

# Building a Weighted Graph based on OpenStreetMap Data for Routing Algorithms for Blind Pedestrians

Research Thesis

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## List of Abbreviation

OSM	OpenStreetMap
GPS	Global Positioning System
VGI	Volunteered Geographic Information
UGC	User Generated Content
GIS	Geographic Information System
PND	Pedestrians Network Data
O&M	Orientation and Mobility
NYC	New York City
APS	Accessible Pedestrians Signals
FC	Feature Class
ID	Identifier

## Abstract

Wayfinding refers to actions people take to complete the navigation process successfully. Since wayfinding is mainly constructed through visual channels, blind pedestrians experience many unique challenges. For example, they are not able to see important landmarks, which are essential to maintaining a reliable wayfinding process. Moreover, physical objects, for instance, cars parking on the pavement as well as shared lanes with bikes and cars, limit their mobility and and pose danger.

This research aims to generate a weighted graph for a pedestrian routing network tailored specifically for blind pedestrians. The weighted graph will enable us to identify routes that, instead of being simply shortest, would fit their needs, be safe and enable blind pedestrians to orient and navigate through easily (e.g., straight-direction route with many landmarks). The pedestrian network is based solely on OpenStreetMap (OSM) data, which is mostly volunteered mapping data collected by the public (i.e., crowdsourced participatory mapping). Since OSM is an open-source mapping platform, it enables insertion and editing of data that are valuable for blind pedestrian navigation and wayfinding, suggesting flexibility in terms of data maintenance and analysis. Still, although volunteered-based map services show an increasing planar (2D) accuracy, completeness and update-rate of their mapping infrastructure, pre-processing of network data is required to handle the development and implementation of the routing algorithm. This research will present the knowledge gained in interviews, observations with blind people and Orientation and Mobility specialists, that lead to the definition of the criteria set that expresses the needs and preferences of blind pedestrians while navigating. All geospatial entities that are required for this implementation, together with the detailing of the data pre-processing that was implemented to handle the construction of the pedestrian network, together with the weight graph that was built based on the criteria set. Developments and implementations were tested and analysed in two cities with different users. An investigation of the outcome of these show that mostly the proposed criteria set expresses correctly blind pedestrian needs and preferences while navigating. OSM data has the potential to be an effective and valuable database for this task, at least in urban cities in developed countries, providing routes tailored for blind pedestrians, thus filling the gap- in the state-of-the-art.

# 1. Introduction

Wayfinding is a natural skill that pedestrians do throughout their entire life that helps them to successfully navigate from one place to another. It involves the integration of perceptual and cognitive structures of space into spatial information to stimulate mental representations. Modelling this process has practical applications (e.g., identifying architectural problems, enhance a tourist wayfinding experiences). However, wayfinding processes are mainly constructed through visual channels, which means they are inaccessible to blind pedestrians. In other words, the absence of general knowledge, as in the reading of signs and making use of existing landmarks (LM) to help blind pedestrians orient themselves mainly in unfamiliar surroundings. Other challenges arise from physical obstacles in the street such as large cracks, debris and holes in the walkway, construction work, street furniture, cars parking on pavements, pavements with overhanging objects, shop boards on pavements, tables and chairs on pavements, shared surfaces (i.e., no demarcation between traffic and pedestrians). Therefore, their mobility is restricted, meaning they cannot navigate and perform their basic daily activities, without the support of other individuals or without using any other mobility aid, such as a white cane, guide dog or assistive technology; and even then, they still experience challenges. Furthermore, blind pedestrians had pointed out that they want to go out much more than they normally do. Also, evidence shows that there is a significant relationship between mobility, independence and well-being [1].

Research in the field of wayfinding and navigation for blind pedestrians has advanced tremendously over the years. Commercial devices and software products, designed to provide mobility assistance, rely mainly on the Global Positioning System (GPS). Apps that use a GPS sensor to help blind pedestrians navigate with voice instructions are being used today (e.g., Sendero Group<sup>1</sup>). There even exist smartphones designed specifically for blind pedestrians, which include apps built to help blind users conduct their daily activities, such as catching a bus, reading printed text and knowing their exact whereabouts in unfamiliar areas (e.g., GeorgiePhone<sup>2</sup>). Several studies introduce real-time obstacle detection and classification systems designed to

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<sup>1</sup> <http://www.senderogroup.com/>

<sup>2</sup> <http://www.georgiephone.com/>

assist blind pedestrians in navigating safely, in indoor and outdoor environments, using handling a Smartphone device. For example, applications that detect relevant obstacles for blind pedestrians by using a set of video streams and photos from the camera in smartphone and detection algorithms (e.g., [2]).

However, blind pedestrians should have information not only on their location, but also on the objects around them - type of an object (obstacles, hazards, or landmarks, size and shape, its relation to other objects), and metadata (e.g., the next bus in case of object "bus station"). Even for systems that provide the necessary information about the relevant objects, they still need to keep this information dynamic and updated. Moreover, the technology should be across the board so that every blind pedestrian has equal choice and equal access. And finally, and perhaps most importantly, how blind pedestrians can obtain a safer route so they can avoid obstacles and hazards as much as possible. OpenStreetMap (OSM) project presents an opportunity to solve these complications.

OSM is a project based on the concept of Volunteered Geographic Information (VGI). OSM is an open data project, meaning that everybody can add features or update existing features on the map. In other words, data can be integrated from various sources, such as private or public cooperation and authorities, to get a powerful, flexible and updated service. Moreover, developers are offering an enormous range of exciting products, services, and experiments making use of OSM data, which would simply not be possible without the access to OSM's raw map data. Contrastingly, Google Maps, for example, is not open at the level of OSM's raw map data. Such that Google (like other data owners) keeps data locked, to maintain a commercial advantage, while exposing only downstream products and services generated from its raw map data. Additional services that can make use of OSM data are routing tools.

Routing is the process of selecting best paths in a network (e.g. circuit switching, electronic data networks, and transportation networks). Even though the optimal path is usually considered to be the shortest or the fastest path, for blind pedestrians the safest path is more appropriate to be defined as optimal. Applications that generate routing solutions suitable for blind pedestrians, and routing solutions that make use of OSM data, exist today. Whereas, applications that make

use of OSM (or other VGI projects) data to build a weighted graph for applying routing solutions based on a set of criteria that are suitable for blind pedestrians needs do not exist yet.

This research aims to build a pedestrian network for routing algorithms intended for blind pedestrians based on OSM data. Using OSM, this solution and system can get continuous updates, varied and accurate mapping data, rate the objects according to particular criteria, to consequently compute the most appropriate and optimal route for blind pedestrians. An optimal route in terms of safety, accessibility and easy to navigation and a wayfinding process. Practically, the weighted graph can be integrated into a web-based application to be used by O&M specialists to efficiently find the optimal route in a certain area. This is instead of a tedious procedure of actually surveying the area that can take several days. In addition, integration of the weighted graph into existing navigation applications can suggest practical routing solutions for blind pedestrians.

This goal will be achieved by investigating the challenges and preferences of blind pedestrians while wayfinding in built environments then constructing an incremental criteria system criteria which focuses on factors such as mobility, accessibility and safety. Then, OSM's dataset will be utilised to analyse the feature-catalogue in terms of the criteria. As a result, ranking algorithms will be developed to support the creation of a weighted graph which quantitates the accessibility and safety level of each segment. Quantitative evaluation of routes and routing algorithm are made, in addition to a pilot study that has conducted with various blind volunteers in several urban scenarios and routes.

## 1.1 Research Objectives

This research aims to build and implement a weighted graph that is based solely on OSM data, designed and tailored specifically for wayfinding for blind pedestrians. The objective is to construct and implement a routing algorithm that will deliver with the preferred route for blind pedestrians, instead of the default shortest route, that in most cases is not the optimal one concerning blind pedestrians. The methodology includes the study and identification of environmental features and abstract phenomena, materialized using OSM data that have an impact on the mobility of blind pedestrians. The building of a weighted graph that is constructed

via a set of topological and geometric rules derived from the built environment structure and organization.

## 1.2 Research Contributions

Engineering contributions - The study will prove new options related to accessibility of the environment to blind pedestrians by using OSM data and infrastructure. It is expected that the developments, implementations and new insights gained from this research will be used by navigation systems for blind pedestrians, to enhance their independence while wayfinding in urban environments. Additionally, it is expected that this research will provide insights in support of accessible wayfinding for blind pedestrians planning of the built environment, e.g., planners who evaluate the accessibility of the built environment, updating routing databases with accessibility and obstacle information, understanding of the wayfinding needs and preferences of blind pedestrians.

Scientific contributions - It is expected that this research will optimize routing algorithms for the wayfinding of blind pedestrians based on OSM data. The methodology developed during this research can be expanded to other groups and communities (e.g., different communities and pedestrians with other disabilities). Additionally, the criteria system developed to support the creation of a weighted graph used in the routing algorithm could be used as an analysis tool to other research that involves blind users in general, and pedestrians in particular.

