KnE Engineering

STARTCON19
STARTCON19 - International Doctorate Students Conference + Lab Workshop in Civil Engineering
Volume 2020

Conference Paper

Making Cycling Spaces in Hilly Cities

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Abstract

Traffic congestion and environmental pollution in cities have stimulated the rise of policies to encourage practices of less polluting, and more economic and healthier modes of transportation, such as cycling. Several factors influence bicycle use, including the steep gradients which can limit it use, but do not completely prevent it. In this context, urban planning and transport engineering play a key role in promoting cycling, with particular emphasis on the definition and design of cycling networks at hilly cities, according to the citizens' needs on their daily commutes. To address this challenge, this paper describes the starting developments and the methodological approach of a doctoral research having the following goals: to define the data to be considered in feasibility studies of designing cycling mode in hilly cities; to develop a bicycle suitability model based on demographic, travel-generating poles, type of bicycles (regular vs. electric) and road network criteria; to develop a model to support the definition of cycling network based on connectivity, network intersections, integration with other modes of transportation, parking and safety; and to define a procedure for assessing solutions and define cycling routes hierarchy, having as case study the hilly city of Covilhã, at Serra da Estrela mountain.

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Received: 7 January 2020
Accepted: 21 April 2020
Published: 3 May 2020

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the STARTCON19 Conference Committee.

1. Introduction

Nowadays, cities are struggling in order to improve their sustainable indicators, given that problems such as traffic congestion or environmental pollution have been increasing. Policies and measures are rising to encourage practices of less polluting, more economic and healthier modes of transportation. Among these strategies soft mobility is a pivotal approach, including the use of the bicycle. In fact, soft mobility is on the top of the agenda as a strategy for cities liveability, referring to non-motorized transportation solutions in order to promote the human mobility [1]. It is a crucial issue towards a most sustainable urban environment [2].

However, in hilly cities, there are particular factors that influence bicycle use such as the steep gradients, which can limit it performance as a soft mobility element. This article aims to show how urban planning and transport engineering play a key role in promoting cycling, focused on the definition and urban design of public spaces of hilly cities. Thus, in boosting cycling networks that meet the needs of citizens as daily commuters. This research point of view is the starting point for a doctoral thesis which aims to be able to define the basic data required on the implementation of the cycling mode of mobility in hilly cities, having Covilhã as case study at Serra da Estrela, the highest mountain in the Portuguese continental territory.

2. Bicycle As Sustainable Urban Transport

In recent decades there has been a growing use of the private car, and consequently many problems associated with this mode of travel, which have turned the cities into places that are not welcoming and have no quality of life. For this reason some cities have been implementing more sustainable alternatives, investing in projects, studies and infrastructures that enable and motivate the movement of pedestrians, cyclists and public transport use, as well as the integration between these modes.

Promoting smooth mobility in urban areas is an effective strategy to improve urban sustainability, especially in small and medium-sized cities. In fact, in these cities, a large proportion of journeys have distances compatible with pedestrian or bicycle mobility.

In short-term trips, the bicycle presents itself as an alternative with several advantages for both the user and the community in general, and for that reason its use as a mode of transportation has been increasingly studied worldwide.

The graph in Fig. 1 shows the distance-time relation for different modes of transport. It can be seen that for distances up to 5 km, which may increase depending on the congestion, the bicycle surpasses the car.

This value increases for the case of trips made with electric bicycles (e-bikes), since they allow the users to travel longer distances than with a conventional bicycle [4] (see Fig. 2). In the Netherlands it is generally considered that 7.5 km is the maximum distance for which users agree to exchange another mode of transport for a conventional bicycle, however, for e-bikes this limit can at least be raised up to 10 km [4-5].

The freedom to move around the city, whether walking, cycling or by public transport - preferably on routes - is one of the factors that contribute to the sense of individual and collective well-being. The existence of heavily landscaped, well-lit public walkways designed for pedestrians, including those with reduced mobility, provides cities with

