An Alternative and Smarter Route Planner for Wheelchair Users
Exploring Open Data

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Abstract: In this paper we describe a bottom-up approach to integrate GIS maps (endorsed by discrete features, such as points, lines, polygons), in order to develop a route planner for wheelchair users. We integrate public available data with a novel model for route planning, based on sidewalks, crosswalks and curb ramps, as opposed to traditional street-based approaches. We show that our sidewalk-based model is more suitable than available planning routes under mobility constraints, using a case study in Curitiba, Brazil.

1 INTRODUCTION

Efforts have been made to develop route planning services for people with disabilities (Kulakov et al., 2015; Menkens et al., 2011; Sumida et al., 2012). This is a challenging problem that involves the processing of a huge amount of data, such as maps, images, detailed public transport information and collaborative user feedback, to properly define wheelchair accessible paths. Nevertheless, there is a lack of route planning services (such as the route planner of Google maps[1]) for wheelchair users.

The available solutions for wheelchair users are street-based. Nevertheless, a myriad of complex spatial factors could be considered in order to locate the best routes, such as sidewalks, crosswalks and curb ramps. In many applications, such as geographic information systems (GIS), data can set the stage by displaying individual maps of decision criteria, in order to provide the detailed information needed to locate the best route.

In this paper we are concerned with the routing problem for wheelchair users. The input data for this problem is a set of base map layers (streets, sidewalks and city blocks). The output data is a cost weighted map, which we also present as a graph. The novelty is, taking advantage of open data, to include additional factors (such as distinct sidewalks in a street or missing curb ramps), in order to propose a best route to a wheelchair user. We explore our method using open data from Curitiba, Brazil. The city belongs to the *C40 cities*[2], a group which set ambitious targets to improve urban life quality and protect their environment. The remainder of this paper is organized as follows. Section 2 contains a description of related work. Section 3 presents an overview of our method. Section 4 presents the experiments and, finally, section 5 state the conclusions and future work.

[1]https://maps.google.com Last visited on 01/07/2015.

2 RELATED WORK

Several online libraries and services are already available for route planning (such as Google Directions API[3], the JavaScript API Yandex.Map[4], or other online services[5]). In particular, fewer of them are toward specific functionality, such as wheelchairs (as OpenRouteService[6], Routino[7],and OpenTripPlanner[8]). Nevertheless, some of the online libraries also present acessibility problems (Medina et al., 2015).

There are norms for urban environments that define accessibility specifications as DIN 18024-1 (Ger-

[2]http://www.c40.org Last visited on 30/05/2015.

[3]https://developers.google.com/maps/documentation/directions/ Last visited on 23/06/2015.

[4]https://tech.yandex.ru/maps/ Last visited on 23/06/2015.

[5]http://wiki.openstreetmap.org/wiki/Routing/online_routers Last visited on 23/06/2015.

[6]http://www.rollstuhlrouting.de/ Last visited on 23/06/2015.

[7]http://www.routino.org/ Last visited on 23/06/2015.

[8]http://www.opentripplanner.org/ Last visited on 23/06/2015.

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man Institute for Standardization , 1998) from Germany and ABNT NBR 9050:2004 (ABNT (Brazilian Association of Technical Standards), 2004) from Brazil. Other studies as Kasemsuppakorn and Karimi (Kasemsuppakorn and Karimi, 2009) investigated the most relevant aspects regarding wheelchair accessibility, for each segment of the route network (i.e. length, width, slope, sidewalk surface, steps, sidewalk conditions and sidewalk traffic). Moreover, some studies consider not only barriers but also provide information about relevant locations (called Points of Interest - POI) as restaurants, bus stops, accessible toilets, and police departments (e.g. Menkens et al. (Menkens et al., 2011), and Wheelmap[9]).

Sumida et al. (Sumida et al., 2012) argues that barriers information should be collected through actual measurement data and adapted an electric wheelchair for collecting data as the force necessary to move the wheelchair and the passage width. Other studies use data provided by the routing service users (e.g. OpenRouteService, and Menkens et al. (Menkens et al., 2011)), volunteers (e.g. OpenRouteService; Menkens et al. (Menkens et al., 2011); Kulakov et al. (Kulakov et al., 2015)), authorities (e.g. Kulakov et al. (Kulakov et al., 2015)). Consequently, the collected data is usually limited to a city or a district. An exception is the Wheelmap project [9] that provides resources for crowd sourcing information based on OpenStreetMap data.

