

PEDESTRIAN MOBILITY - MAPPING CIRCULATION CONDITIONS FOR PEOPLE WITH MOBILITY CONSTRAINTS IN A CENTRAL URBAN AREA

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Abstract: Nowadays, pedestrian mobility is regarded as a key issue to urban planners since several studies have pointed it as an influential factor to the quality of life in central city areas. Consequently, walking conditions must be evaluated and some measures should be taken whenever the results show inappropriate implementations. This concern increases when focusing on the movement of people with mobility constraints, because for them a physical obstacle can represent an insurmountable obstruction. The goal of the present work is to analyze factors that limit the circulation of people with mobility constraints and to map those conditions in central urban areas. Taking into account only the physical characteristics of urban spaces, the assessment is performed in agreement with the standards specified in the Portuguese Law, defined by Decree-Law Nr 163/2006, in short DL 163/2006. The first part of the work introduces a multi-criteria model developed to evaluate the compliance of urban spaces with those standards. This model defines the normalization of measured values for each considered criterion, as well as their aggregation to achieve an index that expresses the compliance level of the evaluated urban spaces. The integration of the model within a GIS platform was performed in order to implement a spatial analysis of the results. The second part shows and discusses the results of a case study in a central area of the city of Braga, Portugal. The chosen area allows for the analysis of sidewalks and crosswalks of streets as a continuous network. Some sidewalk segments constructed before the approval of this law were also included allowing a comparative analysis with new (or improved) segments. The map of results highlights the sidewalk segments with worst performance, reflecting lower index values. This map is very helpful to city managers when identifying critical areas that require an intervention in order to improve the mobility of those pedestrians. Moreover, the proposed model can be easily adapted for other cities and countries.

Keywords: Urban Planning, Planning Support Systems, Pedestrian Mobility, Circulation Map

1. INTRODUCTION AND OBJECTIVES

The pedestrian mobility is not restrained by the same factors as other means of mobility: for instance, it is not restricted by the availability of roads or railways. Furthermore, travelling on foot is always present in human basic daily activity, as a primary means of locomotion or as supplement to other modes of transportation. This type of mobility is getting more attention in city centers, where the maximum distance is less than 2 or 3 kilometers, as it is commonly related with quality of life in urban areas. Another aspect that helped to increase the interest in this topic is that the required infrastructures are usually considerably less expensive than those for other means of mobility.

So, mainly in urban areas, safety and comfort of pedestrians are nowadays a key issue for planners and city managers. Even more concern is required when considering mobility impaired people. For those people, several obstacles become barriers which cannot be overtaken and thus significantly decrease their level of mobility.

The present work propose a spatial model for the analysis of the physical urban environment for pedestrian, classifying the urban space in terms of its compliance with the requirements defined for the urban circulation of people with mobility constraints. Furthermore, the study focuses the physical characteristics of walking spaces in a global perspective, and does not analyze the network level of service or the characteristics of the pedestrians. This way, the study intends to improve the analysis of the characteristics of those areas as basic infrastructure for walking mobility, not necessarily to adequate the capacity of the sidewalks to the demand.

The classification proposed by the model highlights qualities and flaws of the urban space for walking mobility. The analysis refers to the urban spaces with pedestrian circulation, such as pedestrian streets, sidewalks, squares and other open spaces. The proposed analysis only takes into account the physical characteristics of urban spaces according to the standards specified by Portuguese Law, defined by DL 163/2006, namely sidewalk dimensions, position of urban furniture, ramps, etc. The analysis of several criteria results in an index classification model, which assesses the level of compliance of the case study urban spaces. Through its integration in a GIS platform, maps are produced to reflect the conditions that mobility impaired pedestrians will face in the studied area.

Although pedestrians select their walking path considering also the pleasantness or appeal of the path and other subjective aspects, the emphasis of this study was kept exclusively on the physical characteristics of urban spaces.

