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COMBINING INTEGRATION WITH WALKING CONDITIONS IN URBAN ROUTES:

Development of a test model

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ABSTRACT

Walking conditioning urban characteristics, hereafter just denominated walking constraints, consist of characteristics of natural and built environment that are inherently relevant to pedestrian routing decision making (e.g., stairs, street crossings, and slopes). Beyond these constraints, space syntax provides high level spatial metrics, such as integration, which has been related to pedestrian motivations (Penn et al., 1998; Lerman et al., 2014; Koohsari et al., 2016), and so may contribute to improve current route generation. We believe much can be done concerning route generation in order to promote walking, especially through improvement on underlying geographical data, and on adaption to pedestrian motivations. Space syntax findings concerning pedestrian motivations should start to be considered in the latter improvement point.

With the previous preamble in mind, we have developed a model for a routing tool that supports (1) parameterization based on walking constraints and integration, (2) generation of alternative routes, and (3) comparison of alternative routes in terms of time, energy expenditure, and integration. We report here the development and implementation of that model, including (1) gathering and processing data using a GIS software (pedestrian footpaths and crossings, digital terrain model, walking speed and physical effort, footpath shading, and integration measurements), and (2) generating the pedestrian routes. We show the model in action in two case studies for two areas in the city of Lisbon, and compare results with well-known route generation tools (route generators).

KEYWORDS

Active Living, Healthy City, Pedestrian Route Generation, Urban Walking Conditions

1. INTRODUCTION

Current route generators already provide help for pedestrians regarding time estimating and rudimentary route finding, similarly to what is offered for car travelling. However, much needs to be done in order to take full potential of urban georeferenced data and to provide proper help for using the city by walking. Taking the example of cars, the introduction of traffic information was a recent improvement in route planning. However, in the case of pedestrians' route planning, routes matter more than just the time to be travelled. Each person has varying personal motivations and physical conditions, paths include different walking constraints, and there are more or less dynamic walking influencing factors related to weather and land use. As a contribute in this direction, the model we bring here considers walking constraints, sun exposition, and integration.

Our model has a main geographical data layer corresponding to a network of segments, where each of these represent a path part with a set of attributes, such as slope, speed, length, shading, and integration values. The model allows time, oxygen consumption, and energy expenditure calculations and generates pedestrian routes according to any of these attributes and results. Most of this information can also added as map layers.

We divide the rest of the paper in four sections. The following section contains the theoretical background, with important concepts and previous works encountered on route generation and related areas. Afterwards, we explain the model and its construction in the third section. In the fourth section we present two case studies that demonstrate the functionality of the model. Finally, we make some considerations about the success here reported in using the last development stage of our model (which includes the use of integration), and the motivation for improving it in the future.

2. BACKGROUND

Active design aims for principles of intervention at city scale that promote health-related physical activity through non-intrusive and intuitive solutions. For instance, focusing on daily walking routines and active transportation (Badland and Schofield, 2005; Sallis et al., 2004). Gomez et al. (2010) analysed various districts and their socio-economic status, slopes, proximity to the transport system and the percentage of area dedicated to public parks. Among other findings, a negative relationship between slopes higher than 4% and regular physical activity was found. Slope corresponds to a walking constraint that should be considered by route generators.

There are several route generators that offer directions for walkers who want to take a trip from one specific location to another (Bing Maps, 2015; Google Maps, 2017; OpenRouteService, 2015; OpenStreetMap, 2015; Wheelchair routing, 2015; Yahoo Maps, 2015). However, these applications, besides leaving out walking constraints, such as slopes, miss footpaths that can be hiked, like parks and gardens. The quality of geographical data used in these applications is crucial for the adequacy of routes. However, this data is typically based on motorized and not on pedestrian travel. It has been detected that this limitation translates into very different results in various kinds of analysis (Chin et al., 2008). Notably, WheelchairRouting (2015) is an application that provides accessible paths for wheelchair users by identifying obstacles and showing the slopes.

KESUE project developed a network model, going from one model based on roads' centre lines to a model based on sidewalks, crosswalks and all existing footpaths in the studied region (Ellis et al., 2013). In another work (Gonçalves et al., 2015), rules were created for digitizing all footpaths, including informal pedestrian crossing, thus helping to streamline and standardize the creation process of network models. This work also developed an evaluation procedure for walkability, i.e. the measure or ability to perform pedestrian travel (McCormack and Shiell, 2011), using the slopes and a quantitative and qualitative assessment of the constraints of the footpaths. Frank et al. (2005) used pedometers to measure physical activity and have positively related the results to several urban metrics, which were translated into a walkability index.