The lack of public available information regarding accessibility of urban spaces (e.g., streets, sidewalks, curbs, and type of surface) contribute to the fact that most of studies on accessible routing are constrained to cities or districts. Some initiatives as Wheelmap explore the aspects of crowds for collecting relevant information regarding POI. Currently, to our knowledge, none of such initiatives are widely adopted in Curitiba (e.g. there are only about 10 POI registered in Wheelmap, most of them are accessible bus stops).

Routing estimation is another challenging task. In order to improve the results of routing estimation, some services provide additional parameters (e.g., maximum inclination, type of surface, maximum curb height [6]), personalized estimation according to the users' profile (e.g. Menkens et al. (Menkens et al., 2011)). As already noted by A. M. Bishop within the Routino application, routing planning can use graph algorithms (e.g. Dijkstra and A*) for calculating the shortest/least-cost path. Some of those studies adapt these algorithms aiming at improving performance in terms of execution time (e.g. the concepts of super-segments and super-nodes from A. M. Bishop [7]). Others claim that there is no clear answer as to shortest path algorithm which runs fastest on real road networks (due to real time computation, the large network size, and the resulting intensive computing) (Zhan, 1997). Among other critical factors for route planning we can mention: (1) types of barriers considered for collecting and estimating routes, (2) data sources for maps information and barriers, and (3) approaches for route planning.

[9]http://wheelmap.org/en. Last Visited 24/08/2015.

3 OUR METHOD

Problem Formulation. For GIS applications, the shortest path based on a road is a basic operation. In practice, however, users are always interested in several constraints (such as the combination of spatial and textual information). From GIS and map analysis perspective, the routing problem can be described as a three steps process: the calculation of discrete cost, accumulated cost and steepest path (Berry, 1993). The idea is, using base maps (such as roads), create other derived maps (to calculate information that is too difficult to collect, such as curb ramps) in order to finally create cost/avoidance maps which translate this information into decision criteria. Within this perspective, map layers are thematic representations of geographic information, as shown in Figure 1. In particular, base maps can be represented by streets, street blocks (Figure 5) and sidewalks, among others.

The derived maps, composed by large polygon subdivisions, are often simplified in order to reduce the total number of vertices which defines it (known as the map simplification problem (Estkowski and Mitchell, 2001)). The calibration of the individual cost maps is an important and sensitive step in the siting process. Since the computer has no idea of the relative preferences this step requires human judgment. As an example, you might be interested in identifying the most preferred route for a wheelchair user that minimizes its visual exposure to huge avenues, and maximizes the visual exposure to bus stops.

From the geometry perspective, streets are one or more single lines (which can also be represented by one ore more edges in a graph), which thereby are composed by points (which can also be represented by a vertice in a graph). Blocks (Figure 5) can be decomposed by the respective lines, and lines can be decomposed by respective points (Figure 6).

Formally, a GIS database contains a set of geometries which can be resumed as a set P of points on a network $G = (V, E)$, where V represents vertices and E represents edges. The network is a directed connected graph. A point $p \in P$ locates on an edge $e \in E$. The distance between any two points (or vertices) can

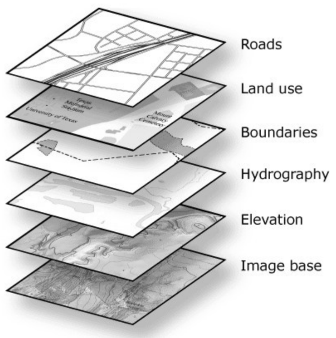

Figure 1: Map Layers[10].

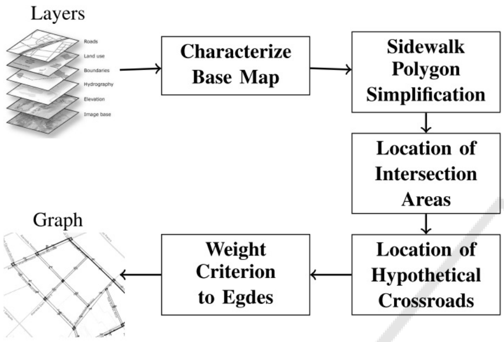

Figure 2: Overview of the proposed system.

be denoted as $d(p_i, p_j)$, as the length of the shortest path connecting them.

Our Approach. Our method comprised the following steps (shown in Figure 2) toward a sidewalk-based model: (1) the base map (streets, sidewalks, blocks, etc.) characterization; (2) the creation of derived map for sidewalk polygon simplification; (3) the creation of derived map for location of intersection areas; (4) the creation of derived map for hypothetical crossroads; (5) the establishment of a weighting criterion to edges (in particular, considering wheelchair users); and (6) the generation of the graph.

For the characterization of the base maps (identified by Figures 5 and 6), external open data were integrated with data from Open Street Map with a spatial database.