2. PEDESTRIAN MOBILITY IN URBAN ENVIRONMENT

Nowadays, due to environmental, economical and health issues, the population and city managers have a new attitude towards pedestrian mobility. With the growing interest of local authorities, soft modes of transportation are getting more importance and becoming more often the focus of urban planners. "Walking is the most reliable form of transport, whilst also improving the health of its users through improved fitness levels and reductions in the risk of obesity and heart disease" (Department of Health, 2004).

From all the soft modes, walking is one of the most important because it completes the other modes of transportation. "People walk for many reasons: to go to a neighbor's house, to run errands, for school, or to get to a business meeting. People also walk for recreation and health benefits or for the enjoyment of being outside. Some pedestrians must walk to transit or other destinations if they wish to travel independently. It is a public responsibility to provide a safe, secure, and comfortable system for all people who walk." (Zegeer *et al.*, 2002). However, the necessary conditions to turn walking into a pleasant and safe experience are sometimes forgotten. Tight *et al.* (2004) referred that walking has perhaps been partly overlooked by those responsible for urban areas because it is ubiquitous and seen as a benign mode of transport.

To promote pedestrian mobility it is necessary to attend to walking capacities. However, pedestrian walking capacities differ for several reasons, such as age, physical conditions and social class. The obstacles present in urban spaces should also be considered, since these may dissuade travelling on foot.

Many factors can condition pedestrian circulation. Some can be intrinsic to the person and others originate from the urban environmental, social aspects or infrastructural limitations. One of the factors that influence the decision of walking is the age of the pedestrian. For instance, young and elderly users have different needs as, due to their physical condition, they get tired more quickly. Another important aspect is that they have more difficulties in perceiving danger, making them more accident-prone. For these reasons, their motivations for walking are different from the majority of pedestrians (Tight *et al.*, 2004).

Distance and time are also important factors that influence the decision of travelling on foot. In a study concerning the travelling modes for short distances, Forward (1998) concluded that travel time was identified as a factor in the decision to walk and if the individuals believed to be «in a hurry» they were less likely to make a walking trip.

In major cities, the increasing distances between services, residence and work place, make walking less relevant in the urban mobility. Additionally, rush people prefer faster modes of transportation to minimize time between tasks. Thus, for longer distances or to minimize time travel, travelling by foot is not the preferred form of mobility (Tight *et al.*, 2004).

The urban form, weather, pedestrian environment and the physical effort spent in travelling affect pedestrian mobility and decrease the level of comfort, influencing the option to walk. If the pedestrian journey is unlevelled, the sidewalks are undersized or in bad conditions, if it is raining, very cold or hot, and if the urban surrounding is unpleasant, people will most likely choose another means of transport due to the low level of comfort felt (Tight *et al.*, 2004). However, if there is only one negative factor, such as sidewalks in bad conditions, but the surrounding is pleasant and the weather is nice, then the discomfort level is minimized.

On the other hand, there are also some factors that encourage pedestrian mobility such as health benefits, the contribution for fitness, or even its relaxing aspect. These factors were pointed out by people that usually travel on foot.

In a study carried out at the Metropolitan Area of Porto, the second major city of Portugal, the authors referred that, in addition to its economical advantages, pedestrian streets help people develop a healthy lifestyle, by exercising regularly, and also by promoting social interaction (UCP, 2008).

3. SPATIAL CLASSIFICATION MODEL

The implementation of the proposed spatial classification model was taken in several steps, which are explained in the following paragraphs.

The first step of the spatial classification model is the identification of a set of compliance items, related with the walkability conditions of public urban spaces for people with mobility constraints. In the present study, this feature was performed by analysing the Portuguese Law to gather the design criteria for public urban spaces, particularly the pathways for pedestrians, in order to provide good conditions of mobility for all. The selected criteria adopted in the analysis model were structured so that the evaluation criteria (indicators) can be used in similar studies for other cities or countries.

