Circulation environment in urban spaces for pedestrians with mobility constraints: A case study in Braga, Portugal

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Abstract: Mobility is pointed as a key issue to urban planners and managers. In particular the case of pedestrians with mobility constraints implies considering specific parameters. The goal of the present work is to analyse factors that limit the circulation of people with mobility constraints and to map those conditions in central urban spaces. Taking into account only the physical characteristics of urban spaces, the assessment is performed in agreement with the standards specified in the Portuguese Law. A multi-criteria model was developed to evaluate the compliance of urban spaces with those standards. Its integration within a GIS platform was performed in order to implement a spatial analysis of the results. A case study was conducted in a central area of the city of Braga, Portugal. Maps showing levels of compliance with the standards were produced and the results were discussed.

Key-Words: Urban Planning, Planning Support Systems, Pedestrian Mobility, Circulation Map

1 Introduction

Zegeer *et al.*[1] referred that "People walk for many reasons: to go to a neighbour'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." However, the necessary conditions to turn walking into a pleasant and safe experience are sometimes forgotten. Tight *et al.* [2] 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. The disregard for the conditions of the walking environment happened also because when transportation planning began, the main goal was to achieve a fast increase of use of the automobile. In this context, a scale issue emerged because most transportation projects models movement patterns was only applicable at higher scales than those used for the walking level studies [3].

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 of impaired people. For those people, several obstacles become barriers which cannot be overtaken and thus significantly decrease their level of mobility. Despite the importance of this theme, the impact of the built environment on pedestrian mobility is an underdeveloped issue [4].

In Portugal, the authors of the Decree–Law 163/2006 [5], in short DL163/2006, state that the promotion of accessibility constitutes a basic element in people's quality of life, being an essential way for exercising the rights that are given to any member of a democratic society, contributing decisively to a bigger reinforcement of the social relationships, for a wider civic participation, and consequently, for a growing deepening of the solidarity in the social State where the rule of law prevails. They refer also that it is crucial to guarantee and protect the rights of persons with special necessities. Those persons are confronted with environmental barriers that block their possibilities of having an active and integral civic participation.

In this context, the present work proposes 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 pedestrians with mobility constraints. Furthermore, the study focuses on the physical characteristics of walking spaces in a global perspective, and does not

analyse 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 adopted classification highlights qualities and weaknesses 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, [5], 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.

2 Methodology

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 mobility conditions 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 was the analysis of the Portuguese Law DL163/2006 (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 [6]. 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 were 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 is listed in Table 1. The groups and subgroups are detailed as described by Rodrigues *et al.* [7]. Since 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.

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

Group	Subgroup
Public areas: Sidewalks and walkways	Accessible route Sidewalks and other pedestrian walkways 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

Subsequently, the index to classify the compliance of the urban space 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 were gathered. Table 2 shows those values for the criteria of the subgroup "sidewalks and other pedestrian walkways".
The selected criteria are in some cases specific and cannot be globally applied to the network segments: for instance, levelled crosswalk criteria are not applicable to underground pedestrian passages. Furthermore, the number of criteria to be considered

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for a subgroup can also vary according to the existence or not of some elements.

Table 2: Classification of sidewalks and other pedestrian walkways

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

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

$$CIS_s = \sum_i w_{is} \times c_{is} \quad (1)$$

where:

CIS_s: compliance index of subgroup s
w_{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

In equation (1), it can be seen that a weight is applied to each criterion defining their relevance to the whole subgroup index. Specifically for this study, an equal contribution of the criteria to the subgroup compliance index was adopted. As such, Equation (1) can be classified as a Weighted Linear Combination (to an extensive description, see Weighted Linear Combination in [8]).
In order to assign equal weights to each criterion of a subgroup, the following formula was used:

$$w = 1/n_s \quad (2)$$

where:

w_{is}: weight of the criterion 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).

Then Equation (3) is applied to obtain each group index.

$$CIG_g = \sum_j ws_j \times CIS_j \quad (3)$$

where:

CIG_g: compliance index of group g
ws_j: weight of subgroup j
CIS_j: compliance index of subgroup j

Finally, Equation (4) is used to combine all group indexes to obtain the global compliance index for each segments of the network:

$$GCI = \sum_j w_j \times IC_j \quad (4)$$

where:

GCI: Final Compliance Index
w_j: weight of group j
g_j: compliance index of group j

3 Results

The methodology presented in the previous section was implemented and tested on a case study in some streets of the city of Braga, Portugal. The study area is inserted in the urban perimeter of Braga, in the boroughs of S. Vicente, S.Victor, S. João do Souto and S. Lázaro. It was chosen for the fulfillment of some requirements that were considered important to validate the study: the continuity between areas allows defining networks which interconnect locations; and the date of construction/rehabilitation of the streets makes it possible to analyse the practices before and after the DL163/2006.
Taking in consideration these standards, the chosen network interconnects the area of the Municipal Cemetery (post DL163/2006), *Santa Margarida Street* (pre DL163/2006), *Avenida Central* (pre DL163/2006) and *Avenida da Liberdade* (pre DL163/2006 and partially rehabilitated in 2009).
After defining the study area, 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.