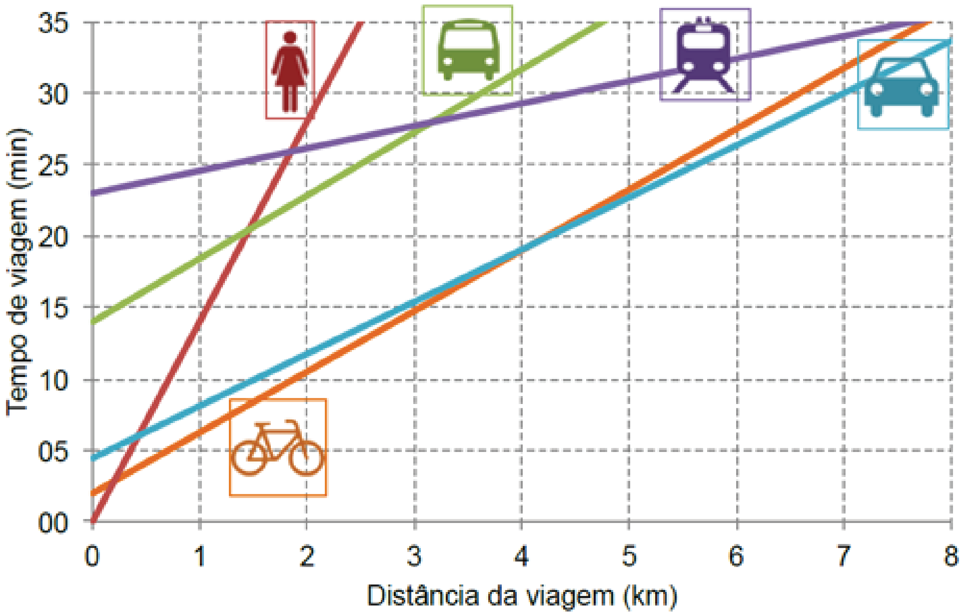

Figure 1: Comparison of door-to-door travel times for a travel distance of 5 km [3].

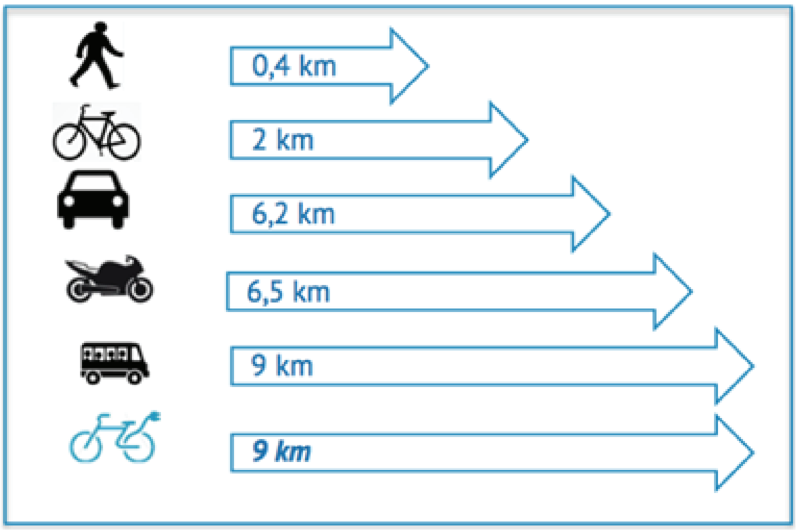

Figure 2: Estimated average distance traveled by e-bike compared to other modes of transport in the Paris Region [5].

good environmental quality. Prioritizing the pedestrian and bicycle systems reveals a humanistic, social, public and collective urbanism, as opposed to urbanism where the automobile is favored over people.

In Europe this approach has been promoted [6-7] and considers the decision-making hierarchy presented in Fig 3.

The bicycle, which during its locomotion does not emit any atmospheric pollutant or greenhouse gas and occupies a small space on the public road (see Figure 4), provides

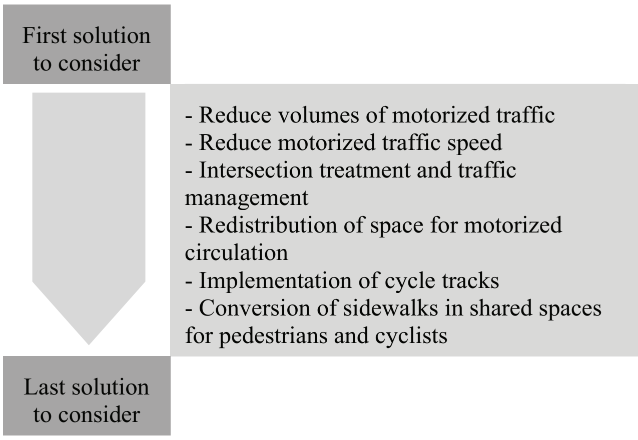

Figure 3: Hierarchy of decision making (adapted from [8]).

an eco-friendly alternative to car use, which is responsible for carbon dioxide (CO2) that causes the greenhouse effect and climate change. The following benefits can be associated to bicycle use [3]:

- Economic (e.g. reduction of the household budget devoted to car, reduction of lost work hours in congestion and medical expenses due to the effects of regular physical exercise);

- Policy (e.g. reduction of energy dependency, saving of non-renewable resources);

- Social (e.g. democratization of mobility, improved autonomy and accessibility of all equipment for both young and old);

- Ecological (with a distinction between local short-term effects - notion of environment - and long-term non-localized effects - notion of ecological balance).