The second step started with the simplification of sidewalk polygons and their derived points (performed with a spatial database function named *st_simplify*).

The next derived map comprised the road intersection areas, basically discovering the average distance among streets and sidewalks. Circles in Figure 7 represent this phase, performed with spatial functions, such as *st_buffer*.

The last derived map comprised the hypothetical crossroads, identified by lines, triangles and rectangles inside the road intersection area (circles). Basically this map was derived using spatial database functions such as *st_convexhull* (shown in Figure 3).

The weighting criterion (step 5) was initially set as the distance between points if the ”edge” has no barriers, or infinite if it does. Lately these weights could be modified to register temporal issues, such as constructions which might impact the normal flow of pedestrians. In practice, these distances can be obtained with spatial functions, such as *st_distance*.

```
create table batel_cruzamentos201509 as
select B.gid, st_convexhull(st_collect(K.points))
from (select B.gid, pointsfrompolygon points from batel_simp A,
        batel_raioteste B
       where st_contains(raiogeom, pointsfrompolygon)) K,
       batel_raioteste B
where K.gid=B.gid
group by B.gid
```

Figure 3: Example of SQL query to compute crosswalks.

From the GIS perspective, the shortest path would not be based on the street map, but on the composition of the sidewalk map and on the derived map for the crossroads. Note that: (i) the same sidewalks could have temporally distinct costs (if for example, one sidewalk is next to a construction during the beginning of an year) and (ii) the distinct crossroads geometries could help the identification of most dangerous locations for pedestrians.

4 EXPERIMENTS

We concentrated our efforts in preliminary experimental results, using an ordinary linux server, and exploring spatial database functions. In order to simplify our tests, we explore the shortest path as a graph (step 6), but indeed, there are already ongoing projects (such as pgRouting[11]) which could be used within the spatial database.

Datasets. In particular, we are exploring a case study in Curitiba. Curitiba has 1.8 million people inside a total area of 430,9 km^2, IDH of 0,823, according to the Brazilian Institute of Geography and Statistics (IBGE)[12]. This area encompasses 75 neighborhood districts. According to the same census, Curitiba had in the urban region approximately 95 thousand people with some degree of motor disability. Among them, more than 31 thousand informed to experience,

[10] http://webhelp.esri.com/ Last access on 17/09/2015.

[11] http://pgrouting.org/ Last visited on 23/09/2015.

[12] http://www.ibge.gov.br. Last visited on 14/05/2015.

at least, great difficulty for locomotion. Despite of not providing more detailed information regarding barriers for motor impaired people, the Census revealed that only 12.6% of the urban area of Curitiba presented lowered curbs. Thus, currently, providing effective and efficient route plannings for people with motor disabilities, especially wheelchair users, is potentially relevant for removing barriers to people's daily lives.

For the acquisition/characterization of the base maps, the dataset from the Institute of Research and Urban Planning of Curitiba (IPPUC[13]), along with data from Open Street Map[14] were used. Figure 4 shows the DDL example for the creation of street block table. The complete data set initially included streets (39,948 rows), sidewalks (9,614 rows) and blocks (13,459 rows) from Curitiba. The complete data set was inserted in a PostGIS[15] database. Later, specific tablespaces and indexes were created in order to optimize the access. Nevertheless, several semantic errors were present (such as different street geometries and names - more details in (Barczyszyn, 2015)).The data was visualized with QGIS[16].

```
CREATE TABLE arruamento.arruamento_quadras
(
  gid serial NOT NULL,
  tipo character varying(50),
  shape_area numeric,
  shape_len numeric,
  geom geometry(MultiPolygon,4326),
  CONSTRAINT arruamento_quadras_pkey PRIMARY KEY (gid)
)
WITH (
  OIDS=FALSE
);
```

Figure 4: Example of SQL for street block creation.

Figure 5: Example of Street Blocks.

Tests. For our tests, the three base maps toward the selected area of the Batel district resulted in 51 streets,

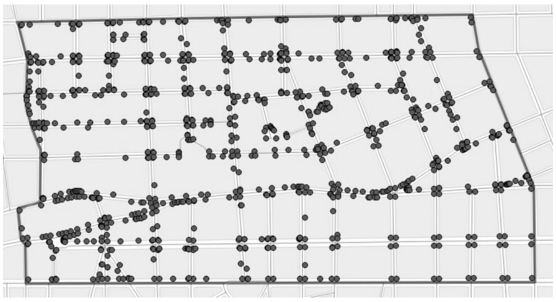

Figure 6: Example of Sidewalk Points.