A route generator has to consider reference values of walking speed. For instance, we use Tobler's hiking equation (1), which receives the slope angle S (in degrees) and returns the speed W (in km/h) (Tobler, 1993). In this case, no slope will correspond to a speed of 1.4m/s.

$$W=6e^{(-3.5|S+0.05|)} \quad (1)$$

More authors have worked on determining reference walking speed. Fruin (1987) considers an average walking speed of 1.36m/s. This author further mentions that speed on stairs depends on the dimensions of the risers and treads, that the average speed of climbing is about one third of walking speed without any slope, and that down stairs speed increases by 10%.

Considering reference walking speed in road crossing, Faria et al. (2010), who compared short urban travels in several means of transportation, also included pedestrian, and measured several waiting times for signalized pedestrian crossings, zebra pedestrian crossings and informal crossings. They concluded that a unique waiting time of 10.9 seconds should be used in any signalized crossing, and zero seconds in zebra and informal crossings; without mentioning the walking starting time or the time used to check crossing's safety. The Transportation Research Board (2000) considers that a starting time of three seconds is reasonable to calculate pedestrian crossing. For this purpose, we also found that local authorities do not store the green and waiting times for the signalized crossings and that the majority of these times are dynamic.

The best found estimates of energy expenditure need data that our model does not have. Yamazaki et al. (2009) developed equations that calculate energy expenditure based on accumulated acceleration, which allow to estimate values very close to those obtained experimentally, and published a table with measurements for energy expenditure and oxygen consumption, combining different values of speed (rest, slow, moderate, fast and very fast) and slope (positive and negative), which we have used.

It is possible to estimate the oxygen consumption, which allows the calculation of calorie expenditure (American College of Sports Medicine, 2013), in terms of speed, slope, or both. Several equations and the corresponding graphs were evaluated before the choice of the equation to be used in the model (Luta, 2016). This equation was estimated (with interpolation) using the mentioned findings of Yamazaki et al. (2009).

3. MODEL

This section is divided in three subsections: (1) building - describing how the model was created, (2) measuring and using – showing the first layer of model data and explaining how the model can be used to generate routes, and (3) testing – reporting how a set of tests were carried out.

3.1 BUILDING

Having access to a previously developed model of a pedestrian travel network (Gonçalves et al., 2015), we started from it and added several characterization aspects to the already digitized footpaths using a GIS application. For each segment, the walking speed was calculated according to the slope, using Tobler's equation. Additionally, the speed for walking up and down stairs was calculated following Fruin's work.

The slope of each segment is calculated using only the start and ending points, so we divided it into smaller segments looking for the right granularity for the network. To identify the elevation of each segment of the network, which was necessary to calculate the slope and walking speed, a Digital Terrain Model (DTM) was necessary. If it had insufficient spatial resolution it could result in too many small segments with no slope. Additionally, segments too close to the DTM's cell limits could end up with an incorrect slope. At the end, a new DTM was created with one meter resolution, 100 times bigger than the initially available DTM.

Accordingly with previously related works, we considered that the pedestrian stops at the beginning of each informal and zebra crossing, resuming the march immediately with no waiting time, being only considered the starting time of three seconds according to the best references found.

Almost all the signalized intersections in Lisbon have some degree of dynamic adaptation of the green time, and therefore both the average green time for every crosswalk and the temporal relationship between them are unknown. Several crossings are divided in segments and as a result it is not possible to know which pedestrian walking speeds allow the crossing of a given number of segments in one go. Therefore, we are unable to identify the situations where there may exist several stops on a crossing. Without a correct way to characterize the signalized crosswalks, these were treated as the remaining crossings – three-second penalty, the pedestrian start time.

Another option included in the model is the choice of routes depending on the shade of footpaths. To be able to identify footpaths exposed to the sun or the shade it was first necessary to create the volumes that represent the shading of the buildings. These buildings were modelled using the map data used in the DTM creation. Due to the nature of this data, the model ignores walls and simplifies the buildings, not including archways and cantilevered elements. Because of their inherent complexity the plants and street furniture elements were ignored. To represent summer and winter, the hottest day and the coldest day recorded for the city of Lisbon were chosen, respectively, which are the extreme days to consider the motivation for each criteria – avoiding shaded or in the Sun footpaths. The winter shading volumes were created for five moments of the day: 9h00, 11h00, 13h00, 15h00 and 17h00. For summer six volumes were created, being represented in addition the 19h00 moment. Being created the various representative volumes of shading, the footpaths were identified as fully shaded, partially shaded or not shaded.

To add integration to the model, axial lines were used in DepthMap to create a segment analysis which used the following radius: n, 1200m, 800m and 400m. The segments and its values were imported into the GIS application and were associated with the built pedestrian networks using angle and distance spatial relations. For comparisons between paths these values were weighted with the length of each segment. The route creation is solved by the Dijkstra's algorithm through the ArcGIS software. To enable using integration as an impedance cost, these values were inversed, weighted and stored in new fields.