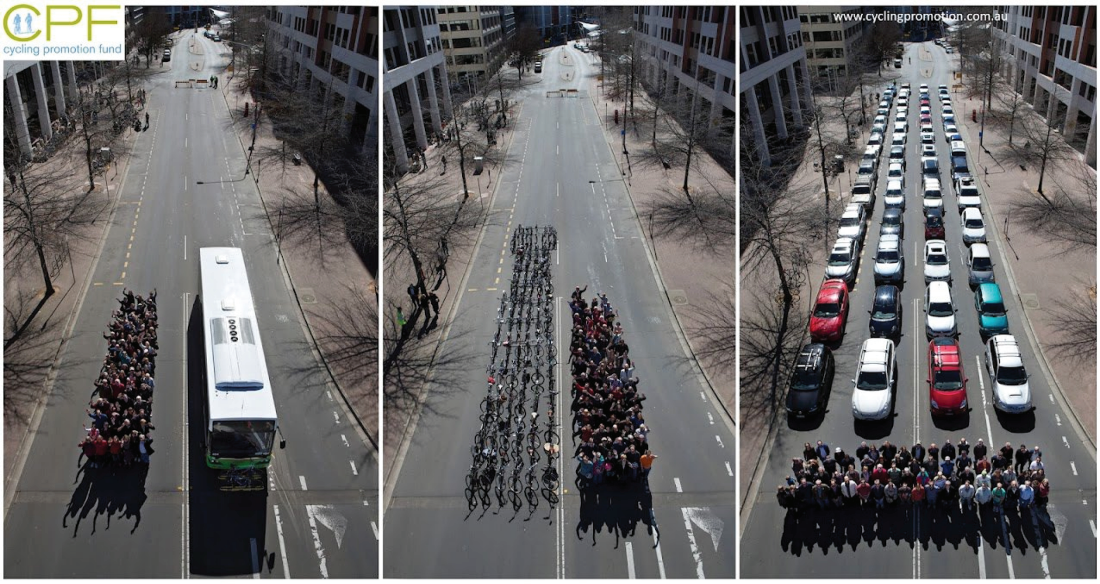

Figure 4: Space required on a road to carry the same amount of people by bus, bicycles and cars [9].

The negative impacts of car use has been motivating debates on alternative modes that diminish the environmental impact, promote the health of users and that are economically viable, stimulating the development of Mobility Plans that favour sustained mobility based in soft modes and public transport (see Fig. 4).

3. Steep Gradients and Bicycle Use

Despite the benefits of cycling, the bicycle use has been viewed in the past as a sport, recreation or leisure vehicle rather than a daily mode of transport, being ignored in the urban planning process and in particular in the transport planning process. This situation is slowly reversing. In 2015, the EU declared cycling as an environmentally friendly mode of transport and defined a plan with a set of actions including the development of a strategic document but also the inclusion of cycling in urban, local or regional projects [10].

As a mode of transport, the use of the bicycle is conditioned by several factors, namely [11]:

- The physical capacity of the user;

- The travel distance;

- The spatial structure of cities and the available cycle infrastructure, with implications on the travel speed and consequently on the travel time;

- Road safety;

- The weather;

- The relief, mainly the slope and the extension of the sloping areas.

The latter condition, typical of hilly towns, when marked, i.e. more than 5%, limit and restrict the use of the bicycle since it requires an additional effort of the users to overcome these territories. Grades greater than 5% on significant extensions are not desirable because climbs are too hard to beat by cyclists and are dangerous in downhill direction (increases speed). However, a higher grade can be considered for reduced lengths [12] (Fig. 5).

The AASHTO Guide to Bicycle Facilities [13] makes the following recommendations to mitigate excessive grades on shared use pathways:

- Use higher design speeds for horizontal and vertical curvature, stopping sight distance, and other geometric features.