The starting point to identify the criteria to be adopted in the model was the analysis of the Portuguese Law DL 163/2006 (similar to laws adopted in other countries). The standards found in this law establish the accessibility design condition to public buildings and establishments, to public urban open spaces and to residential buildings. Also, the law defines accessibility as a part of a wider role of government instruments to establish a global and coherent system of rules, capable of providing equal opportunities of mobility to all persons (Teles *et al.*, 2006-2009). The new law replaces the previous law (published in 1997), as referred in the document, due to "... insufficient solutions proposed by the previous law". This new law aims to establish a solution of continuity with the previous law, by amending the identified imperfections, improving the fiscal mechanisms and sanctioning efficiency, increasing the level of communication and responsibility of the involved agents, as well as by introducing new solutions in line with the verified evolution of social, technical and legislative aspects between the publication of the two laws.

From this analysis, two main groups of criteria were identified. Both groups are also divided in subgroups, containing specific criteria that will be used to feed the proposed classification model. The structure of groups and subgroups of criteria are listed in Table 1. As the focus of the study is the assessment of the compliance of urban spaces, the criteria published in the law concerning indoor circulation were not considered.

Subsequently, the index to classify the urban space compliance was obtained by the aggregation of all criteria after the normalization process. For that, all criteria must be assessed and the normalization process establishes two possible values, 0 or 1; the criterion score is 0 when it does not comply with the law standards and is 1 when it is according to the law parameters. The standard parameters defined by the law for each criterion, used as control points to the normalization process, are also listed in Tables 2, 3a and 3b.

Table 1: Group and subgroups of criteria to assess walkability conditions of urban spaces

Group	Subgroup
Public areas: Sidewalks and walkways	Route Sidewalks and other footpaths Stairs Public Stairways Public Stairways between ramps Ramps Ramps in public spaces
Public areas: Crosswalks and pedestrian passages	Crosswalks (pedestrian crossings) Pedestrian overpasses or underpasses Other places of circulation and staying of pedestrians

Table 2: Classification of sidewalks and other pedestrian walkways

Classification = 1	Classification = 0
Free sidewalk width, along primary and distributor roads $\geq 1.50\text{m}$	Free sidewalk width, along primary and distributor roads $< 1.50\text{m}$
Width of pedestrian walkways in planted areas with a length not greater than 7 m $\geq 0.90\text{m}$	Width of pedestrian courses in planted areas with a length not greater than 7 m $< 0.90\text{m}$
Ramp slopes – not greater than 6%; length not lower than 0.75m or full multiples of this value	Ramp slopes – greater than 6%; length lower than 0.75m or not full multiples of this value

Table 3a: Classification of crosswalks and pedestrian passages

Classification = 1	Classification = 0
Curb height - less than or equal to 0.02 m along all crosswalk width	Curb height - over 0.02 m along all crosswalk width
Pavement - ramped, with slope below or equal to 8% in the crosswalk direction and below or equal to 10% in the curb sidewalk direction	Pavement - not ramped or ramped with slope above 8% in the crosswalk direction or above 10% in the curb sidewalk direction
Width of the intersection zone of the crosswalks and the median strips - Greater than or equal to 1.20 m	Width of the intersection zone of the crosswalks and the median strips - Less than 1.20 m
Pavement slope - less than or equal to 2% in the crosswalk direction	Pavement slope - greater than 2% in the crosswalk direction

Table 3b: Classification of crosswalks and pedestrian passages

Classification = 1	Classification = 0
<i>With lighting system</i>	<i>With lighting system</i>
Height of the activation device – between 0.8 m and 1.20 m	Height of the activation device – below 0.8 m or above 1.20 m
Green light timing must allow crossing at a velocity of 0.4m/s. The traffic lights must be complemented with audible signals	Green light timing does not allow crossing at a velocity of 0.4m/s. The traffic lights is not complemented with audible signals

The selected criteria are in some cases specific and cannot be globally applied to the whole study area: for instance, leveled crosswalk criteria are not applicable to underground pedestrian passages. Furthermore, the number of criteria to be considered for a subgroup can also vary according to the existence or not of some elements. For example, when dealing with crosswalks, some of the criteria can only be evaluated when a lighting system is available.