## 2. State of the Art

### 2.1 Wayfinding and Navigation in Built Environment

The action of observation of our surroundings is not sufficient to obtain complete and precise knowledge for navigation. Thus, pedestrians take more actions, retrieving supplementary observation to derive environmental knowledge, until the goal is achieved or the wayfinder gives up [3]. This process, termed wayfinding, is a natural skill that pedestrians do throughout their entire life as they navigate from one place to another, such as driving across a country, walking in a city, or moving through a building [4]. Generally, wayfinding activity is based on mental representation pedestrians do about their environment. It means the integration of perceptual and cognitive structures of space into spatial information to stimulate mental representation [5]. Chandler et al. argue that wayfinding has four principles: a) getting information, b) orientation, c) navigation, and d) entrance and exit identification [6].

Some research tried to explain the process of wayfinding by applying formal models. Choice-clue wayfinding model determined by people's perceptual and cognitive structures can be used to explain the complexity of wayfinding tasks in built environments [5]. Another discrete, dynamic model of knowledge and action based on transitions within a wayfinding finite graph can approximate the real process of human wayfinding [3].

Landmarks have a key role in the process of wayfinding. A landmark is a recognizable natural or artificial feature used for navigation, a feature that stands out from its near environment, and is often visible from long distances (Wikipedia: "landmark ", 2017). Landmark can play a 'global' or 'local' role. 'Global' landmarks tend to be highly visible from around the city – take for example Chords Bridge in Jerusalem, or Toronto's CN Tower. 'Local' landmarks tend to refer to those that are visible at shorter distances; still, occasionally it is the user perspective in situ, which can change the status of a landmark from 'local' to 'global' within the context of the same trip [7]. Unsurprisingly, evidence suggests that perceptual markers, like features, colour and size, may contribute to landmarks being used as navigation aids. In addition, researchers report the relevance of the shape and structure of landmarks [8], or the socio-cultural [9], such as landmark buildings preserved as living history museums. Evidence shows that directions are best understood with the inclusion of terms for landmarks, since memory for routes linked with street names is inferior to memory for routes linked with landmarks [10].

Modelling of this process has practical applications, for example, identifying architectural problems that might have an effect and then design these intelligently (with regard to wayfinding) prior to their construction [5]; enhance tourist wayfinding experiences, such that landmarks like street furniture beyond their original conventional function can play an important role in urban wayfinding. On the other hand, overprovision of external clues can lead to a lack of cognitive involvement related to spatial processes [11].

Navigation and wayfinding processes are mainly constructed through visual channels, which means inaccessible to blind pedestrians. Still, many are adept at compensating for missed information through increased awareness of other environmental cues and the use of navigational aids, both low-tech (e.g., white canes or guide dogs) and high-tech solutions (e.g., handheld GPS devices). Nevertheless, situations exist in which individuals with visual impairments are not able to travel as independently as they would like to [12].

## 2.2 VGI and Crowdsourcing

OSM, Wikimapia and Google Map Maker are only a few examples out of many mapping applications and infrastructures, in which users can upload and contribute with geographic information or geographic observations into the web (GeoWeb2.0). This voluntary information can be produced in a variety of tools, such as GPS tracking of bikes and hiking routes (spatial trajectories), places of interests - and more [13]. The term VGI was first coined by Goodchild in 2007, referring to the new phenomena in which people voluntarily upload geographic data into the web. This term is a special case of a more general case of users collaborates in collecting diverse types of data, which is called UGC ("User Generated Content"). A good example of UGC is Wikipedia, a free internet encyclopaedia, in which almost every user can access the site and contribute or edit information about any entry he or she sees fit. In addition, one of the most famous by-products of Wikipedia, and a good example of crowdsourced VGI, is Wikimapia<sup>3</sup>.

Due to the emergence of VGI, the web is now overflowing with geographic data and geo-tagged postings (such as photos) in a usable and searchable format, making Geographic Information System(GIS) no longer the realm of specialists only [15]. Moreover, VGI can provide an immediate

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<sup>3</sup> <http://wikimapia.org>

source of information, due to the update process that is event-based and not based on authoritative data (cyclic update), and thus is easy to extract, serving as a reliable source of information [16]. Therefore, VGI has an enormous potential in enriching existing geographic data as well as existing location based protocols and applications, and even serve as an alternative source for the use of traditional data and information.

Nowadays, current research shows that OSM data and other Open Source Systems have come to a matured state, in terms of data completeness and accuracy [17]. Such that they can serve as a data source and interface for applications designed, among others, for blind pedestrians. For example, whether there are sound or vibrating signals for blind pedestrians or whether there is a tactile arrow available at the traffic light pole to indicate for blind pedestrians in which direction the pedestrians crossing leads, information about obstacles on the way such as bicycle rental spot, subway entrance and recycle bins – to name a few. Perhaps more importantly, it holds the capability to insert and edit additional environmental features essential for blind pedestrians' wayfinding and navigation that other mapping infrastructures, such as Google Maps, do not.

Usually the process of working with OSM data consists of downloading XML and style files of OSM data being converted into database tables using a utility program (e.g. `osm2pgsql`), then inserted into a GIS database. A database management system (e.g. PostgreSQL that is used along with PostGIS<sup>4</sup>) is also required to handle the GIS data. OpenLayers and open source JavaScript library supplies with additional functionality to OSM data [18], or by using with JOSM (an extendable editor for OSM) [19]. Complete et al. defines guidelines to enhance OSM data with blind pedestrians' related attributes. Authors explain most of the existing OSM tags, which are useful for blind pedestrians. Therefore, if the style file does not include tags for blind pedestrians, such as tactile paving, signals with sound, and obstacles, it must be modified before downloading, so that it would include the related tags [20].

Völkel et al. illustrated the concept of using VGI for blind pedestrians' wayfinding purpose. Their method enables blind pedestrians to annotate existing geographical data with their own information, such as specific points of interest, environmental features usable for orientation,

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<sup>4</sup> **PostGIS** is an open source software program that adds support for geographic objects to the PostgreSQL object-relational database.

the location of obstacles, or specific safety and convenience ratings. As a novelty, additional data can be shared anonymously among predefined user groups to broaden map data available to each individual user [21]. Elsafty developed an assistive OSM editing application with an adaptive user interface that matches blind pedestrians' needs to enable blind people to edit OSM [22].

Recently, Smartphone apps that assist blind pedestrians based on OSM data to navigate indoor and outdoor environments have been proposed. Leung et al. introduce a robust system for delocalization in dynamic environments, based on a camera system designed to help the visually impaired navigate, where maps are provided based on OSM data [23]. Guy et al. developed navigation application called CrossingGuard that provides "sidewalk to sidewalk" directions along with detailed information about the geometry (shape and width) of intersections, traffic control systems and new intersections. Additionally, the application is designed to optimize the amount of attention it asked of the user. CrossingGuard uses OSM data to calculate intersection geometry and capture meta-data that raises the comfort level of blind pedestrians. BlindSquare<sup>5</sup> is another example of navigation app that relies on the Foursquare social network for points of interest data and OSM data for street information [24]. Novel solutions designed for wearable devices have the great advantage of not requiring the user to hold the device while walking [25].

OSM data can also assist in creating maps exclusively designed for blind people. A tactile map refers to a sheet of a map, which is portable and has an advantage of being explored by touch at home elaborately beforehand. Since 2004, systems automatically generating tactile maps are available on the Web have been in use. In 2009, researchers have begun to utilize OSM data to enable the creation of tactile maps at any location in the world in a very short period of time [18].

In the past few years, the scientific community turned its interest to non-visual forms of representation, using the haptic and the auditory information channels to overcome the inability of blind people to interpret graphical information, which severely restrict access to 2D visual maps. However, only recently a substantial decrease in price has allowed a strong diffusion of these technologies into the accessibility domain[26]. Rifat et al. proposed a Location Based Information System that provides audio messages of the location and description of the route to

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<sup>5</sup> <http://blindsquare.com>

the destination. This technology is designed to show the usability of OSM, but not to serve as a practical solution for blind pedestrians [27]. Kaklanis et al. present a tool that uses OSM data to generate a multimodal map. The map can be explored using a haptic device (recreates the sense of touch by applying forces, vibrations, or motions to the user). A sonification (according to which pitch is generally a good dimension for representing continuous variables like temperature or distance in this case), and a text-to-speech mechanism provides audio navigation information during the haptic exploration of the map [28].