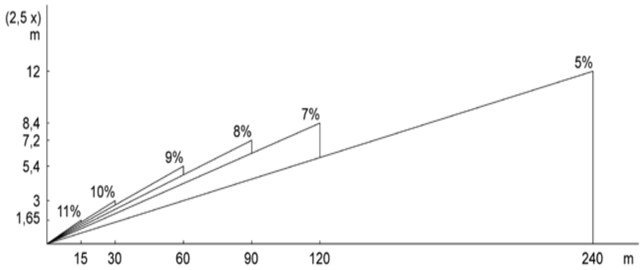

Figure 5: Grade and maximum recommended length for the use of bicycle according to ASSHTO [12].

- When using a longer grade, consider an additional 1.2 to 1.8 m of width to permit slower bicyclists to dismount and walk uphill, and to provide more manoeuvring space for fast downhill bicyclists.

- Install hill warning sign for bicyclists and advisory speed plaque, if appropriate

- Provide signing that alerts path users to the maximum percent of grade

- Exceed minimum horizontal clearances, recovery area, and/or protective railings.

- If other designs are not practicable, use a series of short switchbacks to traverse the grade. If this is done, an extra 1.2 to 1.8 m of path width is recommended to provide manoeuvring space.

- Provide resting intervals with flatter grades, to permit users to stop periodically and rest.

In general, the ideal grade for conventional bicycle use will be the lowest possible, preferably less than 3%, as can be seen in Table 1.

Table 1: Criteria for cycling potencial (Adapted from [8]).

0 to 3%	Level	Good for cycling
3 to 5%	Gentle slope	Suitable for cycling up to medium distances
5 to 8%	Moderate slope	Inappropriate for long and medium distances
8 to 10%	Steep slope	Acceptable for very short distance

These figures change when electric bicycles are considered, also known as e-bikes or pedelec. E-bikes are in general similar to conventional bikes in terms of general appearance and components, but are additionally equipped with an electric motor which can assist the user in the action of pedalling. The e-bikes are easier to use from the point of view of possible restrictions in terms of the physical condition of the driver, allows to relativize the problems associated with steep slopes and the loads to be carried and to increase the area of influence of the daily trips to about 15 km [8]. It should be noted that these bicycles do not replace the rider's effort but only complement or relieve it.

By overcoming what is undoubtedly one of the greatest impediments to bicycle use, e-bikes helps to materialize the concept of sustainable mobility [14].

4. Cycle Network Planning

Cycle network planning must take into account the existing urban environment and the cyclist's needs. This can be achieved through consideration of coherent, fast, pleasant, safe and comfortable pathways, i.e., thought the planning of friendly environments for cycling (concept of *bikeability*). The following criteria to guarantee the necessary conditions of circulation must be considered: connectivity and suitability; accessibility; road safety; security services; readability; comfort; attractiveness and user-friendliness.

Others factors to consider in the planning of cycling networks are [8]:

- The orography / relief: since the grade contributes to the suitability of the route to cycling (Table 1 and Fig. 5);

- The traffic characteristics: the need to introduce visual or physical separation increases in the presence of buses or heavy vehicles;

- Proximity to a car park: increases the danger for cyclists, for example due to the frequent maneuvers of vehicles and the opening of doors;

- The street width: if reduced, does not allow physical or visual separation;

- The frequency of intersections: increases the danger, even in paths dedicated to cyclists.

The IMTT [8] proposes the application of the methodology presented in Fig. 6 in the process of planning a cycling network.

5. Geographic Information Systems As a Decision Support Tool

The use of GIS is increasing among professionals responsible for land management, urban planning and transport problems resolution. The application of GIS in the planning process of infrastructures to support the use of the bicycle covers several aspects as the selection of the most suitable routes for bicycle use, the analysis of route choice by cyclists, the identification of risk areas for cyclists and the planning and development of support infrastructures. In highly complex decision-making processes, techniques and methodologies with scientific foundations are used, as is the case of multicriteria analysis. This methodology allows to solve, evaluate and formulate models