For these reasons, when defining the criteria aggregation function to calculate a subgroup compliance index, all those nuances had to be taken into account and reflected in the calculation process. Equation (1) shows how a subgroup compliance index is obtained.

$$IC_s = \sum_i p_{is} \times c_{is} \quad (1)$$

Where:

- IC_s : compliance index of subgroup s
- p_{is} : weight of the criterion i in the subgroup s
- c_{is} : normalized value of criterion i in subgroup s
- i : index of criteria applicable to the analyzed spaces

After evaluating the compliance to the standards defined in the law, it was decided to assign equal weights to all criteria. Using this option, each criterion of a subgroup has the same contribution to the subgroup compliance index. As such, Equation (1) can be classified as a Weighted Linear Combination (to an extensive description, see Weighted Linear Combination in Malczewski, 1999).

In order to assign equal weights to each criteria of a subgroup, the following formula was used:

$$p_{is} = 1/n_s \quad (2)$$

Where:

- p_{is} : weight of the criteria i in subgroup s
- n_s : number of criterion evaluated in the group s

This approach results in equal weights to all criteria and also guarantees that the condition is fulfilled in specific cases. When one or more criteria are not applicable in an

area, the evaluation is still possible because the index only counts the number of estimated criteria (n_s). For example, in Table 3, there are only three criteria that are valid for all the crosswalks and two others that are only estimated when traffic lights are present. In the first case n_s takes the value of 3 and in the second case n_s is equal to 5.

Finally, Equation (3) is used to combine all group indexes to obtain the global compliance index for each segments of the network:

$$GCI = \sum_j p_j \times g_j \quad (3)$$

where:

GCI : Final Compliance Index

p_j : weight of group j

g_j : compliance index of group j

4. CASE STUDY

The methodology presented in the previous section was implemented and tested on a case study in some streets of the city of Braga, Portugal. Braga is located in the Minho region at the Northwest of the country. It is surrounded by the municipalities of Amares at North, Póvoa de Lanhoso at East, Guimarães at Southeast, at South by Vila Nova de Famalicão, at West by Barcelos and at Northwest by Vila Verde.

Braga has an area of 183.40 km² (INE, 2011) and is composed by 62 boroughs (smallest Portuguese administrative division): 23 are urban, 22 are mainly urban and 17 median urban. Braga is the capital of the district and of the Metropolitan area of Minho. It is one of the largest cities of the country with 176154 habitants and a population density of 960.50 hab/km² (INE, 2011). According to the National census of 2001 (Census 2001), 35% of the city population are between 0 to 25 years old, 54% was in the group age of 24 to 64 years and the elderly represents 11% of the population, making Braga a youthful city.

The study area is in the central area of the city of Braga, in the boroughs of S. Vicente, S.Victor, S. João do Souto and S. Lázaro. It was chosen by the fulfillment of some requirements that were considered important to validate the study: the continuity between areas allows defining networks which interconnect locations; streets/sidewalks in a services and commercial area daily strongly used by pedestrians; and the date of construction/rehabilitation of the streets makes it possible to analyze the practices before and after the law DL 163/2006.

Taking in consideration these standards, the chosen network (Figure 1) interconnects the area of the Municipal Cemetery (post DL 163/2006), *Santa Margarida Street* (pre DL 163/2006), *Avenida Central* (pre DL 163/2006) and *Avenida da Liberdade* (pre DL 163/2006 and partially rehabilitated in 2009).

After defining the study area, the work entered a more practical phase: the field work was initiated in order to collect data regarding the physical characteristics of the streets. It

consisted of collecting the characteristics required for the study, such as sidewalk width and height, ramp slopes, position of the urban furniture, like dustbins, benches, poles, bushes, etc.