Research has proposed hybrid approaches combining sources and services as part of their application. One study uses highly accurate differential GPS, an electronic compass, spatial audio and OSM data to name streets and other landmarks in their proper location in space [24]. Research enabling the blind user to provide an audio message of address name being passed to the Google Maps web service, which returns the corresponding coordinates ('geocoding') to an OSM web service. (Google Maps return much more accurate results compared with the corresponding OSM Geocoding mechanism) [28] [18]. Besides OSM data, Timothy et al. utilize two additional data sources, which were integrated into the navigation application, i.e., a high-resolution LIDAR-based Digital Terrain Model and a General Transit Feed Specification data set [19].

Prior research showed that success of OSM-embedded techniques for blind pedestrians are highly dependable on the quality of the OSM dataset. Almost three-quarters of the members who ever contributed to the project are from Europe – most active community of the project is in Germany – however, the percentage of members that actively collect information each month is less than 2%. In addition, since the active community members usually sit in cities, hence urban areas are better mapped than rural areas in term of quality and quantity; also described as “urban bias”, which means that data concentration and quality correlates in most cases with the population density [29]. Another problem related to the fact that only in few numbers of major cities the volunteers collect information about sidewalks, road surfaces, road incline, pedestrian crossings, and tactile paving. This level of detail is essential when considering the creation of suitable techniques for blind people [19] [24] [29]. Lastly, navigation devices that are based on OSM data mainly utilize inexpensive GPS receivers, which are often inaccurate and unreliable, therefore improvements in positioning accuracy are required [30].

## 2.3 Pedestrians Network

A "pedestrian" is "any person who is afoot or who is using a wheelchair or means of conveyance propelled by human power other than a bicycle" [31]. A "pedestrian path" refers to any pathway that is designed for pedestrians to improve pedestrian safety, reduce potential accidents, and promote mobility and accessibility. Most people only consider sidewalks as part of the pedestrian paths, but pedestrian paths can be considered to encompass more. Pedestrians network relates to spatial and non-spatial data for sidewalks, crosswalks, footpaths, accessible entrances, pedestrians underpasses, pedestrians overpasses, steps, and trails [32].

The increasing capabilities of mobile devices and their mobile positioning technologies have shown great promise in location-enabled applications, such as navigation systems. One of the essential components of a navigation system is a spatial database as it provides the base data to perform navigation and routing functions, among others. With the popularity of vehicle navigation systems, road network databases are now well developed and well suited for vehicles traveling on roads. However, road networks are not suitable for pedestrian navigation systems as pedestrians do not walk along the middle of street lanes, and are not constrained by the boundaries of the road. A pedestrian navigation system, which uses a road network as a substitute for a pedestrian network, might suggest a route with missing sidewalks or pedestrian paths. Consequently, pedestrians network data is needed in location-enabled applications for pedestrians and other applications including transportation planning and physical activities study [33], [34]. In particular, transportation of vulnerable people, such as the disabled, elderly and pregnant women, require more detailed guidance than other pedestrians, because they have a higher likelihood of trial and error when finding their way to destinations [35].

Traditionally, digital maps of pedestrian network are collected by cartographers and geographers, among other professionals, through advanced specialized equipment and are disseminated by national commercial mapping agencies. This is an expensive and labor-intensive approach, subjected to restricted licensing terms. Due to such shortcomings of this approach, other approaches were developed, the most common one for constructing pedestrians network data is to manually digitize the pedestrians path centerlines by using satellite images [36]. However, satellite or aerial images are not always available, mainly in the public domain, or have

low resolution in some areas. Moreover, the accuracy of the features extracted is easily affected by the quality of the images and the image processing techniques employed [37].

Kasemsuppakorn et al. presented an innovative approach that is based on location-based social networking for collecting pedestrian network data. The proposed approach stems from the concept of collaborative mapping, where pedestrians network data can be collected by members of a social network recording GPS trajectories. His result shows the trajectories collected both around open sky and in urban canyons are of quality useful for constructing a pedestrians network [32]. However, the process of constructing geographic information from collected GPS data in current collaborative mapping projects still relies on human intervention. Therefore, they proposed an another improved algorithm for automatically identifying geometries of pedestrians path segments and constructing a pedestrians network from multiple GPS traces [38].

Another type of methodologies that have used pre-existing road data was also developed. Kim et al. generated a pedestrians road network by utilizing existing spatial datasets [39]. Liu et al. proposed the rules and logic model and attributes for a pedestrians network and proposed a connecting model with an existing vehicle network [40]. Another approach proposed sidewalk detection that corrects occlusion errors by interpolating available visual data [41].

Karimi et al studied three approaches for generating a network map for pedestrians, generating Pedestrians Network Data (PND) by: network buffering, collaborative mapping using GPS trace data, and image processing. The results from each process were evaluated and recommendations about a suitable approach for a given situation were provided [42].

However, PND lacks detailed information for transportation of blind pedestrians. A detailed information on pedestrian facilities and obstacles should be included. Pedestrian facilities, such as tactile paving marks or Accessible Pedestrians Signals (APS) that can be used to support them to navigate safely and independently; obstacles, such as stairways, narrow passages, and bad paving blind users might have access problems so that they are obliged to make detours to avoid those obstacles on the path.

One approach to identifying specific spatial information considered computer vision techniques. Computer vision techniques can use satellite and street-level images to assist blind pedestrians. For example, a technique based on Support Vector Machines to recognize pedestrians crossings

from satellite images [43], or allow pedestrians with visual impairments to detect crosswalks with a smartphone camera [44]. Hara et al. introduce a new scalable method for collecting bus stop locations and landmark descriptions by combining Google Street View data and online crowdsourcing intended for blind bus riders [45]. Other studies focused on obstacles and accessibility issues blind pedestrians might experience along the route. Matthew et al. gather information on temporary road accessibility issues (e.g., roadwork, potholes) [46]. Kotaro Hara et al. detects inaccessible sidewalks in Google Street View images. Wheelmap<sup>6</sup> website allows accessibility issues to be marked on OSM [47].

However, the collected information remains separate from an existing PND. Park et al. provide a methodology for integrating new pedestrian information with an existing pedestrian network. The study extracted the significant points from user-collected GPS trajectory by identifying the geometric difference index and attributes of each point. Then the extracted points were used to make an initial solution of the matching between the trajectory and the PND. Two geometrical algorithms were applied to reduce two kinds of errors in the matching: on dual lines and on intersections. Using the final outcome for the matching, they reconstructed the node/link structure of PND including the additional information [48].

## 2.4 Routing algorithm

Routing is the process of selecting best paths in a network; the shortest path is one example. Routing is performed for many kinds of networks, including the telephone network (circuit switching), electronic data networks (such as the Internet), and transportation networks. The most popular algorithm, mostly used for shortest path computation, is Dijkstra's algorithm. Still, there exist other routing algorithms, which are based on various techniques, e.g. dynamic/static routing, fuzzy routing, heuristic/hierarchic routing – to name a few.

In general, five requirements are needed for routing planning [49]: (1) A procedure to set origin point and destination point; (2) a connected network (routing graph), on which the routing can be performed; (3) an algorithm that computes the route between origin point and destination

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<sup>6</sup> <https://wheelmap.org/map#/?zoom=14>

point; (4) The inclusion of user requirements in the route computation and selection; (5) the presentation of the results to be used.

In terms of wayfinding, most routing algorithms usually aim to find the shortest path, which is not necessarily the most preferred path in the case of people with different disabilities, such as blind pedestrians. Their individual requirements include the provision of supplemental points of interest and specific geographic map data usable for the calculation of optimized and suitable routes [21]. In addition, safety is one basic requirement indispensable to blind pedestrians who probably would prefer to take a longer but safer route – than the shortest one [50].

The open approach to data collection efforts in OSM lead to high object densities and details in numerous cities all over the world, hence provide detailed information about the “best” individual route based on the user’s limitations. Moreover, additional relevant details are being added to the map every day, including public transportation information, address-data, such as house numbers, or detailed information that can be used for an adequate route-planning application for people with disabilities [29].

Chen et al. propose a formal modelling approach based on an objective orientation idea. The features are organized as a series of function objects that meet the various needs of blind pedestrians. The geometric shapes of the proposed objects and their topological information are also recorded for local navigation and comprehensive path planning for identifying the least-cost paths tailored specifically to blind pedestrians. This model can be implemented in a mobile phone application to aid them during urban travel. These solutions and tools are based on low-cost technology and planned to be used worldwide [51].

Miesenberger et al. developed a prototype of a navigation system for blind pedestrians tailored to their specific requirements. Routing algorithms are also included, i.e., a cost function for the route planning algorithm, which avoids dangerous paths like zebra crossings with no traffic lights [50]. Völkel expanded this concept by incorporating multiple criteria when determining optimized routes. Furthermore, customized routes can be directly gained by applying user preferences beforehand [21].