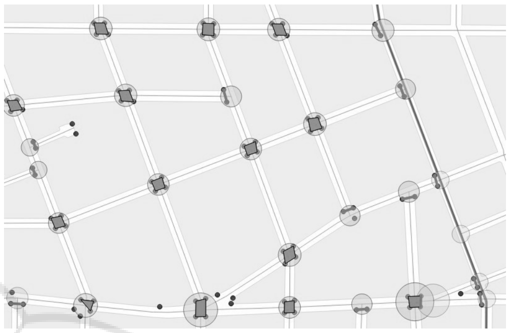

Figure 7: Example of Road Intersection Areas.

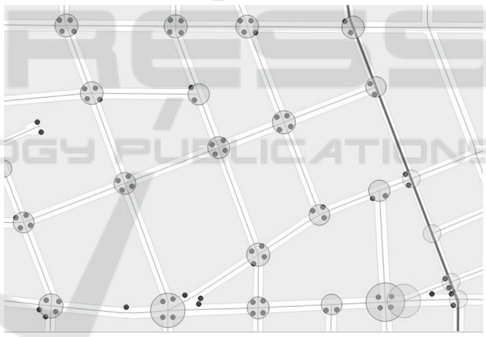

Figure 8: Hypothethical Crossroad.

94 sidewalks and 71 blocks. The derived maps resulted in 309 road intersection areas (within a zoom in Figure 7) and 185 number of possible crossroads (within a zoom in Figure 8). Note that crossroads within Figure 8 can belong to geometric groups: lines and polygons (with three or four edges).

Consider the shortest walking path (highlighted in Figure 9) from point A on Benjamin Lins Street to point B on Vicente Machado Avenue. The path is computed by considering the possible combination of streets that can be followed in order to get from one point to another. A subset of the combinations can be modeled by a graph as the one in Figure 9. The vertices are a set of intersections and the edges are segments of streets defined by two intersections.

The graph reflects the input data used for comput-

[13]http://www.ippuc.com.br. Last visited on 14/05/2015.

[14]http://www.openstreetmap.org Last visited on 14/05/2015.

[15]http://www.postgis.net Last visited on 15/05/2014.

[16]http://www.qgis.org Last visited on 15/05/2015.

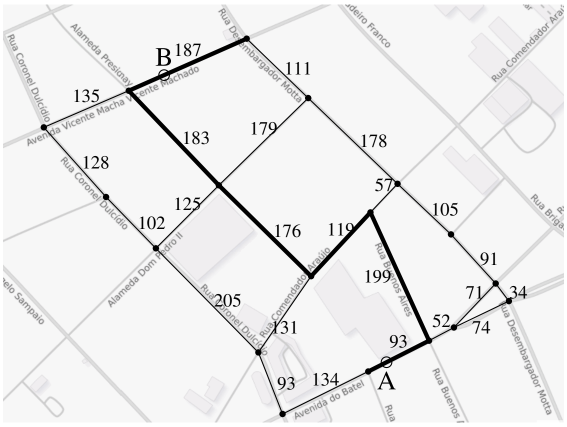

Figure 9: Shortest walking path between points *A* and *B* computed using a street-based graph.

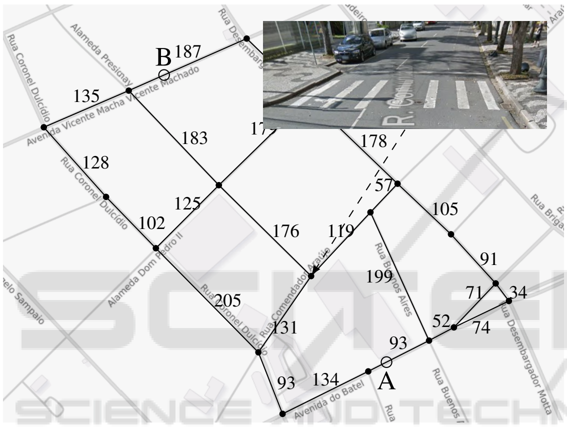

Figure 10: Ordinary route planners do not consider accessibility constraints.

ing shortest paths on common route planning. This is a street-based graph which takes into account a weight factor for each edge according to known properties of street segments, such as the distance between two intersections, the slope of a street segment and the condition of a sidewalk. The graph in Figure 9 considers distances between intersections.

People with disabilities, such as wheelchair users, may face some problems due to conditions not captured in route planners considering such a model. As highlighted in Figure 10, there is a crossing without curb ramps that would make it difficult to proceed along the route. The model must be able to encode that kind of constraints perhaps by using a weight on the vertices of the graph or by making it reflect on the weight of the streets. Anyway, those can also be flawed solutions: it is possible one street has sidewalks on both sides and one side has problems while the second one is in perfect conditions to go along.

