. Residents (n)	1.658	5.248	0.372	0.138–199.899
4. Commerce (m2)	0.776	2.174	0.440	0.303–15.607
6. Global integration (n)	−0.396	0.673	0.691	0.095–4.749
11. Crossroads (n)	−2.909	0.055	0.151	0.001–2.883
12. Parking (n)	3.187	24.223	0.045 (*)	1.067–549.887
13. Bicycle racks (n)	−1.001	0.367	0.251	0.066–2.032
14. Bicycle lanes (m)	1.643	5.173	0.052 (*)	0.966–27.712
15. Univ. centres (n)	1.957	7.080	0.041 (*)	1.088–46.073

Notes: the sign of B indicates the direction of the relationship between dependent variable and independent variables; OR (Odd ratio) = indicates the strength of the relationship between dependent variable and independent variables; CI = confidence interval (95%); p = statistical significance; (*) = with statistical significance $p \leq 0.05$. Source: Compiled by the authors.

Table 4. Characteristics of cyclists in/close to green areas.

Measurement	N (Unique)	Male	Female	No Data
30 days by bike 2019 challenge	560 (560)	288 (51%)	227 (41%)	45 (8%)
In all green areas	1292 (497)	635 (49%)	499 (39%)	158 (12%)
In green areas with a high probability of cycle routes	1169 (483)	559 (48%)	464 (40%)	146 (12%)

Note: N = nº of cycling routes. Source: Compiled by the authors based on data from Ciclogreen.

Finally, in spite of the above, it should be noted that the correlation between cycling flow (variable nº 1) and public car parks (nº 12) was unexpected. In order to explain it, a bivariate correlation analysis was carried out between public car parks, university centres (nº 15), and distance to bicycle lanes (nº 14), independent of cycling, which is discussed later. Given the non-parametric nature of the variables, the Spearman correlation coefficient was used in this analysis. In addition, a BLR was carried out between these three dichotomous variables, without taking cycling into account. The results show that both the BLR and the correlation analysis between the three dichotomous variables are not significant. However, the correlation analysis between the three discrete variables—not dichotomized—shows a bilateral correlation between the public car parks and university centres variables (significant correlation at level 0.01; Spearman's Rho = 0.504).

Figure 3 shows the elements of the significant variables found next to the green areas with the most cycling routes, i.e., cycle lanes, university facilities, and public car parks. A high concentration of these urban elements can be observed surrounding the university campuses in the city. As an example, the 1 km isochrones surrounding some green areas identified in the zone of influence of the campuses have been highlighted in the figure.