In order to generate the pedestrian routes (PR) it's necessary to create the network database. The various footpaths were added and from its stored values the model impedance costs were selected and created. In this model a PR may be generated according to distance, oxygen consumption, time ignoring slopes, time considering the slopes, time considering the slopes and stairs or integration. Any value that is not used as the impedance cost can be calculated and stored. This allows knowing the oxygen consumption in a PR generated according to time, for example. Other fields were also added to the model as restrictions and descriptors. These identify the footpaths as stairs, their slope and their shade state for every modeled moment. Finally, with the footpaths identified as pedestrian crossings, midpoints for each were created and added to the model as added cost points.

3.2 MEASURING AND USING

After being fully characterized, the pedestrian network had a segment average length of 7.79 meters with a standard deviation of 2.52 meters, in a total of 21393 segments which together measure 166693 meters. For each calculated field we stored two values, one in each direction of the footpath. Therefore it is possible to calculate all results in both directions, which is essential to identify the effect of slopes in pedestrian walking.

The network of footpaths has an average slope of its segments of 4.60%. Given that the various segments that compose this network have different lengths, performing a weighted average gave the average slope of the network: 4.53%. In figure 1 is visible the full pedestrian network with the footpaths spread over different slope ranges. In table 1 the number of segments, the total length of footpaths and the percentages for each slope range are visible. An interesting fact to take from this table is that 83.4% of the study area has slopes under 8%, a figure relevant to the study of some user groups with reduced mobility.

Figure 1 - Footpaths' slope [%]

Slope [%]	Number of segments	Length [m]	%	Accumulated %
0-2	7627	59580	36%	36%
2-4	4821	37861	23%	58%
4-6	3157	24720	15%	73%
6-8	2105	16835	10%	83%
8-10	1311	10252	6%	90%
10-12	852	6499	4%	93%
12-15	652	4846	3%	96%
15-20	422	3073	2%	98%
20-30	186	1219	1%	99%
>30	34	218	0%	99%
Stairs	226	1590	1%	100%

Table 1 - Footpaths' slope

Knowing if the footpaths are shaded allowed us to create another analysis of the network. As mentioned above, the partially and fully shaded footpaths were identified. Partially shaded footpaths were all treated the same, not being detailed the percentage of shade and sun. The study area with modelled shading is limited to the north by Avenida Elias Garcia and Avenida António José de Almeida, to the west by Rua Marquês Sá da Bandeira, to the south by Rua Tomás Ribeiro, Rua Almirante Barroso and Rua Pascoal de Melo, and the east by the Avenida Almirante Reis. It has 6120 segments which together measure 49017 meters. The segments have an average slope of 3.09% and the network 3.14%. In table 2 the length and percentage of fully shaded, partially shaded or not shaded footpaths for the several modelled moments are shown.

	Fully Shaded		Partially Shaded		In the Sun	
	Length [m]	%	Length [m]	%	Length [m]	%
			Winter			
09h	9520	19%	35888	73%	3609	7%
11h	29024	59%	7630	16%	12363	25%
13h	23559	48%	9526	19%	15933	33%
15h	32911	67%	6837	14%	9269	19%
17h	46756	95%	1135	2%	1127	2%
			Summer			
09h	23997	49%	8692	18%	16328	33%
11h	15644	32%	8044	16%	25330	52%
13h	9498	19%	8369	17%	31151	64%
15h	11601	24%	7144	15%	30272	62%
17h	15675	32%	8754	18%	24588	50%
19h	30266	62%	7581	15%	11171	23%

Table 2 - Shaded footpaths

In order to generate routes, at least two locations must be added, representing the starting point and destination. One of the created impedance costs must be selected to generate the route, the remaining ones can be selected as accumulation attributes which help characterize the route: length, time ignoring slope effect, time with slope effect, time with slope and stairs effects, oxygen consumption (and therefore calories consumption), weighted integration and inversed weighted integration.

In addition, any combination of the restrictions can be used as prohibited, avoided or preferred, further specifying the degree in which they are avoided or preferred: stairs, informal pedestrian crossings, slopes (choosing the breakpoint), Sun and shading (from any of the modeled moments). To remove or add the penalty for each pedestrian crossing, the added cost points need to be removed or added, respectively.

Being implemented in ArcGIS, each model generated route can be saved and stored with all resulting values.

3.3 TESTING

Three different sets of tests were carried out as a proof of concept of how the model should be validated in the future.