The sidewalk-based model proposed in this paper allows to make all of these conditions explicitly available for a route planner, making it more suitable for searching paths that meet the needs of people with disabilities. The model for the same region of the previous discussion is summarized by the graph in Figure 11. The hypothetical curb ramps are vertices of the graph and its edges are sidewalks or adjoining curb ramps on streets. Thereafter, every sidewalk can have its own weight and the lack of curb ramps between adjoining streets also be encoded on the edges connecting them. It is possible, therefore, to avoid streets without curb ramps and sidewalks on poor conditions. The shortest path in our model is highlighted in Figure 11, depicting not only which sidewalk to follow along a street but also which curb ramps to use.

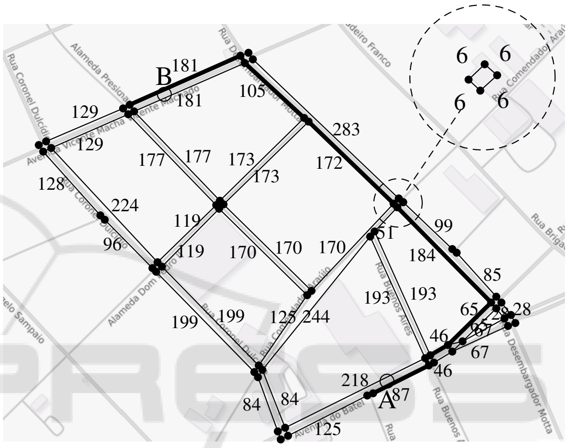

Figure 11: A sidewalk-based model and a route considering accessibility.

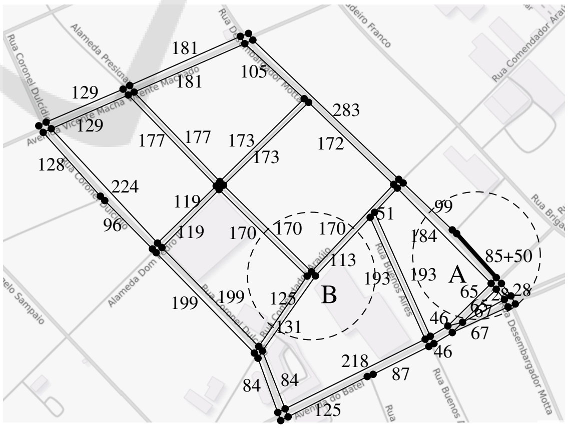

Figure 12: Modified walkway-based model: a sidewalk was given a bigger weight (see region A) and a curb ramp, along with a crosswalk, was added (see region B).

The model may have its attributes modified by users: (i) an edge (segment of a sidewalk) of the graph could have its weigh increased if the condition of the sidewalk is degraded due to holes in the pavement, narrow width, obstruction, among others; and

(ii) previously nonexistent curb ramps and their related crosswalks could be added to improve the route planning. The two types of modifications are illustrated in Figure 12. The weight of one edge was modified due to a possible poor condition of the sidewalk. In the second modification a vertex and an edge were added to the model to illustrate that a new curb ramp has been built.

Discussion. Among the parameters which impact the planning of a route for wheelchair users, we can mention: **Database Issues:** lacks of standard within the data sources (the different data semantics, geometries, etc.), the domain understanding of how GIS geometries might be mapped and how they can be explored in other domains (such as graphs), the theoretic abstraction of how different layers of points, lines, geometries can be mapped to multigraphs, among others; **Domain Issues:** how to manage different areas (such as databases, human computer interaction, theory, urbanism, etc.) toward working in an unified solution, regarding terms and technologies; **Theory:** how to theoretically add temporal events which might change in a graph (such as edge weights which change along the interactions); how to develop a mathematical approach and elaborate algorithms of route building on the graph on condition of various types of obstacles; how to better calculate the edge weight estimation. Although being preliminary, the tests state that the implementation of the method is suitable for wheelchair users. In summary, we understand that better approaches to the routing problem depends on a sinergic combination of data, knowledge domain, and user feedback.

5 CONCLUSIONS

Research in accessibility and GIS is not recent, but the exploration through different domains using real data is still an ongoing effort. The possibility of implementing models within GIS and integrate them with different sources provides planners with a powerful and flexible tool for analyzing applications, and deciding on new business permits. This paper presents the concepts, application, and challenges of exploring a route planner for wheelchair users. Later these definitions are explored in a practical case study, within the Curitiba metropolitan region, Brazil.Future work includes the personalization of weights for different users, and integration of a off-line mode, among others.

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