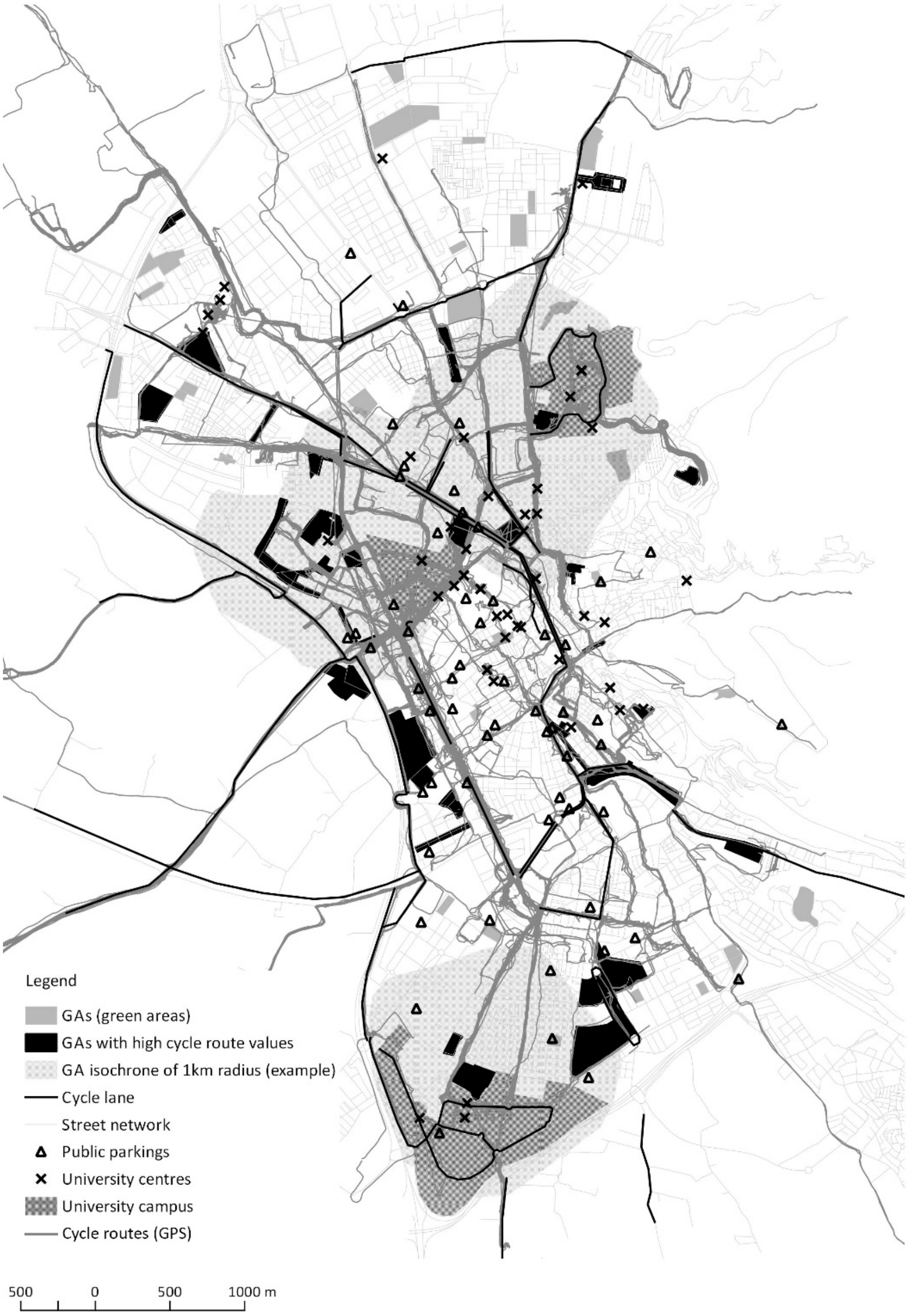

Figure 3. Spatial identification of the significant variables. Source: Compiled by the authors.

4. Discussion

4.1. Influencing Factors of the Built Environment

This work, focused on Granada (Spain), showed that there were environmental features influencing the number of cycling routes in/close to green areas. More specifically, it found a high probability of cyclists being in/close to green areas if these had a cycle lane nearby, and if there were university facilities and public car parks in proximity. Thus, proximity seems to be the most important factor, bringing together in the same nearby urban environment other secondary factors, such as traffic safety and cycle lanes, the latter being often located on the most direct roads of the city (directness). Less influential than the foregoing variables was a large number of crossroads ≥4 streets in the surroundings of the green area, which discouraged cyclists. This supports the argument that a high supply of facilities and opportunities in the built environment (i.e., green areas, cycle lanes, university facilities, and public car parks) promotes cycling, which is sustainable and encourages a healthy lifestyle [48]. There is a great deal of literature proving the correlation between the presence of green areas and a general increase in the levels of physical activity, although this depends on local conditions [47], but very little on the increase in cycling. This research measured the flow of cyclists in green areas since these could act as attractive urban elements for cycling. Such attraction is not normally exclusive, as other environmental factors also intervene.

In fact, the exclusive causality between the existence of green areas and more cycling in the case study has been discarded. Otherwise, intrinsic attributes of green areas, such as their size, would probably have been significant variables. On the contrary, what has been demonstrated here is that a high probability of cyclist flow in/close to green areas correlates with a proximity urban environment around such green areas that is provided with cycle lanes, a high number of attractive destinations, such as university facilities, and public car parks. These results are based on a collection of cyclist flow data taken in green areas, according to the working hypothesis, which aims for a more ecological cycling approach. It is unknown whether data collection at a different location would have produced similar results or not, which might be proved in future research. In addition, it should be noted that many green areas are located in outer urban zones where there is space available for it, next to wider streets to house cycle lanes, which may have influenced the results.

The relevance of this work has been to verify that not only can subjective decisions influence cycling, but that there are also factors of the built environment that encourage or discourage cycling and should, therefore, be a matter of urban planning. Additionally, it has also been novel to study the influence of the built environment on cycling in a university city, given that there is not much research on the subject. In this sense, the method used in other research to study the influence of the built environment on cycling in other medium-sized cities, such as São Carlos and Graz [2,12], was different, although GPS was also used to collect the data and GIS to analyse them. These works compared the actual cycling routes with the shorter routes, determining the characteristics that influence the choice between the two paths. With respect to Granada, the former also found traffic-related factors, in addition to the relationship between pavement quality and more cycling, a variable not studied in the case study. In the latter, the existence of cycle lanes and the presence of green areas also correlated with actual cycling routes. Besides, other correlates, such as the length of the routes or the topography of the green areas were also taken into account in the case study, but in a different way.