To implement the spatial analysis, three steps were performed:

- ✓ collection of the cartography for extraction of the study area;
- ✓ edition of the studied streets in a GIS platform;
- ✓ addition of fields to the attribute tables for storing data collection and calculation results;

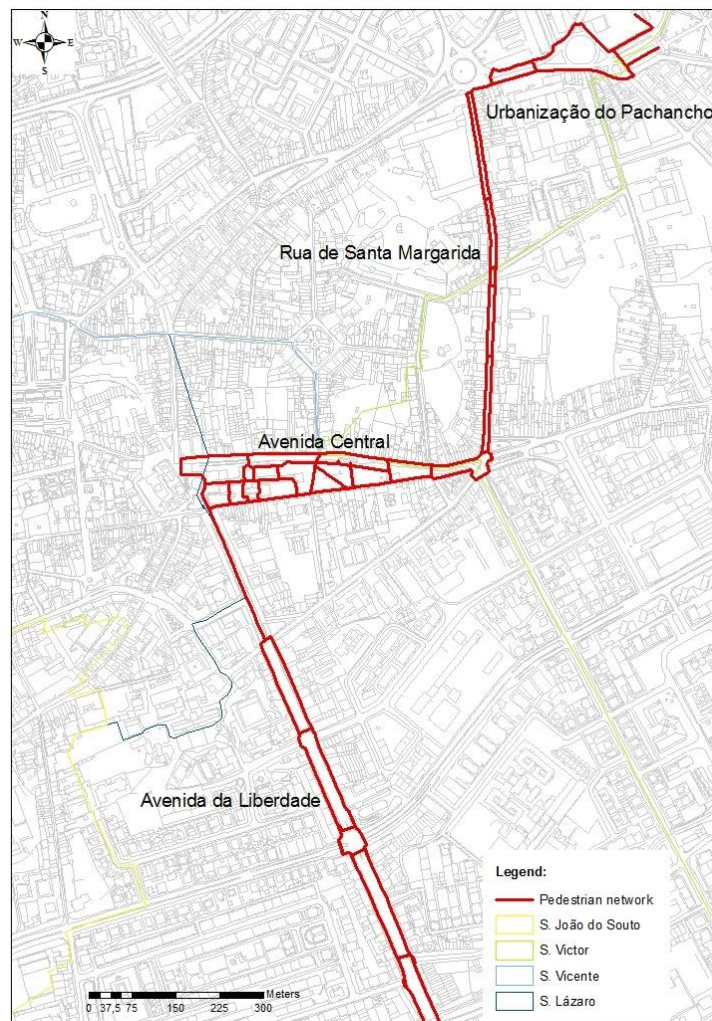


Figure 1 – Network used in the case study

After the insertion of values in the attributes table, the normalization was applied. This stage is crucial to achieve a compliance index because the criteria are expressed in different ranges of values and different units. Normalizing the values to a common scale

enables their combination to obtain an index. As previously referred, the collected values were “transformed” to values of 0 or 1, where 0 represents the non-compliance of the criterion and 1 is assigned when in accordance with the law. Figures 2 and 3 present maps showing the results of the normalization of two criteria. Figure 2 is a map that shows the levels of compliance for the criterion of slope of sidewalk pavement, while Figure 3 is the same for the criterion of sidewalk width. Three colors were used for better understanding the map: green to show when the criterion is respected, red when the standards are not complied with, and yellow to indicate when the criterion is not applicable.