Dornhofer et al. reviewed routing services that use OSM data to generate a routing graph: (1) PgRouting - an extension to the PostGIS standard; (2) OpenTripPlanner<sup>7</sup> - a collaborative effort among several independent developers, to develop an open-source multimodal trip planning software system; (3) OpenSourceRouting - computes the shortest paths in a graph by Contraction Hierarchies technique. Some research benefit one of these services in their application. However, the service must retrieve all OSM attributes that are needed to find the optimal route for blind pedestrians [49].

For example, a geospatial barrier catalogue and a prototype of a web-based intermodal door-to-door routing application for people with physical impairments. Within the geospatial barrier catalogue objects and structures, built in indoor or outdoor environments, are outlined regarding their influence on the locomotion of people with physical, visual, and hearing impairments. The catalogue comprises also routing relevant information concerning road types and public transportation. The spatial representation of the catalogue is materialized through a data model within the OSM framework. The prototype provides intermodal transition-free routing between indoor and outdoor environments. It has been implemented through customization of the open-source OpenTripPlanner [19].

Neis et al. introduced a newly developed algorithm that generates a routing network for disabled people from a freely available and collaboratively collected geodata set, provided by the OSM project. The newly created network has several advantages over traditional routing networks and is highly adaptable. The variety of supported attributes during the network generation allows the algorithm to be used for different use cases such as route planners or personal navigation assistants for people with disabilities. Furthermore, the new representation of a sidewalk network can be implemented in several types of online, offline and printed maps. Several improvements to the algorithm are feasible, for example, during the generation of the sidewalk network it could be useful to consider building information, which is also available in the OSM project database, to position the sidewalks correctly between the road and a row of houses [29].

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<sup>7</sup> <http://opentripplanner.com>

### 3. Methodology

The methodology was divided into four stages:

1. Investigating the needs and preferences of blind pedestrians.
2. Formulating and quantifying the criteria.
3. OSM mapping data collection and arrangement.
4. Building the routing graph.

#### 3.1 Investigating the Needs and Preferences of Blind Pedestrians

This stage was designed to gain insights, learn and better understand how blind pedestrians navigate in the urban environment - what are their considerations and preparations before they leave their origin, and once they are outdoor - what are the devices (aids) they use, activities and approaches they practice, to arrive safely at their destinations.

To accomplish this goal, I have consulted specialists from MigdalOr, a non-profit organization that provides rehabilitation services for people with visual impairments or blindness throughout Israel. Rehabilitation services include Orientation and Mobility (O&M) training, where specialists at MigdalOr teach blind and low vision people how to navigate and wayfind in an urban environment. I have organized and participated in observations of O&M training sessions and meetings, and consulted them, and conducted interviews with several blind people. I have also consulted an O&M specialist from California, U.S.A, and had interviews with blind people from New York City (NYC), U.S.A. Consulting professionals and users from various places allowed me to gain broader knowledge and insights on the topic.

In these consultations/interviews with O&M specialists I asked them about their work -What does job entail? What kinds of services or training do they provide for blind people? What is a typical training session with a blind person like? What are the goals of a training session? Afterward, I had several questions about the routs: what concerns do blind pedestrians have when walking along routes in an urban environment? What kinds of routes are more challenging? Which ones are easier? Then, I asked about the methods the O&M specialists teach that help blind pedestrians to better wayfinding and navigation. Table 1 summarizes the techniques we have used during this stage.

**TABLE 1. SUMMARY OF THE USED TECHNIQUES<sup>8</sup>**

Type	Participants	Place	Conducted by	Recording	Goal
Interview - two sessions: 1. Open-end interview. 2. Conversational interview.	➤ Manager in MigdalOr	Israel	Two researchers	➤ Self-report	Gain general insights regarding the challenges blind pedestrians face while navigating.
Conversational interview	➤ O&M specialist ➤ Blind woman	Israel	Three researchers	➤ Self-report	Investigate methods and strategies blind pedestrians use while navigating.
Observation	➤ O&M specialist ➤ Blind woman	Israel	Three researchers	➤ Self-report	Examine in natural settings how blind pedestrians navigate.
Conversational interview and observation	➤ Blind man ➤ Blind woman	Israel	One researcher	➤ Voice recorder app	Extend our understandings by meeting blind pedestrians in a new and unfamiliar environment.
Conversational interview and observation - two sessions	➤ Blind man ➤ Two blind women	US	Two researchers	➤ Voice recorder app	Observe existing differences related to various environments.
Conversational interview	➤ O&M specialist	US	Two researchers	➤ Voice recorder app ➤ Self-report	Obtain additional methods and strategies blind pedestrians use.

Main insights gained from these observations and interviews that relate to the spatial objects and environmental arrangements are as follows:

<sup>8</sup> I did not analyze research bias that could be the result of conclusions derived from the interviews

- **Complexity** – A **straight** route is mostly preferable over a (geometrical) **complex** one, especially in case the route is nearby a road or have a clear and distinct **border** (grass, curb, etc.).
- **Landmarks** – These are essential in wayfinding for blind pedestrians; these can be restaurants, traffic lights, trees, bus stops, subway stations, etc. Only fixed (static) landmarks are meaningful for blind pedestrians and assist them - as opposed to temporal or dynamic ones.

Landmarks related to distinctive smells, sounds and shapes are also meaningful. Coffee shops, for instance, have a typical coffee smell, which enables blind pedestrians to orient themselves better in the environment. Another example is noises from a nearby supermarket, such as carts, bags, beeps of the supermarket machines. However, when blind pedestrians attempt to learn traffic patterns in intersections through the auditory perception, surrounding noises might have a negative effect that distracts them.

Landmarks are not always necessary. When streets run at right angles to each other, forming a grid (like Manhattan, for example), it is easier for them to wayfind and navigate. Thus, they normally rely on the streets' grid arrangement, which they need to learn beforehand, rather than on landmarks.

- **Accessible aids** – These can be tactile paving before crossings or public transport stations and Accessible Pedestrians Signals (APS), which are devices that communicate information about the WALK and DON'T WALK intervals at signalized intersections in non-visual formats to pedestrians who are blind or have low vision<sup>9</sup>. These can be helpful in wayfinding, although blind pedestrians should manage even when these are missing.
- **Roads** – These features can assist the blind since they serve with sound and a sense of direction of going vehicles for orientation.
- **Obstacles** – **Squares**, for example, are a very difficult area for blind pedestrians to wayfind, worse in crowded squares. Also, **Park** is an area in which blind pedestrians find it hard to orient since usually the paths are not straight and without valuable spatial clues alongside. Unsafe spatial obstacles, for example, are **shared lanes** of pedestrians

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<sup>9</sup> [http://www.apsguide.org/chapter1\\_aps.cfm](http://www.apsguide.org/chapter1_aps.cfm)

with bikes and sometime even with cars. A **Parking lot** is an example of a hazardous shared space for pedestrians and cars that should be avoided by blind pedestrians.

- **Intersections** - These are considered as complex surroundings for blind pedestrians because they involve safety and accessibility issues. Moreover, intersections could be different in terms of:
  - **Visibility** - Refers to features (e.g., trees, hills, curves) that might prevent a driver to see the pedestrians.
  - **Shape** - Refers to the number of road segments (arms) that form the intersection in terms of geometry and spatial arrangement. An intersection might consist of three-way arms (a T junction or Y junction), four-way arms (often in the form of crossroads), five-way arms (depicted in Figure 1) - or more arms. The more complex the intersection is; more difficult it is for blind pedestrians to orient.



**FIGURE 1. AN EXAMPLE OF FIVE-WAY INTERSECTION**

- **Traffic control** - Can consist of many strategies, such as crosswalks, pedestrians-directed traffic signals, roundabout, and over/underpasses, managing pedestrians' traffic in the intersection. Pedestrian islands are also part of the traffic control system, allowing pedestrians to divide their crossing into separate crossing segments for each traffic direction, possibly with a separate signal for each.

At intersections, blind pedestrians should gather all the information, and listen carefully to the traffic patterns, which have an impact on their decision making on how and when to cross the streets. Good intersection, in terms of blind pedestrians, should minimize crossing distance, time and exposure to potential conflicts, while maximizing vehicle visibility approaching the intersection.

T-junction is the preferred shape for blind pedestrians since it allows better attention to the parallel incoming traffic. Conversely, an uncontrolled intersection is dangerous, thus blind pedestrians would prefer to avoid this type of crossing. Evidently, in such cases, blind pedestrians would rather choose to walk a bit further and cross at a safer and simpler (more accessible) intersection.

- **Different preferences** - From interviews of various participants, I have learned that their preference and needs may differ. For example, for one user safety is the most indispensable factor, whereas for another user the route length is the preferable factor. It also depends on mobility aids the user use (e.g., white cane, guide dog); for a person who walks with a guide dog the number of curves along the route has no importance, unlike a person using a white cane. Furthermore, each user has different preferences, which change due to specific temporal factors, e.g., Am I in a hurry? What is the time of day?