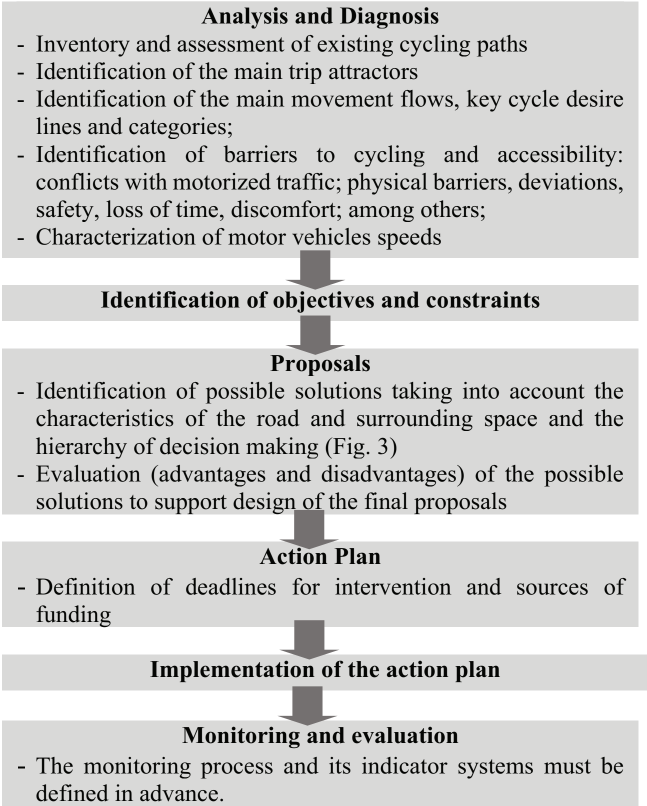

Figure 6: Process of planning a cycling network.

of analysis, and to organize and synthesize the available information to support decision making process. In this sense, for the implementation of a multicriteria GIS analysis, it is necessary to take into account the selection and definition of criteria, the definition of weights for each criteria and also the choice of the procedure for the combination of these [15].

In the development and planning of cycling networks, the use of GIS has evolved from the production of maps to a complex decision support system in an effective and integrated way, capable of identifying weaknesses in the development of the solution, evaluating alternatives and monitoring changes. In the present study, GIS plays an important role in considering road grade in the cycling potential analysis. This factor is especially important in hilly cities. Using GIS available tools, elevation data can be worked to obtain road grade and specific cycling speed and travel time, allowing these aspects to be integrated into the analysis. These enable those responsible for the management of cycle networks to identify and assess existing infrastructures and their location, to determine the capacity of a route for the introduction of a cycle path and to evaluate land use options to identify areas of conflict. In fact, there are a number of applications that demonstrate the potential of GIS analysis and their relationship to the decision-making process for problem solving in the area of urban mobility that can be found in the literature [15-20].

6. Methodological Approach Proposed for Doctoral Research

To allow the definition of a clear and structured working plan to be developed in the doctoral thesis, the main objective and a set of specific goals were initially defined.

The main objective of this study is to define a model for analysing the cycling potential and to support the implementation of cycling routes in medium-sized cities with steep slopes. These cities are seen as less suitable for the implementation of soft mobility. The referred model aims to be used as support tool in the decision-making process related to sustainable mobility policies.

To achieve this objective, is crucial to following a set of proposed goals:

- to define the data to be considered in feasibility studies on the creation and designing of cycling mode adapted to hilly cities;

- to develop a bicycle suitability model based on demographic, travel-generating poles, type of bicycles (regular vs. electric) and road network criteria;

- to develop a model to support the definition of cycling network based on connectivity, network intersections, integration with other modes of transportation, parking and safety;

- to define a procedure for evaluating solutions and define cycle routes hierarchy;

- to test the previously referred models and procedures to the case study of the city of Covilhã, located on the hillside of Serra da Estrela, Portugal.

6.1. System design to support cycling network planning in hilly cities

6.1.1. Bicycle suitability model

The accomplishment of the first two specific goals allows to support the definition of a model for the evaluation of existing networks bicycle suitability.

The literature reveals that the basic data that will support not only the bicycle suitability model, but also the entire cycling network planning process, must include:

- Demographic data: population density, age distribution, employability rate, distribution of the employed and student population by mode of transportation used, characterization of commuting trips (e.g. average duration of commuting trips), among others. These data can be obtained by consulting the Statistics Portugal database (Census 2011) and conducting population surveys.

- Data on the main travel-generating poles: to be obtained by collecting the location of the main city facilities (health, education, public services, trade, transport, leisure, tourism), employers and residential areas, and by conducting population surveys.

- Characteristics of the existing road network: including information on the hierarchical class of existing roads, traffic volumes and traffic speeds, number and lanes width, sidewalk presence and width, and longitudinal grade of roads.

- Specific operating characteristics of conventional and electric bikes: comfortable grades for bicycle use, driving speeds and maximum acceptable distances for commuting trips.