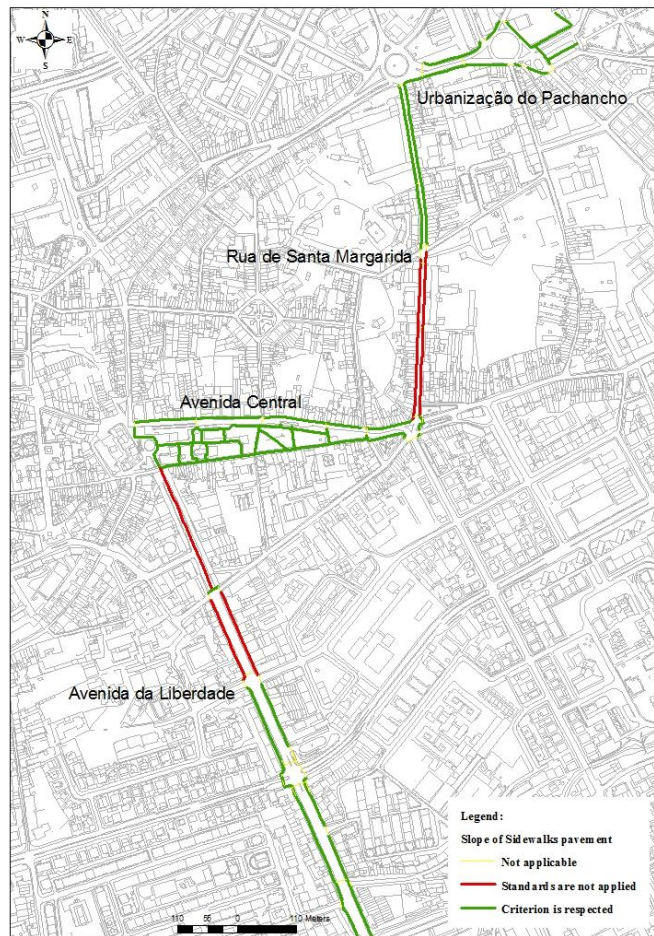


Figure 2 Map showing the compliance of sidewalk pavement slope



Figure 3 Map showing the compliance of sidewalk width

With the aim of evaluating the compliance with the standards defined in the law, an equal contribution of each criterion to the compliance index was adopted. Equation (1), referred in section 3, was used to aggregate the criteria and to obtain an index. For instance, combining two criteria, namely the slope of sidewalk pavement (Figure 2) and sidewalks width (Figure 3), implies that the value 0.5 will be applied as the weight to each criterion. Figure 4 shows the map illustrating the obtained index. Four colors are now present, as shown the legend: red when both the criteria is not fulfilled, green when only one the criteria is respected, blue when both criteria are in accordance with the standards, and yellow when the evaluation is not applicable.



Figure 4 Index map for the combination of the slope and width of the sidewalks

Figure 5 shows the result of the application of the process previously described to obtain the compliance index of crosswalks. However, as referred in section 3, there are two types of crosswalks: with or without traffic lights. Each type implies the evaluation of a different number of criteria (see Tables 3a and 3b). In each case, it was necessary to determine the number of applicable criteria and then calculate the weight using Equation (2). This procedure ensures that the assignment of equal weights to each criterion is executed independently of the number of criteria involved in index calculation. The map shows crosswalks painted with several colors, varying from red to green. The more reddish a crosswalk appears, the bigger is the number of criteria in which the crosswalk fails (red – index equal to 0 - means all criteria have failed). On the contrary, the greener a crosswalk is represented, the bigger is the number of criteria in which the crosswalk is in accordance with the standards (green – index equal to 1 – means all the criteria were complied with).