### 3.2 Formulating and Quantifying the Criteria

The term routing relates with the process of selecting optimal paths between two points (origin and destination) in a network, which consists of edges connected by nodes. To find the optimal path, one should assign a weight to each edge, then, the smallest weight combination of edges from origin to destination is defined as the optimal path. In this research, the edges present pedestrian ways, such as footway, living street, stairs; the weight measures how much a certain way fits blind pedestrian needs while navigating. From the knowledge gained from the interviews, meetings and observations (detailed in 3.1), I have found that blind pedestrians aspire for a safe, short and practical way, preferred with landmarks along the way. Therefore, I defined four criteria that meet these needs: Way Length, Way Type, Way Complexity and Landmarks. In addition, based on these criteria, it will be easier to examine the required OSM data, focusing on ways, to formulate the weights, as will be explained later. The idea is that every way is analysed

by examining its different attributes: geometry, tags, and distance to nodes (landmarks) nearby. Based on the criteria that generate sets of costs, the final weight of each way is assigned that is the aggregation of a way costs.

OSM uses a topological data structure, with four core elements: 1) Nodes - points with a geographic position. 2) Ways - ordered lists of nodes, representing a polyline (representing linear features, such as streets and rivers) or polygon (closed shapes, such as forests, parks, parking areas and lakes); this study refers to Ways only as linear features. 3) Relations - representing the relationships of existing nodes and ways (e.g., turn restrictions on roads); 4) Tags - 'key=value' (e.g., 'amenity=shop') pairs used to store metadata about the map objects (such as type, name and physical properties).

The four criteria are:

#### Length

Generally, pedestrians prefer to walk shorter routes to get to their destination; this goes also to blind pedestrians. The cost for every graph way feature of this criterion is the length value.

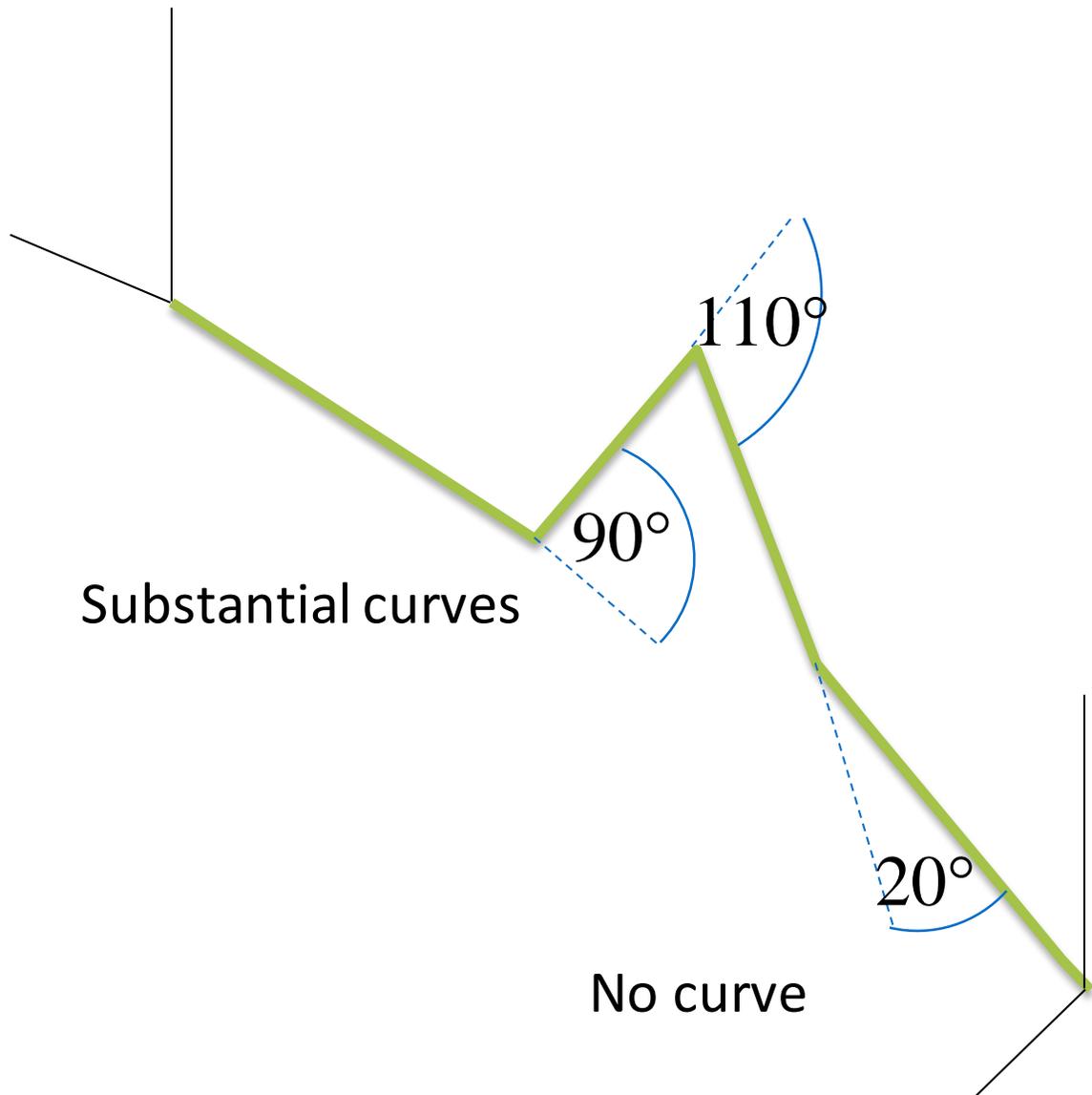
#### Complexity

The cost regarding this criterion is determined depending on the number of curves existing for a certain way. More curves exist, the more complex the way is, and thus it is evident that it will be more challenging for blind pedestrians to navigate and orient. However, not all curves are considered as deviations to the way straightness measure that influences the complexity cost. Accordingly, a substantial curve is defined as the angle between the current and previous way directions that is bigger than an angular threshold of  $45^\circ$  (decimal degrees). This value is selected since navigation typically has eight main directions: north, northeast, east, southeast, south, southwest, west and northwest, where the angle between two consecutive directions is  $45^\circ$ . Figure 2 depicts a way with three curves, and the angles between two consecutive directions. The cost will be derived only from the two curves having an angle larger than  $45^\circ$ .

#### Landmarks

Local or global landmarks are spatial and environmental features that help to complete the wayfinding and navigation processes successfully. Sighted pedestrians use local or global landmarks, helping to update and determine their location in respect to the surroundings and

way. Blind pedestrians cannot rely on global landmarks, while selecting local landmarks differently. Nevertheless, according to interviews with O&M specialists and blind pedestrians, local landmarks play a very important role, and are required for a successful navigation process. Therefore, landmarks considered as important are included in the algorithm.



**FIGURE 2. AN EXAMPLE OF COMPLEXITY CRITERION**

While Length, Way type and Complexity criteria increase the final weight, Landmark criterion decreases it, therefore its cost is determined by using negative values (-). The cost regarding the Landmark criterion is comprised of two elements: first, each landmark within a specified distance to a certain way will decrease the way cost by -1. Threshold distance of 1.5 meters was used, since in Israel, as in many other countries, the standard width for a sidewalk is 1.3 meters. Such

that on-route landmarks should be easily identified by blind pedestrians, filtering landmarks that are more distant, and hence less relevant to the navigation process. This threshold also ensures the existence of landmarks near decision points, e.g., intersections, thus decreasing the way feature cost.

### Way Type

The cost of each way feature is determined by examining the way type, mostly correlated also to its surface quality and accessibility issues. This information is retrieved from tags attached to the OSM features. The 'highway' key is used for identifying way type. The value of this key is very important to specify the accessibility and usage of the feature to blind pedestrians.

Table 3 presents the possible 'highway' key values, their description, and their relevance to blind pedestrians. Relevance was devised by using a scale consisting of six categories in their relevance to (and effect on) blind pedestrians: Preferred, Nice to Have, Neutral, Less Preferred, Better to Avoid, and Avoid. Accordingly, cost is given with values from one to six, respectively. Preferred category describes ways that are ideal to a blind pedestrian in term of road users (i.e., pedestrians only with no cyclist or motorist), accessibility and surface quality. Some features need to be further investigated and mined for more used tags to decide on the cost, as followed:

(\*) Footway is not always a **Preferred route**, such as in:

- Tag 'surface: grade' - values can be: a). zero or one, which means worst quality, e.g., many holes, branches and such; b). two or three, which means excellent quality, i.e., even if some minor faults exist that do not have an actual effect on the pedestrians. Therefore, in the case of value less than two, the cost is decreased to **Neutral**.
- When tag 'footway=crossing' is used, it means the way is crossing, thus, other tags might be involved to identify the suitable situation and consider the appropriate cost (Table 2):
  - Situation 1 - crossing with a traffic light and APS receives a **Preferred** cost. This is the easiest and safest situation to cross a road; in addition, the traffic light can play a role since it is a very good landmark, which can be identified easily, and is regularly located in decision points.
  - Situation 2A - crossing with a traffic light and tactile paving but without APS receives **Less Preferred** cost. On one hand, blind pedestrians must know when the traffic light is green before crossing the road, meaning they must have a clear

understanding of the existing traffic patterns, or alternatively getting help from other pedestrians. On the other hand, tactile paving allows blind pedestrians to identify the crossing easily, and at the same time can play a role of a landmark.