For several routes the final walking time (considering slope and stair effects and adding pedestrian crossing's penalties) was compared with Google Maps' (2017) walking time. From

all routes generated in the case studies showed in the results section, 20 unique ones were identified and recreated in Google Maps (2017), using when necessary additional destinations to force the route's geometry. Five routes were unable to be reproduced because of the absence of Av. Praia da Vitória at the time. With a sample of 15 routes the average difference between the model and Google Maps (2017) is 35s or 3.89% with a standard deviation of 24s or 2.23%.

The model's energy consumption results were compared with the results of two different commercial solutions, Samsung Gear Fit smartwatch and MapMyWalk (2017) fitness tracking application. Eight different routes (four in both directions) were measured 22 times with either solution. The tracking application often had discrepant results which were not used whenever the route was measured having more than 20% of its supposed length. In the end 15 measurements were used and compared giving an average difference of 8kcal or 13.29% and a standard deviation of 8kcal or 12.54%.

To compare the shading measures no other model or application was found, and therefore the model results were compared on site. For this purpose, the shading was modeled for five moments of a new day: 10h00, 12h00, 14h00, 16h00 and 18h00. A 30min route starting 15min before each of the five moments visited 14 locations (selected with the goal of having different street directions and width), and in each one the shading was compared to what was expected in the model for that specific day. From the 70 locations, 14 were unable to be compared due to bad weather conditions, 12 had to be compared from predicting the shading by watching the Sun position behind the clouds and 44 were easily compared. The results were mostly positive with 54 locations having in the Sun or shaded pedestrian paths similar to the model results, and only two locations where the same cannot be said. In the latter both sides of the street were expected to be in the Sun but were not, this can easily be explained by a combination of three factors: the pedestrian travel network used as base for the model was previously developed and didn't specify the distance between the segments that represent the sidewalks and the buildings; the time period where a street with high buildings has both sidewalks without any considerable shading is short and can easily be missed; and the used software doesn't specify how it adjusts for Daylight Savings Time.

4. RESULTS

The first case study has routes between one of the entrances of the Alameda subway station and the Civil Pavilion entrance at Instituto Superior Técnico (IST).

The first route was created ignoring slope effect on walking speed. The second route considered the slope effect, and the third route considered slope and stair effects. To calculate the fourth route, pedestrian crossings were added, with the correspondent time penalty, on top of the effects for the third route. This is the first route using all effects and all following routes in the case studies will only consider these complete application. The previous (building up) routes provide some insights about the incremental use of these effects.

To demonstrate other slope consequences, first a route was created in which the starting point and destination are reversed, and second, routes where stairs are prohibited and slopes higher than 8% are penalized - with moderate penalties (value 2) and with high penalties (value 5). If instead of adding penalties these slopes are prohibited the model cannot find a route. If instead, slopes higher than 9% are prohibited a solution is found. The table 3 and figure 2 summarize these routes. For each one is shown, not only the distance and time, but also the oxygen and energy expenditure calculated by the model.