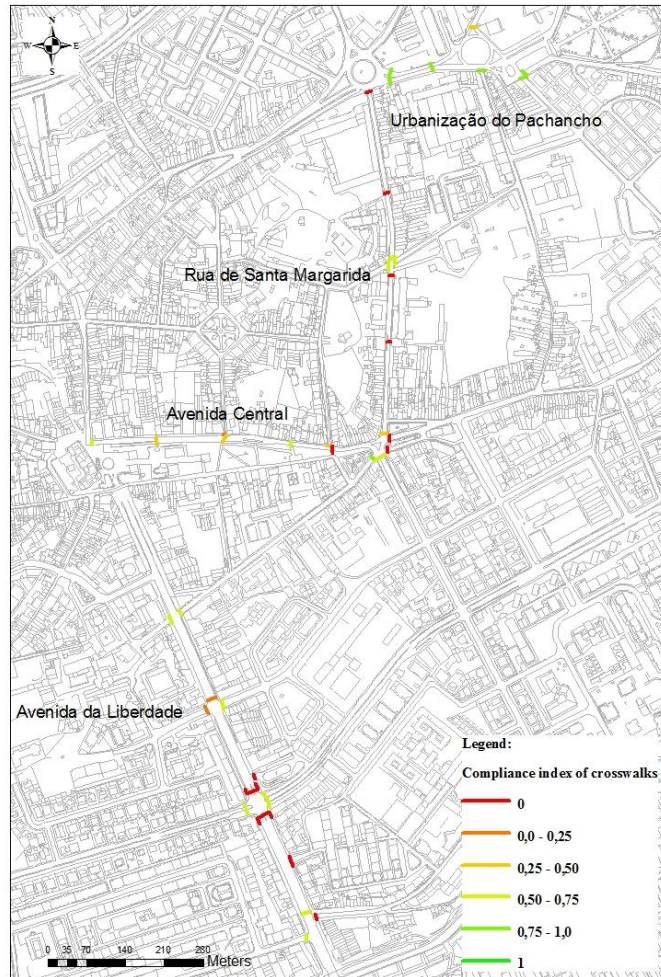


Figure 5 – map showing the compliance index for crosswalks

The global index of compliance with DL 163/2006 for crosswalks and sidewalks was obtained combining all the subgroup indexes of each group, using Equation (3) and considering only the applicable criteria. Figure 6 shows a global map of the index for the chosen study area. As previously, the best performance is represented by the value 1, representing a full compliance with the standards. Conversely, an index equal to 0 means that none of the criteria were positively evaluated. As shown in the figure, none of the network segments reached the maximum index (full compliance). *Avenida Central*, *Avenida da Liberdade* and *Urbanização do Pachancho* are the streets with higher indexes (greener). On the opposite side, the evaluated segments of *Rua Santa Margarida* obtained indexes with values below 0.5 (illustrated in orange and red color in Figure 6).