- Situation 2B - crossing with traffic light but without tactile paving and APS receives **Better to avoid** cost. Beside the cons that were mentioned in situation 2A, a tactile paving is also missing, which means the crossing is more difficult to detect.
- Situation 3A - crossing without traffic light but with tactile paving receives a **Neutral** cost. Beside the pros in situation 2A pedestrians have a legal priority over vehicles when crossing the road. On the other hand, they do not really know whether vehicles see them or not, which may be dangerous to them.
- Situation 3B - crossing without a traffic light and tactile paving receives **Less Preferred** cost.
- Situation 4 - No crossing or traffic light (uncontrolled intersection) receives **Avoid** cost. It is very dangerous to cross the intersection, also because vehicles have a legal priority over pedestrians.

**TABLE 2 . POSSIBLE SITUATIONS AND COSTS FOR 'FOOTWAY=CROSSING'**

<i>'footway=crossing'</i>	<i>APS</i>	<i>tactile paving</i>	<i>Cost</i>
<i>Crossing with traffic light</i>	✓	–	<b>Preferred</b>
	✗	✓	<b>Less Preferred</b>
	✗	✗	<b>Better to avoid</b>
<i>Crossing without traffic light</i>	–	✓	<b>Neutral</b>
	–	✗	<b>Less Preferred</b>
<i>uncontrolled intersection</i>	–	–	<b>Avoid</b>

(\*\*) Stairs with handrail receives a **Neutral** cost.

In stage 3.4.7 I explain in detail how the criteria are combined to generate the final weight

**TABLE 3. COSTS PER OPTIONAL VALUES OF THE KEY: 'HIGHWAY'**

OSM Value	Description	Relevance to Blind Pedestrians	Photo (source: <a href="#">OSM</a> )
<b>Footway</b>	Designated footpaths.	Exclusively for pedestrians - <b>Preferred route (*)</b> .	
<b>Living street</b>	Residential streets where pedestrians have legal priority over cars, speeds are kept very low and where children can play on the street.	Mostly too wide, and shared by bikes, cars, and pedestrians - <b>Better to avoid route</b> .	
<b>Path</b>	Non-specified path.	Usually designed for pedestrians, but difficult to orient, and usually consists of a very bad surface - <b>Neutral route</b> .	
<b>Pedestrians</b>	Roads used mainly by and exclusively for pedestrians in shopping and some residential areas, which may allow accessed by motorized vehicles only for very limited periods of the day.	No landmarks, wide, busy, and access of cars and bikes with pedestrians is allowed - <b>Better to avoid route</b> .	
<b>Stairs</b>	Flights of steps (stairs) on footways.	Mostly challenging and inaccessible for blind pedestrians - <b>Less Preferred route (**)</b> .	
<b>Service</b>	Access roads to - or within - an industrial estate, camp site, business park, car park, etc.	Mainly used by cars - <b>Avoid route</b> .	
<b>Unclassified</b>	Minor roads, which serve a purpose other than access to properties.		

Table 4 summaries the costs that can be obtained from each criterion.

**TABLE 4. SUMMARY OF COSTS PER CRITERION**

Criterion	Qualitative Cost	Quantitative Cost
Length	The shorter the way - the smaller the cost.	The way length in meters. For example, for a way with length of 80 meters, the cost is 80.
Way Type	Preferred Nice to have Neutral Less Preferred Better to avoid Avoid	1 2 3 4 5 6
Complexity	The less significant the curves - the smaller the cost.	The number of substantial curves. For example, the cost of a way with 2 significant curves is 2.
Landmarks	The larger the number of landmarks - the smaller the cost.	The number of landmarks in specified threshold from a certain way or from its intersection with other ways. For example, a way with three landmarks in distance less than 1.5 meters will decrease the cost by -3. One of them is, additionally, within the distance threshold to a nearby intersection of this way, the cost decreases by -1, and the total cost is -4.

### 3.3 OSM Mapping Data Collection and Arrangement

In this stage, I present a case study I have conducted to deal with a crucial problem in OSM database - missing of essential data for blind pedestrians while navigating. Without this data, the routing algorithm unable to propose optimal routes to blind pedestrians.

OSM project has the resources and infrastructures to insert and edit mapping and semantic data and information that is useful for the purpose here. More specifically:

- **Tactile paving** - a tag that gives information about the existence of tactile paving near crossings, together with additional properties ('tactile\_paving = contrasted/ primitive /

incorrect'). This feature is very important since it gives information regarding safe crossing for blind pedestrians, contributing to the effectiveness and safeness of their navigation.

- **Surface** - surface tag gives information about the surface type and its smoothness, hence is very relevant to blind pedestrians using a white cane.
- **Traffic signal** - series of tags that supply with rich and augmented information tailored for and important to blind pedestrians about sound, vibration, tactile arrow, tactile map, and floor vibration.
- **Pedestrians crossing** - this feature informs how the crossing is controlled, and whether it includes an island or tactile paving.
- **Entrance** - point feature that is located in building entrance.
- **Street** – it is possible to insert sidewalks (which are way features) along the road together with attribute information, such as: width, surface type and smoothness, incline, curb, tactile paving and access.

Although the capacity is there, and mapping possibilities are vast, a large volume of data and information are still missing in the OSM database and map, even in very detailed urban areas. Figure 3 depicts one of the most detailed mapped cities in OSM - Santa-Cruz in California. Together with the 'regular' mapped features, also sidewalks and crossings that are usually missing in other places are mapped in detail. Moreover, crossings are tagged with the 'crossing' key that indicates whether it is controlled by a traffic light. However, accessibility information for blind pedestrians, such as tactile paving or accessible traffic signal, are missing. This is crucial when it comes to validation and testing of a tailored routing algorithm that is highly dependent on existing route information; in case only partial information exists, the generated routes might misinform the users and give them ill-defined outcome. For example, without information about accessible crossings, the algorithm will prefer not to recommend a route that includes crossings, even if in fact the crossings are accessible.

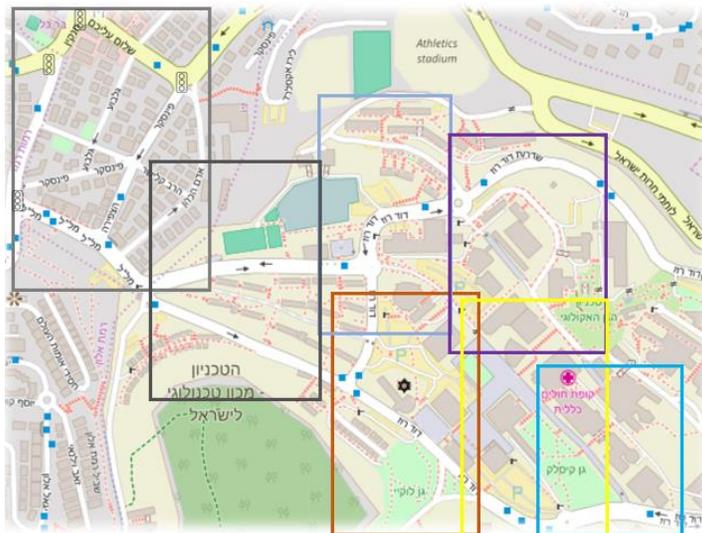
To overcome issues related to missing data and information, I have decided to map into the OSM database an area with all available data and information required for blind pedestrians; adding missing features (e.g., footway), and updating existing features with required information (e.g., attributes regarding whether the crossing has tactile paving).



**FIGURE 3. OSM MAP OF SANTA CRUZ, CALIFORNIA**

I choose the Technion Campus, in Haifa, Israel, as the case study area. The area was divided into seven rectangles, depicted in Figure 4. Each rectangle is mapped by a volunteer, according to instructions I wrote (detailed later). The instructions focus on mapping of data that might be missing in OSM, and are valuable to blind pedestrians.

The Technion Campus serves as a good case study since it presents with almost all the spatial and environmental features detailed beforehand that are valuable for the process. Still, some other features do not exist, e.g., traffic lights. To overcome this, mapping was also performed outside of the Technion Campus – the area depicted on the upper-left corner in Figure 4 having four traffic lights.