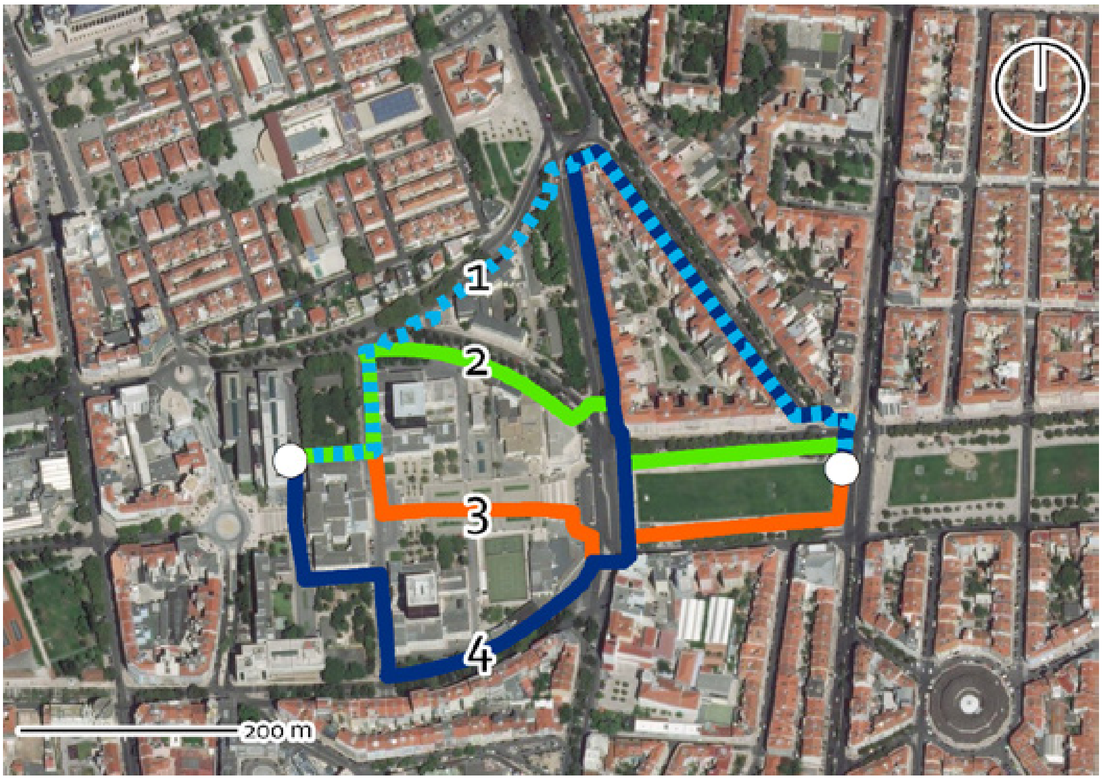

Figure 2 - Pedestrian routes between Alameda and IST

Route	Description	Length [m]	Time [s]	VO2 [ml/kg]	Energy [kcal]	Figure (Route)
Alameda - IST	Ignoring slopes	658	470	--	--	2 (1)
Alameda - IST	Factoring slopes	658	575	154	54	2 (1)
Alameda - IST	Factoring slopes and stairs	700	595	153	54	2 (2)
Alameda - IST	Factoring slopes, stairs and crossings (SSC)	700	610	153	54	2 (2)
IST - Alameda	Factoring slopes, stairs and crossings (SSC)	700	486	111	39	2 (2)
Alameda - IST	SSC - No stairs, avoid: medium slopes higher than 8	700	610	153	54	2 (2)
Alameda - IST	SSC - No stairs, avoid: high slopes higher than 8	876	738	186	65	2 (3)
Alameda - IST	SSC - No stairs, prohibited slopes higher than 9	1326	1053	269	94	2 (4)

Table 3. Pedestrian routes between Alameda and IST

The fastest route created by Google Maps (2017) is not given as a solution in our model. This route uses informal pedestrian crossings which are not modeled, since not only they would be too close to existing pedestrian crossings, but can also be considered dangerous. Google Maps' second fastest route created has the same geometry, distance and time as the fourth route created by our model. Both can be seen in figure 3, in blue the former and in grey the latter.

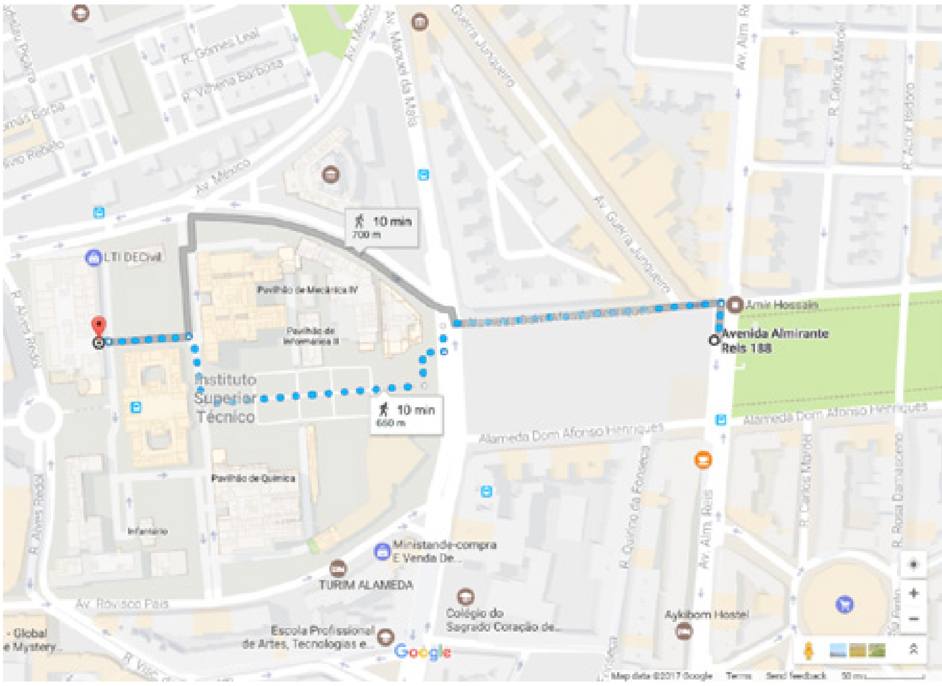

Figure 3 - Routes created by Google Maps (20017)

In the second case study, several routes were created - between Avenida Conde Valbom and Jardim Cesário Verde - using as restrictions the Sun and shading of the several modeled moments described in the previous chapter. In addition to the metrics shown in the first case study, the integration is also shown. The first route (figure 4) is created considering the slope, stair, and pedestrian crossings effects and is used to benchmark the remaining routes. This route has the same length and time as the solution given by Google Maps (2017): 15min and 1.2km. The 1200m value for the integration radius is chosen due to its proximity to the length of this route. Each route's integration is calculated as a weighted average of integrations of all included footpaths.