In contrast to this work, the study of some Dutch medium-sized cities [13] was based on surveys and the analysis of cycling behaviour. The influence of altitude and traffic conditions were also studied, but the characteristics of the population (e.g., ethnicity, the proportion of young people) and some costs of cyclists, such as physical effort and accidents, were further explored. The Preveza's (Greece) case study [14] was based on a structured questionnaire. In this case, the interest in cycling came about as an opportunity to strengthen urban tourism, as well as for other human benefits. The study also reported a lack of traffic safety, as did the above-mentioned research, including the case study. Finally, the research on university campuses of some medium-sized cities in the USA [49] focused on how the campuses are privileged places for cycling, while the case study focuses on urban cycling around them. However, feedback and continuity between cycling routes and urban attributes in both spatial environments may be of interest for future research.

4.2. Cycling Routes and Green Areas

The average length of cycling routes (4.25 km) was longer than those found in other studies, such as Vancouver at 3.7 km [25,29] and Graz at 2.3 km [2]. This is certainly due to a lack of the continuity of the cycling network causing significant deviations. In addition, despite the compactness of the city centre area in the case study, similar to that of other medium-sized cities in Europe, the surrounding geographical features mean that the city 'stretches' from north to south, increasing the length of routes.

Moreover, the cycling infrastructure is little developed, thus increasing the need for deviations, unlike the above example cities.

The total number (n) of single cycling routes in the study (i.e., routes going through a single green area) = 560. However, there are cycling routes going through several green areas. Therefore, the total number of cycling routes crossing (or passing near) every green area is n = 1292, including a total number of single cycling routes of n = 497. If only the green areas with a higher number of cycling routes going through them are included (27 green areas with the cyclist flow median ≥ 13.50), the total number of cycling routes captured is n = 1169 (91% of the total), with single routes standing at n = 483. This means that there is not much difference among the values of both groups of green areas (total number of green areas is 54), which in turn means that green areas with a higher number of routes hold an important cyclist flow attraction function (i.e., they capture a high number of cycling routes).

As said earlier, this attraction is not exclusive to green areas, but there is also a spatial pattern that joins green areas, cycling infrastructure (cycle lanes), public car parks and university facilities in a nearby built environment, which only occurs in certain urban zones, e.g., around the city's university campuses (Figure 3). The strategic potential of this spatial pattern must be emphasised, even more so if it were developed to cover urban areas with a denser population, mainly of university members, making safer and environmentally comfortable daily commuting between home and university destinations. How the built environment affects this type of commuting has been a subject of study in the field of physical activity and health for several decades [31].

4.3. Traffic Infrastructure

Although the significance was low ($p = 0.151$), it was found that a high number of crossroads ≥ 4 streets in the surroundings of green areas reduces the likelihood of cyclists crossing them. In addition, the presence of public car parks in the vicinity of the green areas proved to be statistically significant ($p = 0.045$) when the probability of a large number of cycling routes passing through/near them is high. There is evidence that crossroads, a means of street network connectivity, promote cycling in general [31]. Broach et al. [11] added that to encourage cycling, crossroads must be controlled (i.e., traffic lights, safe crossings). However, crossroads ≥ 4 streets promote not only general transit, but also road traffic [32], usually avoided by cyclists unless the road has suitable infrastructure [1,12,34]. The provision of public car parks [33] seems to reduce the number of drivers going around for some time looking for a place to park in the road, by concentrating the traffic in the access roads to the car parks and freeing others, which could motivate more cycling routes through certain urban areas.

Despite the above, the significant bilateral correlation found between public car parks and university centres regardless of the cyclist flow must be highlighted. This may be due to the fact that university centres are often associated with a high demand for car parking. In addition, the urban centrality of both elements frequently overlaps spatially. This finding relativises the causality of the existence of public car parks in increasing cyclist flow in/close to green areas, which must be taken into account in the interpretation of the results.

4.4. Bicycle Lanes

In Granada, although the cycling infrastructure is small and not good quality in comparison with other similar cities in central and north Europe (e.g., surface S = 88 km^2, approximate total length of cycle lanes L = 36 km, and average use of bicycles A = 4.59% in Granada; as opposed to S = 127 km^2, L = 120 km, and A = 14% in Graz; both are university cities showing a similar municipal population), cyclists prefer to use the cycle lanes if they are available, which was clear in the result that the green areas with a higher number of cycling routes are those with a cycle lane nearby ($p = 0.052$). The cyclists' preference for cycle lanes rather than other types of path coincides with other information from studies on cycling [2,25,34,36]. Without suitable cycling infrastructure (e.g., cycle lanes) cycling becomes complicated, especially for daily commuting such as from home to the university facilities [36], the type of daily commuting made by the university community.