In order to consider this data in an integrated way, a multi-criteria analysis in a GIS environment is proposed. The calibration of the weights of each model variable will be supported by a panel of experts that includes professionals from the transport sector, academics and administrators of the road network.

This dataset allows to incorporate early in the planning process issues relating to safety (e.g. by elimination of roads classified into hierarchical classes characterized by high speeds and volume traffic), comfort and cycle lane/path typology (e.g. through the selection of flatter and wider road segments). These aspects are particularly important as cycling networks often need to be adapted within exiting urban conditions of roads, regarding the urban morphological features.

6.1.2. Cycling network definition model

The application of the bicycle suitability model allows to identify in existing networks the road segments with cycling potential, however, this result must be evaluated and adjusted in order to define a cycling network that verifies an adequate:

- Connectivity: ensuring direct and continuous links between the main travel-generating poles of journeys.

- Accessibility: in particular to public transport interfaces, with particular attention to the physical organization of spaces in order to promote intermodality, and to ensure the existence of parking facilities for bicycles.

- Road safety: minimizing conflicts with motorized traffic and pedestrians.

- Meet user needs for commuting, including potential for higher demand.

This stage of the cycling network planning process results in a set of cycling routes that are of interest for the daily commutes of citizens.

6.1.3. Solution evaluation procedure and route hierarchy

The application of the cycling network definition model can result in several alternative routes for a particular connection. In order to select between the possible routes the most appropriate, a procedure to evaluate cycle route options considering usefulness and value for money must be defined and applied.

Several evaluation approaches can be found in the literature to evaluate and compare options. A needs assessment approach, that is a qualitative assessment, is always important, as many of the issues associated with developing a cycle network are qualitative. For a quantitative assessment, the Level of Service (LOS) method can be used. Cycling LOS assessment is based on a significant volume of empirical research on cyclists' views and reactions to specific road environments [21].

Several cycling methods have been developed and published, such as the bicycle compatibility index (BCI) [22] and the HMC6 methodology [23]. In general, these approaches also allow to define a degree of relative importance among the various options available (hierarchy).

Further research about more flexible and suitable methods regarding the morphological features of hilly cities is required and will be undertaken.

6.2. Application of the methodology to the City of Covilhã

The municipality of Covilhã comprises about 50.000 inhabitants the majority of them settled along to the urban area of the hillside of Serra da Estrela mountain. The urban fabric of Covilhã is mainly spread all-over 400 and 800 meters high, where there is no flat land, and consequently the mobility for pedestrians and cyclists is a major challenge [2]. From an ancient history marked by the textile industry, Covilhã has turned a students' city, with approximately its 8.000 students, who are attending to the University of Beira Interior. Its historical urban fabric has an urban morphology of traditional narrow and winding streets, with difficult conditions for the traffic of cars [2]. The road network of the municipality presents a total length of 1898 km, of which 430 km are included in the urban perimeter. Concerning the hierarchy of urban roads, 7% are arterial, 13% major collectors, 25% minor collectors and 55% access roads.

Taking into account the particularity of hilly cities, a first analysis to test the viability of a model to assess the bicycle suitability of the Covilhã urban road network, based in demographic data, travel-generating poles and road width and grades (determined based on a digital terrain model with accuracy less than 10 meters) was performed by Passos [15]. This analysis allowed to define the bases for a cycling network planning process for hilly cities proposed in the Doctoral research.

Future work to be developed based on the methodological approach proposed will allow to refine the bicycle suitability model and apply the remaining components of the cycle network planning process to the city of Covilhã. This validation will support the promotion of cycling as a mode of transport in medium-sized hilly cities and provide a decision tool to those responsible for urban space management.

7. Conclusions

Three aspects stand out as being important in the cycling network regarding the planning process for hilly cities. First of all, such as in any other cycling assessment, the facility must meet the users' needs. Secondly, the choice of routes must take into account the resolution of conflicts at intersections where the cycling route meets or crosses more heavily trafficked roads. The last aspect refers to the road gradient, which should be considered.

Finally, the hilly cities and their morphological conditions are sensitive case studies regarding the topic of cycling networks, such as in the case of Covilhã. In fact, they represent a challenge for researchers when the main goal is to promote ways of soft mobility based on the bicycle use, in order to achieve a most sustainable urban environment and healthier community.

Acknowledgments

The authors acknowledge University of Beira Interior, CERIS-CESUR (ECI/04625) and C-MADE (ECI/04082) for supporting the performed study. The authors thank C-MADE for the financial support on this work.

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