**FIGURE 4. CASE STUDY AREA OF THE TECHNION CAMPUS**

The instructions for the mapping were:

1. Sidewalks
  - If the feature does not exist on OSM map, update it.
  - Update surface (tag) - paved/asphalt/concrete/dirt.
  - Update entrances to parking lots, buildings, etc.
  - Update broken, raised or uneven sidewalk, holes or cracks in the sidewalk.
2. Crossings
  - If the feature does not exist on OSM map, update it.
  - Update tactile paving.
  - Update traffic islands between crossings.
3. Traffic signals
  - If the feature does not exist on OSM map, update it.
  - Update accessibility - vibration, sound, auditory information.
4. Bus stops
  - If the feature does not exist on OSM map, update it.
  - Update tactile paves.
5. Steps
  - If the feature does not exist on OSM map, update it.
  - Update if there is a railing or not.
6. Traffic sign, poles, trees, entrances and footways
  - If the feature does not exist on OSM map, update it.

In addition, I have asked volunteers to sketch features on the map, based on the legend depicted in Figure 5. This figure depicts an example of one mapping campaign with sketches; this map represents the area depicted as a yellow rectangle in Figure 4. Editing of all new and updated features and attributes was made with the iD-in-browser editor. Based on the sketches, I have mapped all the missing features as points, lines, and polygons according to their definition in OSM. Relevant tags (attributes) were added to the new and existing features.

Figure 6 is an example of a new crossing feature (orange line segment), which was collected (surveyed) and mapped in OSM with all relevant tags: (1) 'highway=footway', OSM element designed for pedestrians; (2) 'footway=crossing', footway OSM element designed for crossing a road; (3) 'crossing=island', crossing ends with a traffic island, which means another crossing will exist right after; (4) 'tactile paving=yes', easier to be identified by blind pedestrians.

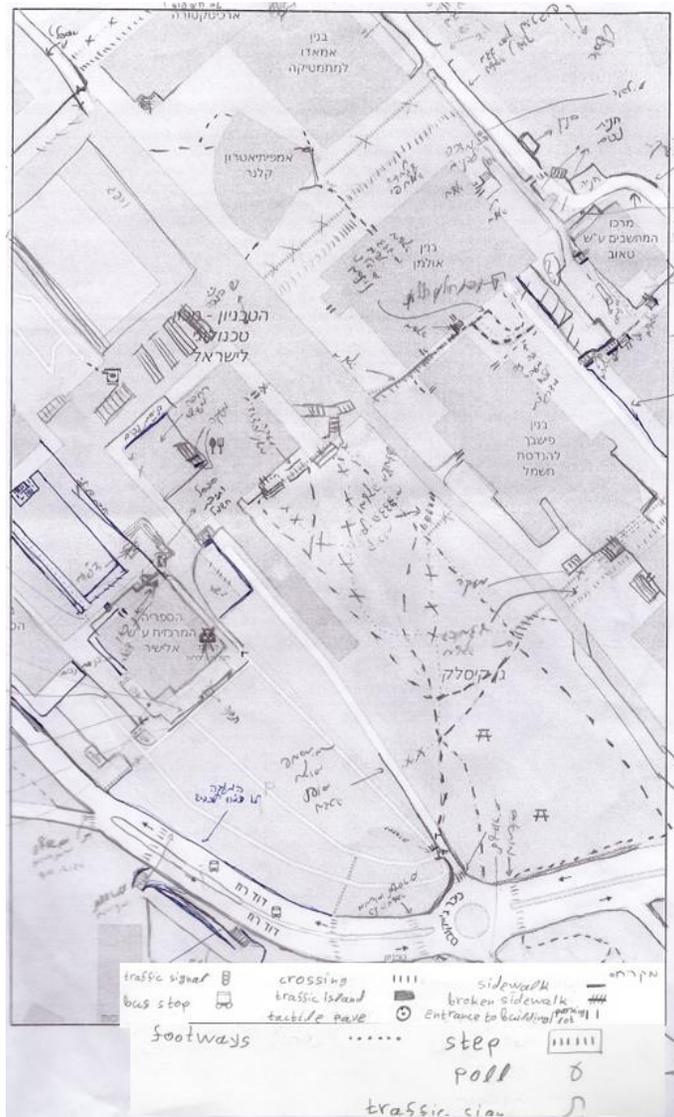


FIGURE 5. SKETCH OF THE AREA MAPPED IN THE TECHNION CAMPUS.

דרכי: 402170643

crossing was missing

ACIV נערך לפני 9 חודשים על-ידי

גרסה #1 · ערכת שינויים #37668370

תגים

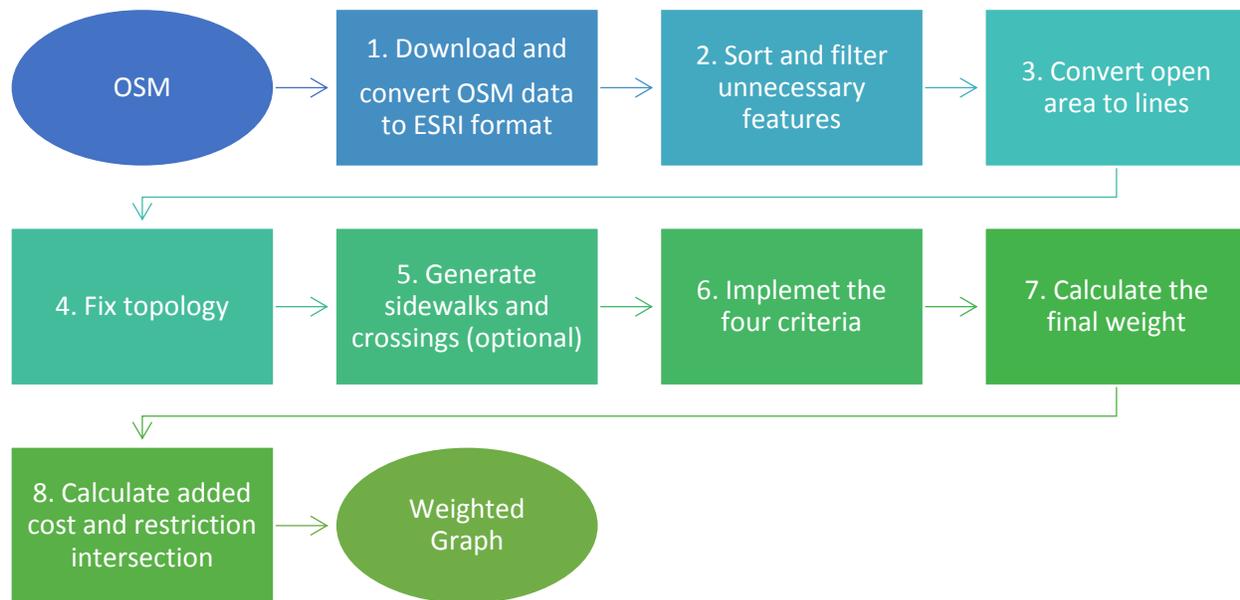
crossing	island
footway	crossing
highway	footway
tactile_paving	yes



FIGURE 6. NEW OSM CROSSING FEATURE.

### 3.4 Building of Routing Graph

This section shows how the OSM map and data and the four criteria are used to build the graph. The graph generation includes many tasks, as depicted in Figure 7. It starts with downloading the OSM data to the local machine and convert it to ESRI format, followed by the tasks of sorting, filtering, and editing data that are required before implementation of the criteria and calculation of the final weight. Another task is to calculate the added cost and restriction intersection.



**FIGURE 7. WEIGHTED GRAPH WORKFLOW.**

Building the graph was implemented using ESRI’s ArcGIS desktop software, which is a GIS that allows editing and analysis of maps and geographic information. For most tasks, a corresponding model is built using ModelBuilder<sup>10</sup>, where other were coded in Python.

ModelBuilder is an ArcGIS application, interpreted as a visual programming language for building workflows, designed to create, edit, and manage different data and models in the ArcGIS working environment. Models are workflows that string together sequences of different geoprocessing tools with data inputs and outputs. Some tools are an integrative part of ArcGIS software, whereas others are not, and must be developed and added manually to the ModelBuilder.

<sup>10</sup> ModelBuilder - <http://desktop.arcgis.com/en/arcmap/10.3/analyze/modelbuilder/what-is-modelbuilder.htm>

OpenStreetMap toolbox is one example of tools developed and designed to work with OSM data on the ArcGIS platform. Figure 8 depicts an example of the workflow model designed to generate a representative skeletal line from input polygons. To that end, the model strings together sequences of: Create Skeleton, Trim Skelton, Add Field, Calculate Field and Append tools. The final graph will be built using 'Network Dataset' ArcGIS tool which models transportation networks and allowing to find the least-weight route with Dijkstra algorithm. Here, a network was designed, modelled and tailored for blind pedestrians.