With data collection concluded and stored, the calculation process was initiated. The first operation was to apply the normalization. As the criteria values are expressed in different ranges of values and different units, this is a crucial stage to achieve a compliance index. 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. To illustrate this process, Figure 1 shows the compliance map for the criterion of ramp slope of sidewalks and pedestrian walkways. Three colors were used for better understanding the map: green to show when the criterion is respected (normalized value is 1), red when the standards are not complied with (normalized value is 0), and yellow to indicate when the criterion is not applicable (no value).

An equal contribution of each criterion was adopted to the subgroup compliance index. Equation (1), referred in section 2, was used to aggregate the criteria and to obtain an index. Then, the compliance indexes for crosswalks and sidewalks were obtained combining all the subgroup indexes of each group, using Equation (3) and considering only the applicable criteria.

Figure 2 shows the map illustrating the obtained index for the sidewalks group and Figure 3 for the crosswalks group. Six colors are now present, as shown in the legend: red when any of the criteria is fulfilled, orange when the index have a classification between 0 and 0.25, light orange when classification is 0.25 to 0.50, yellow are values from 0.50 to 0.75, light green for values between 0.75 and 1, and dark green when all criteria are respected, resulting in the value of 1.

To conclude, a final map showing the global index of compliance with DL163/2006 was generated joining the maps of both groups. Figure 4 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 4).