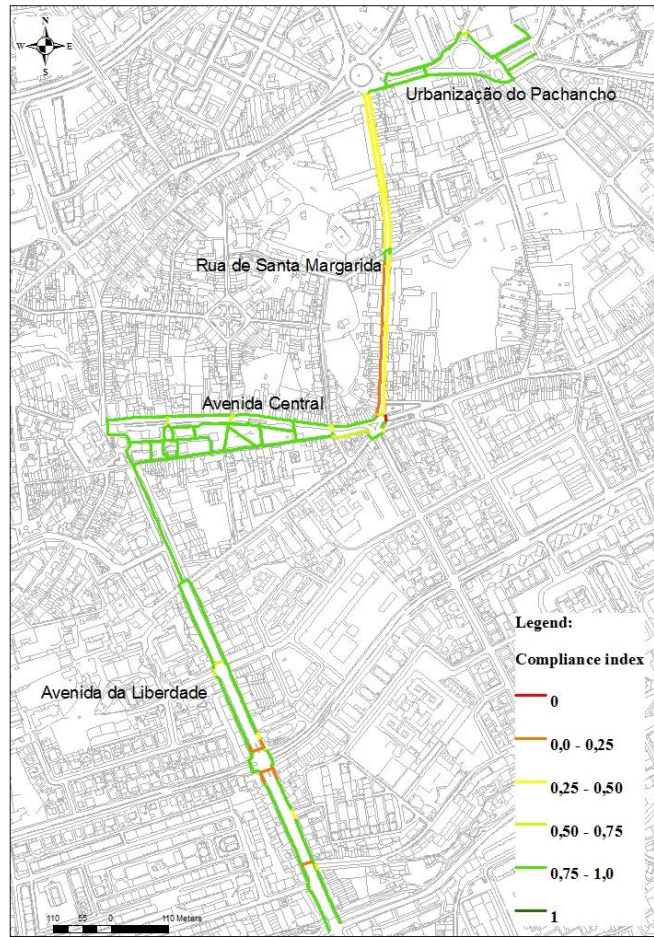


Figure 6 - Map showing the compliance index in the study zone

In order to better understand why *Rua Santa Margarida* has the worst performance when evaluating its level of compliance, some pictures of the street are presented in Figure 7.

5. CASE STUDY CONCLUSIONS

With the goal of evaluating the compliance of urban spaces with the standards defined by law DL 163/2006, the proposed model was applied to several streets of Braga, Portugal.

Observing the map for the slope of sidewalk pavement (Figure 2), it can be seen that the majority of the segments are in compliance with the Portuguese law. However, some are not: those segments are located in a very uneven surface, a fact that can explain this result. This explanation is not valid when analyzing the results in Figure 3, since sidewalk width is not influenced by the terrain. Looking at the sidewalk width map (Figure 3), it is

noticeable that most segments are in compliance with DL 163/2006, except for *Rua Santa Margarida*. From the analysis of the combination of those criteria, in Figure 4, one section of *Rua Santa Margarida* has emerged as the area with the worst level of compliance. Scoring a value of 0, it means that none of the standards is achieved. The segments that obtain a classification of 0.5 fulfilled one criterion. Those that have got the score of 1 fulfilled all the criteria, i.e., are in accordance with the standards defined in the law. This poor performance of the *Rua Santa Margarida* can partially be explained by its strong slope and by the lack of interventions to enhance street conditions. More specifically, *Rua Santa Margarida* performed negatively in the following criteria:

- sidewalk slope should be lower than 6%, but value up to 14% were measured;
- sidewalk width has values comprehended between 0,9 meters and 1,15 meters but values should be over 2.25 meters, when there is no urban furniture, or 1.2 meters in spaces between vertical signalization poles or urban furniture;
- curb ramps at crosswalks should have a maximum grade of 8%; in *Rua Santa Margarida*, grades up to 24% were measured.



Figure 7 – Pictures of *Rua Santa Margarida*

In what concerns the crosswalks (Figure 5), none received the classification of 0 (red color in map) nor 1 (darker green in map). It can be concluded that none of the crosswalks failed in the entire set of evaluation criteria, but also none were totally in accordance with the standards.

As the global index of compliance is a weighted linear combination of groups of criteria, the map of this index did not reveal any segment of the network with maximum score (equal to 1). For this reason, it can be concluded that there are no segments of the network in full compliance with the standards defined in law DL 163/2006.

6. GENERAL CONCLUSIONS

The proposed model is based on criteria extracted from the analysis of the Portuguese law DL 163/2006. For testing the model, a case study was applied, consisting of a pedestrian circulation network selected in the city of Braga, Portugal. This selection was made in order to encompass streets that were built or reconstructed before and after the implementation of this law. The model implementation and the case study analysis were conducted in a GIS platform. This integration was performed with the aim of taking advantage of the GIS edition and analysis toolset, as well as its graphical display capabilities.

Maps for several groups of criteria were generated, showing the level of compliance of the network segments. From the analysis of the results, segments can be pointed out as performing positively or negatively. The same work was developed also for the global index of compliance (combination of the whole set of criteria). This model can be useful for city managers to identify which parts of the city do not yet meet the legal requirements. It is also advantageous to verify whether new projects will implement solutions in compliance with the standards defined in the Portuguese law. When the global index reveals an incomplete compliance, it is also easier to find which group or groups of criteria need to be improved. This analysis is possible since a map for each group, subgroup or even for each criterion can be generated.

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