4.5. Other Environmental Characteristics

Other variables were studied, such as topography, which did not play an important role for cyclists to go in/close to green areas at one altitude or another, unlike results from other studies [1,50], who observed that cyclists did not like pedalling up steep ground. This might be due to the fact that the topography in the study area did not have such sharp differences as to be a determining factor, also observed by Winters et al. [25] in Vancouver. There is not much difference in height (e) between the minimum and maximum elevations of the green areas selected (n): e = 180 m for the percentile interval P0–P100, with n = 54; and e = 50 m for the interval P25–P75, with n = 28.

Neither was a correlation found between a high probability of cycling routes in/close to green areas and high values of spatial configuration of the urban road/street network, which was found in other studies, such as Manum and Nordstrom [27], although it was focused more on the potential for the urban network to house cycling infrastructure. Also, Raford et al. [30] found a larger number of cyclists in streets with a lower total sum of angles (angular distance sum). This parameter was not measured in our study; however, we found more routes in the main straight radial streets in the study area (Figure 2). Future lines of research would help to confirm this observation.

The amount of commercial land use did not prove significant with respect to the probability of a strong presence of cyclists in the surroundings of the green areas. This may be due to the fact that, in the case study, most of the shops are in the central district of the city, a part with almost none of the green areas included in the study (≥0.5 ha). This is due to the historic centre compactness and morphological characteristics (narrow, meandering streets, very long blocks of buildings, density, cobblestones). These characteristics also mean that the historic centre is a first-class pedestrian area in the city, with almost no cycling infrastructure. Most of the green areas are around the perimeter of the city, where plots are larger, and most of the cycling infrastructure is in place. Other studies have reported on cyclists' preference to avoid commercial urban areas [1,2], which could not be studied in this research, for the reasons explained, but returns the same result in this case.

Neither was a correlation found between the size or number of green areas and a strong likelihood of cycling routes in/close to them, similar to research by Kaczynski et al. [51] and Maas et al. [46] focused on residents in the vicinity. However, in the latter (made within a 1 and 3 km radius of catchment area) a correlation was found between the number of green areas and the time spent on cycling daily. It must be remembered that the size of urban green areas in the case study, even over 0.5 ha, is not large enough to definitely encourage cyclists to cross them (but the surroundings do), which on the contrary happens in other regions in central and north Europe where there are larger green areas.

5. Conclusions

This research contributes to knowledge on the relationship between the built environment and cycling in university cities, in line with a few other studies [4,7,15,49]. Particularly, it focuses on green areas as urban elements that, according to the review of the literature, can spatially structure the most influential attributes of the built environment in the frequency of cycling routes. The finding consisted of proving that the green areas do not in themselves influence cyclists, at least in this case study, but that for this several urban elements must unite in proximity relationship: green areas, bicycle lanes, university facilities and relatively public car parks; or, in other words, comfortable environmental conditions (in some stretches of the routes, at least), cycling infrastructure next to these environmentally comfortable spaces, routes with attractive destinations and maybe some control of in-between traffic. Therefore, the probability of a high number of cycling routes in/close to certain green areas has more to do with cycling infrastructure, the attraction of the environment and traffic control than with the characteristics of the green areas or the spatial configuration of the urban fabric. The link found between the locations of green areas, the availability of cycling infrastructure and the layout of university facilities is important enough to interpret synergetic spatial strategies among these aspects promoting the continuity, cohesion, and comfort of the cycling network. Together with the variables mentioned, identifying public car parks in the proximity of green areas as another environmental factor involving more frequent cycling routes might be a related aspect in the decision-making strategy based on the 'traffic calming' measure for sustainable mobility such as cycling, which should be studied further in future lines of research.

Consequently, this work opens up new possibilities with regard to a potential cycling layout based on the links between green areas and university facilities by redefining the current cycling structure according to the spatial distribution of the above elements. It provides a method of analysis and a view of a strategy transferable to other cities, in the search for a more sustainable, healthy, and attractive urban model. This potential could be significantly increased if the information from GPS implemented in an app incorporates new functionalities that improve the ability to detect the relationship between the built environment and cycling (e.g., the location of green areas, traffic flow, accidents, cycling facilities, attractive destinations, etc.). Therefore, data and decision-making could be feedbacked by focusing on collaborative approach, which would translate into greater access to the city for cyclists.

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