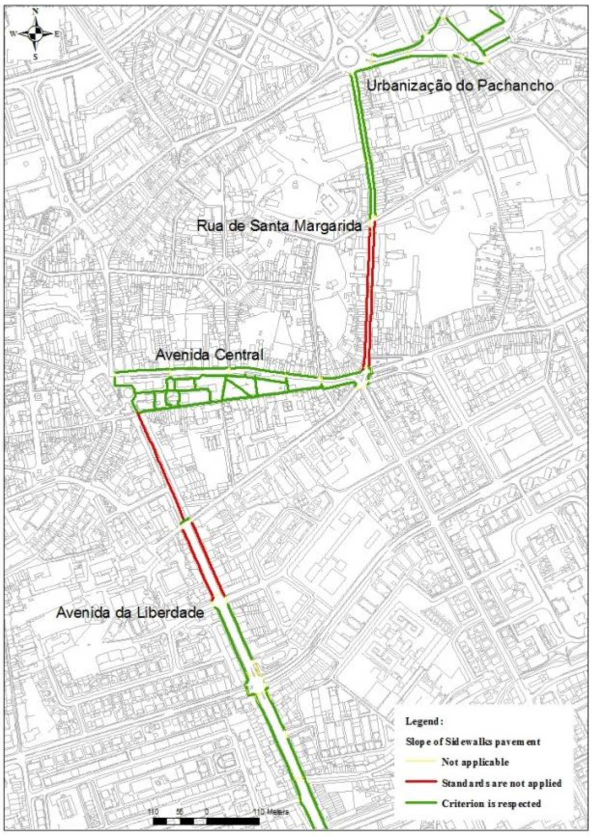

Figure 1 Compliance map for ramp slope of sidewalks and pedestrian walkways

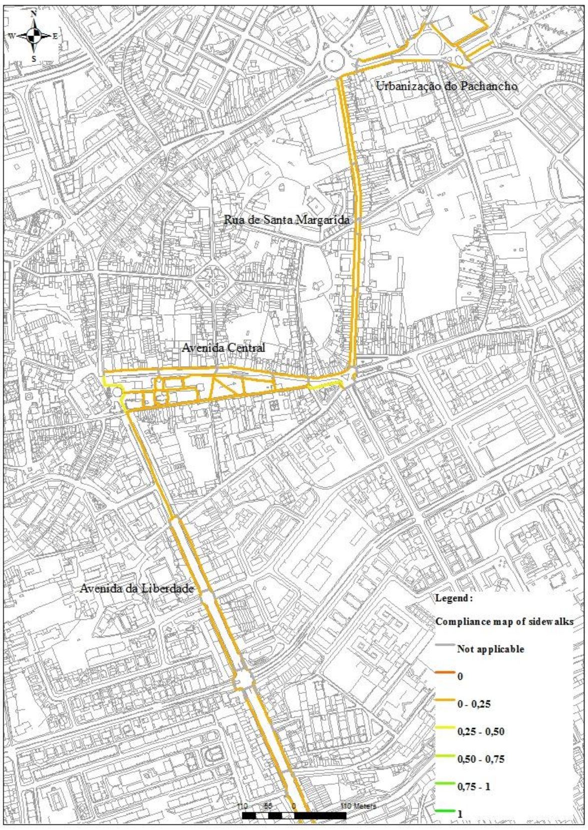

Figure 2 Compliance map for sidewalks

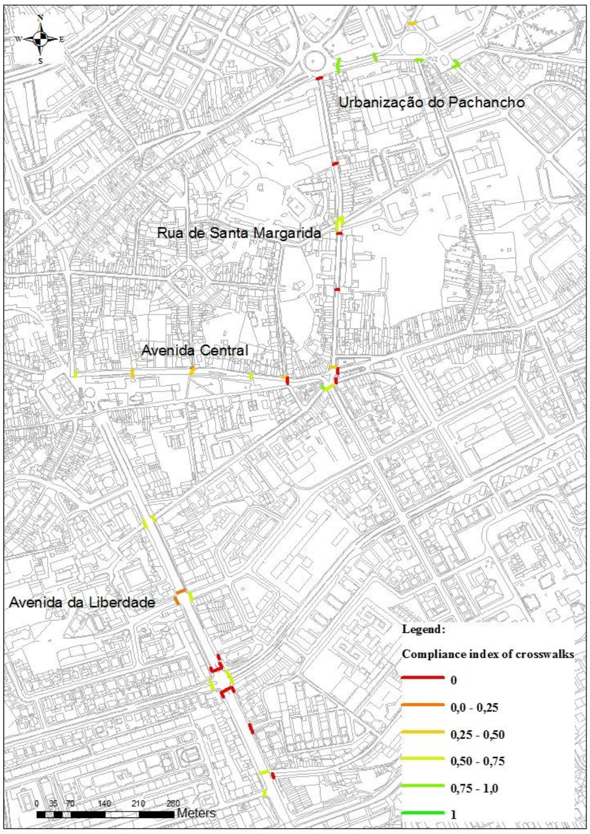

Figure 3 Compliance map for crosswalks

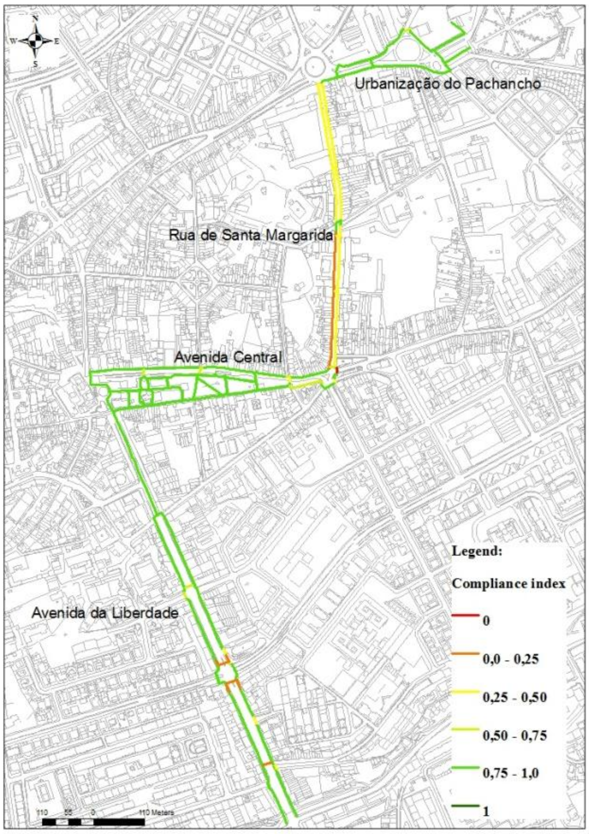

Figure 4 - Compliance index map

4 Discussion

With the goal of evaluating the compliance of urban spaces with the standards defined by law DL163/2006, the proposed model was applied to several streets of Braga, Portugal.

Observing the map for the ramp slope of sidewalks and pedestrian walkways (Figure 1), 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. The poor performance of the *Rua Santa Margarida* can be partially explained by its strong slope and by the lack of interventions to enhance street conditions, as it can be seen in Figure 5.

(a)

(b)

Figure 5 – Pictures of *Rua Santa Margarida*

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In what concerns the crosswalks (Figure 3), none received the classification of 0 (red colour 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 was 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 DL163/2006.

5 Conclusions

Using the Portuguese law DL163/2006 as framework, a set of criteria was collected and used as the base of the proposed model. 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. Using maps, i.e. a graphical representation, simplifies the analysis of the global index to find where compliance is not achieved. In those cases, it is also easier to identify 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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