Figure 4 - Pedestrian route between Avenida Conde Valbom and Jardim Cesário Verde

For summer routes the footpaths with no shade were moderately avoided having a value of penalty 2, meaning that each footpath was accounted with a double impedance cost - but the returned costs are correct. The footpaths partially shaded have a lighter penalty valued 1.3 and the fully shaded paths are not penalized. In winter routes this logic is reversed, and the fully shaded footpaths are penalized. To simulate situations where the Sun in summer, and the shade in winter want to be avoided at higher costs, some routes were created with penalties increase - from 1.3 to 2 and 2 to 5, respectively. Figures 5 and 6 show routes in winter and figures 7 to 9 routes in summer, in each figure the pedestrian paths are coloured according to its shading properties.

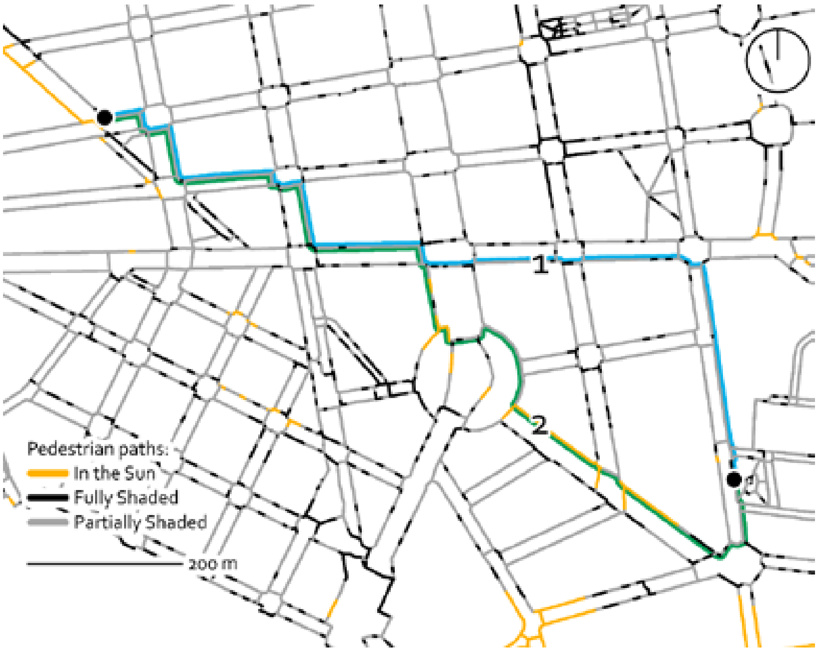

Figure 5 - Pedestrian routes for Winter 09h

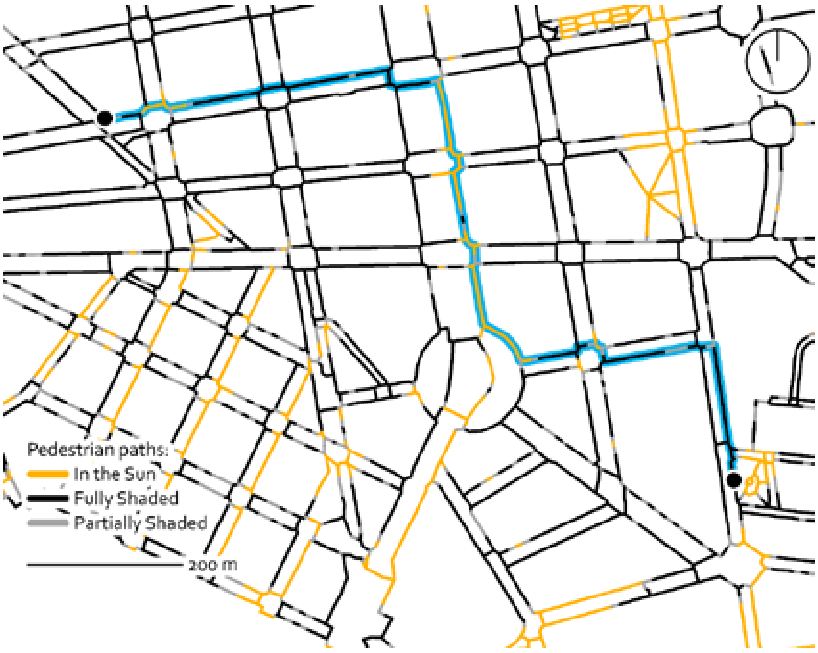

Figure 6 - Pedestrian route for Winter 15h

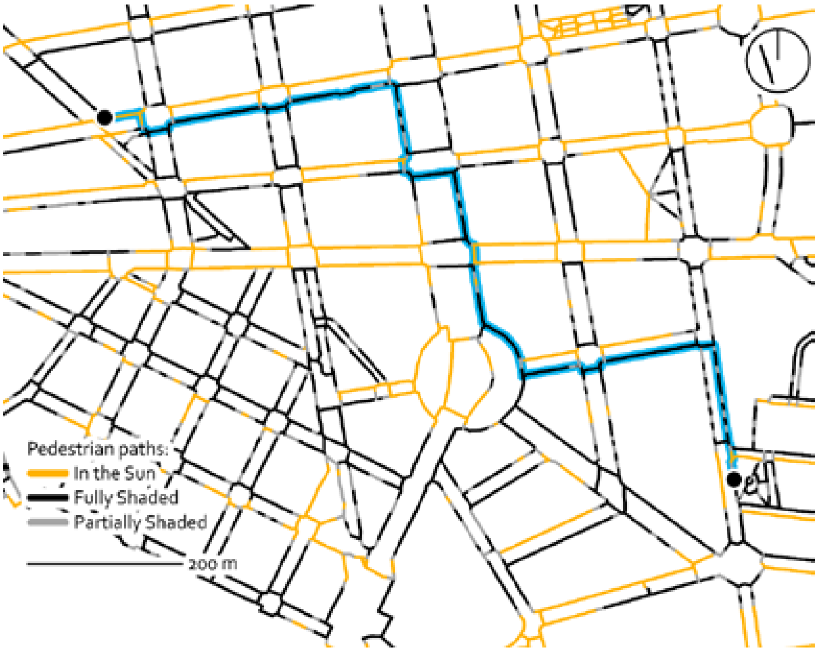

Figure 7 - Pedestrian route for Summer 09h

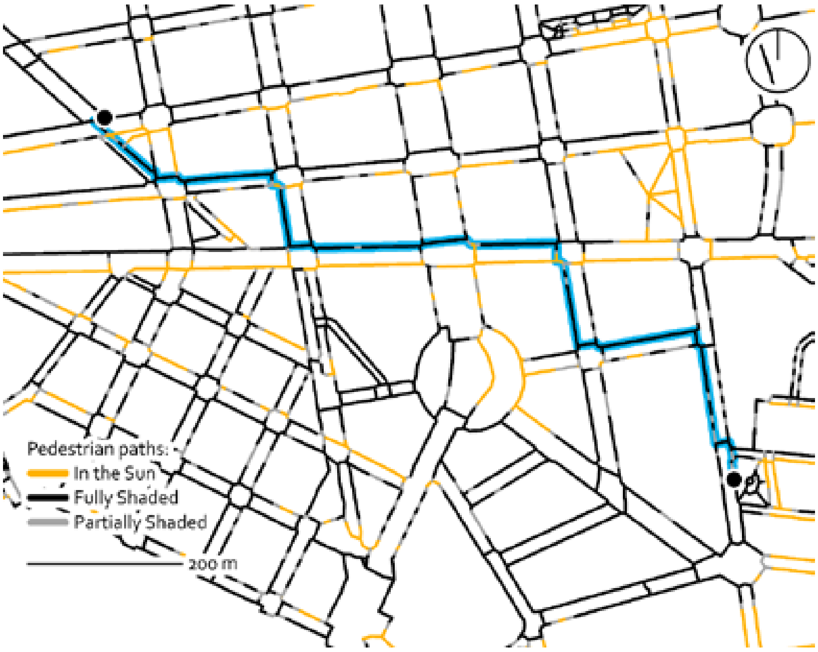

Figure 8 - Pedestrian route for Summer 13h

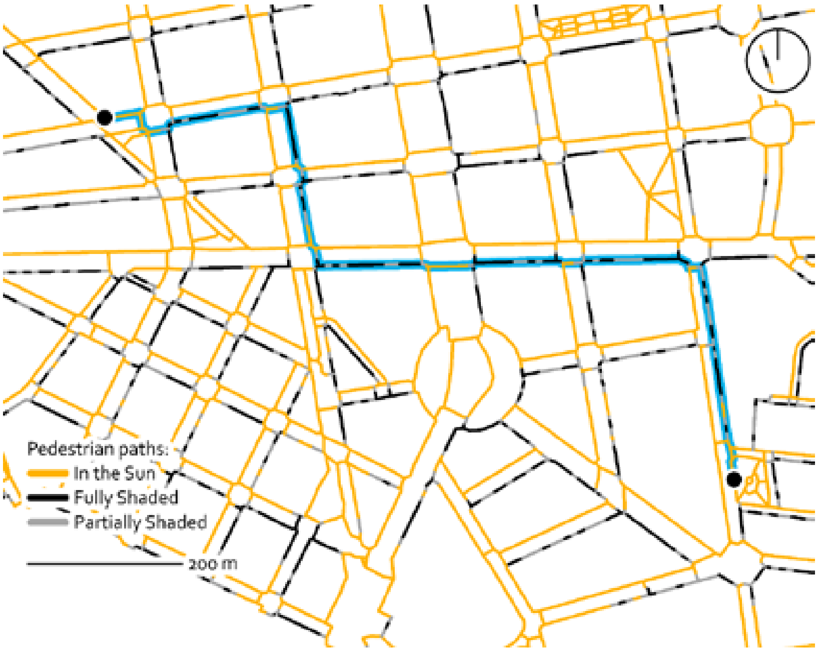

Figure 9 - Pedestrian route for Summer 19h

Figure 10 - Pedestrian routes based in Integration values

The integration was used to generate routes (figure 10). The table 4 summarizes all routes for this case study. In this table, we can notice that the higher integrated route does not correspond to the highest value in the average integration column. To create this route the algorithm finds the lowest total cost route using the selected impedance - the weighted inverted integration value (WII) – and not the lowest average cost. For the lower integrated route the weighted integration value is used.

Starting point	Description	Length [m]	Time [s]	VO2 [ml/kg]	Energy [kcal]	Average Integration	WII	Figure (Route)
Av. Conde Valbom	SSC	1185	896	219	76	397	3,12	4
Jardim Cesário Verde	SSC	1185	909	223	78	397	3,12	4
Av. Conde Valbom	Winter 09h	1213	914	224	78	396	3,20	5 (1)
Av. Conde Valbom	Winter 09h - Higher penalties	1312	1008	243	85	362	3,70	5 (2)
Av. Conde Valbom	Winter 11h	1232	946	228	80	363	3,49	--
Av. Conde Valbom	Winter 13h	1205	920	222	78	370	3,34	--
Av. Conde Valbom	Winter 15h	1295	984	241	84	383	3,42	6
Av. Conde Valbom	Winter 17h	1185	896	219	76	397	3,12	--
Av. Conde Valbom	Summer 09h	1303	990	242	85	378	3,50	7
Av. Conde Valbom	Summer 11h	1229	930	228	80	385	3,33	--
Av. Conde Valbom	Summer 13h	1242	934	229	80	404	3,17	8
Av. Conde Valbom	Summer 15h	1223	927	225	79	396	3,17	--
Av. Conde Valbom	Summer 17h	1217	917	225	79	395	3,22	--
Av. Conde Valbom	Summer 19h	1235	942	228	80	375	3,40	9
Av. Conde Valbom	Most Integrated	1214	941	224	78	402	3,08	10 (1)
Av. Conde Valbom	Least Integrated	1265	1009	232	81	338	3,85	10 (2)

Table 4 - Pedestrian routes between Avenida Conde Valbom and Jardim Cesário Verde

5. CONCLUSIONS

The main achievement of this work is the use of integration in a route generation process. Our model aims the generation and comparison of routes, providing also the parameterization of the generation process, as well as the comparison of the generated alternative routes. Previously to this work, we have included footpaths' slopes, stairs, pedestrian crossings, and shading as variables of parameterization; including also time, distance and physical effort as variables for the comparison. Now, with the work here reported, we are convinced that integration may improve models such as ours in every stage: parameterization, generation and comparison of routes. In the studied cases, new routes were achieved meeting integration based metrics, validating the ability of the model to adapt to new pedestrian motivations.

The presence of shaded and non-shaded footpaths and its use brought relevant results allowing the users to choose either type of footpaths and encourages the continuation of its development. The signalized crosswalks' characterization should be further developed since they were treated like the remaining crosswalks and may be missing relevant and useful characterization.

Energy expenditure is a crucial metric to inform the pedestrian movements in this research and related areas. It will be important in works like ours to keep up with necessary improvements on results about calculating this metrics based on walking speed and slope. Likewise, space syntax measurements depend on the adequateness and completeness of underlying data, therefore also improvement of quality of geographical data is necessary. We only explored starting ideas and surely integration values can be used in additional and different ways in the route creation algorithm, identifying and testing them should be considered as future work.

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