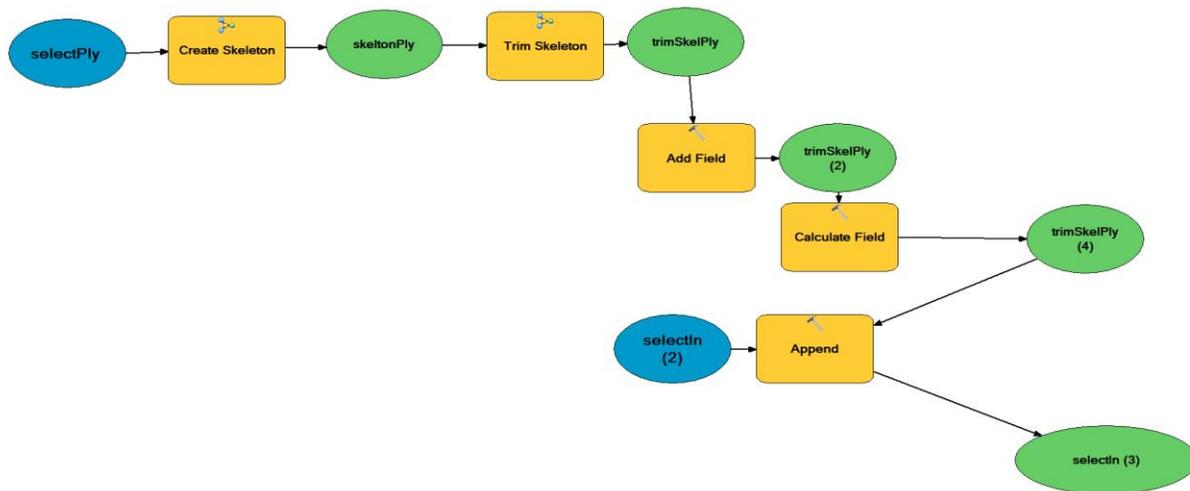


FIGURE 8. OPEN AREA TO LINE MODEL.

### 3.4.1 Download and Convert OSM Data to ESRI Format

1. ArcGIS allows displaying OSM map in its platform by using the OpenStreetMap toolbox, extracting and symbolizing the OSM data – geometry and attributes. Table 5 shows the tags that were stored, filtered by their keys, which will be used later.
2. OSM data were converted to Feature Class (FC), which is ESRI’s format for a collection of geographic features with the same geometry type, such as node, line, or polygon, having the same attributes and the same spatial reference<sup>11</sup>. Each FC has an attribute table with rows storing the different elements (IDs), and attributes in the columns (it is named also fields).

<sup>11</sup> GIS dictionary: Feature Class - <http://support.esri.com/other-resources/gis-dictionary/term/feature%20class>

**TABLE 5. THE STORED TAGS THAT WERE FILTERED BY THEIR KEYS ACCORDING TO FEATURE TYPE (GEOMETRY ELEMENTS).**

	Nodes	Lines	Polygons
Keys	Amenity	Crossing	Highway
	Building	Footway	
	Crossing	Handrail	
	Highway	Highway	
	Leisure	Sidewalk	
	Natural	Surface: grade	
	Power	Tactile paving	
	Shop		
	Traffic signals: sound		
	Traffic signals: vibration		

### 3.4.2 Sort and Filter Unnecessary Features

Many features downloaded from OSM database are not necessary to model, thus were deleted. Only features with one of the ‘key=value’ tags detailed in Table 6 are stored. Table 6 details tags relevant to the Technion Campus, while some more tags might be required to other places. For example, the node features are mostly stored for Landmarks criterion, whereas in Manhattan, NYC, the main public transportation is subway and considered as reliable landmarks; therefore ‘railway=subway entrance’ can also be considered in Table 6 for features of node element.

Implementing this task, all line features with one of the ‘key=value’ tags in the green column in Table 6 are kept in FC, which form the graph ways named GraphWays FC; the next tasks will be mainly performed on this FC. Lines with one of the ‘key=value’ tags in the red column – roads, which blind pedestrians should avoid, are stored in another FC, which will be used in task 8 - ‘Calculate added cost and restriction intersection’, and as restriction lines on the graph. The stored node features will be used when a Way Type and Landmark criteria will be executed, and the stored polygon features will be used for the next task.

TABLE 6. USED KEY-VALUE PAIRS OF STORED OBJECTS

	Nodes		Lines	polygons
<b>Highway</b>	<b>Amenity</b>	<b>Highway</b>	<b>Highway</b>	<b>Highway</b>
'traffic signals'	'telephone'	'footway'	'cycleway'	'pedestrian'
'street lamp'	'fountain'	'path'	'motorway'	
'crossing'	'bicycle parking'	'pedestrian'	'motorway link'	
'bus stop'	'bicycle rental'	'service'	'primary'	
'stop'	'fast-food'	'steps'	'residential'	
'steps'	'waste disposal'	'unclassified'	'secondary'	
<b>Building</b>	'wastebasket'		'tertiary'	
'entrance'	'vending machine'		'trunk'	
<b>Natural</b>	'restaurant'		'trunk link'	
'tree'	'recycling'			
<b>Power</b>	'post-box'			
'pole'	'parking'			
<b>Leisure</b>	'fuel'			
'picnic table'	'food court'			
<b>Shop</b>	'fast-food'			
'supermarket'	'cafe'			
'bakery'	'bus station'			
'kiosk'	'bench'			

### 3.4.3 Convert Open Area to Lines

Routing can be implemented only on linear elements. However, some streets in OSM map are displayed (and stored) as polygons, e.g., squares, considered here as an open space. To fix this, I have developed an algorithm comprised of these steps (depicted in Figure 9): a) create a Thiessen polygon from nodes along each polygon's outline; b) Thiessen polygons' nodes are triangulated into a Triangulated Irregular Network structure according to Delaunay criterion<sup>12</sup>; d) generate perpendicular bisectors for each triangle line, forming the lines of the Thiessen polygons. Locations at which the bisectors intersect determine the locations of the Thiessen polygon

<sup>12</sup> Wikipedia: Delaunay triangulation-[https://en.wikipedia.org/wiki/Delaunay\\_triangulation](https://en.wikipedia.org/wiki/Delaunay_triangulation)

nodes<sup>13</sup>; d) convert each Thiessen polygon outline to lines. Lines that are part of the source polygon outline are removed; e) connect open space lines to GraphWays FC.

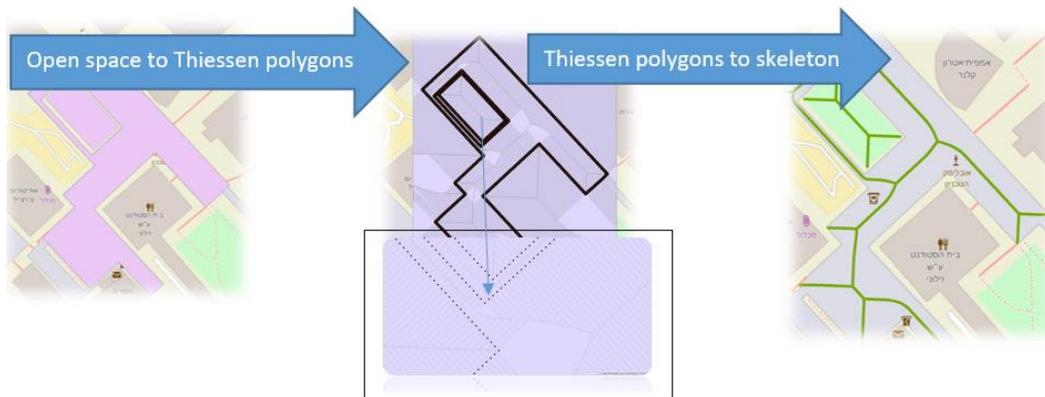


FIGURE 9. FROM OPEN SPACES TO LINES

### 3.4.4 Fix Topology

In OSM, strict regulation and inspection have not been performed on the mapping elements (i.e., nodes, lines, polygons), which can result in topological errors that do not match the graph requirements. Hence, I had to fix this prior to the implementation of the four criteria.

#### a. Fix discontinuity

In OSM, when road intersects footways, occasionally topological errors occur as discontinuities and gaps between the footways lines (Figure 11:A). For example, if in OSM the footways are connected to the external road border, gaps between these features are evident when a road is being represented as a line in this study. These gaps lead to errors in the final graph and accordingly in the routing algorithm. To solve this, I have developed a topology rule that fixes this gap, comprised of the stages described in the Pseudo-code in Figure 10 and in Figure 11.

#### b. Intersections defined only at start/end of line

To run Dijkstra algorithm properly, the network intersections are set out only when a start/end line has the same location as at least one other start/end line. Otherwise, the Dijkstra algorithm will ignore intersections that do not comply with this condition, which will deviate results in case an intersection does exist.

---

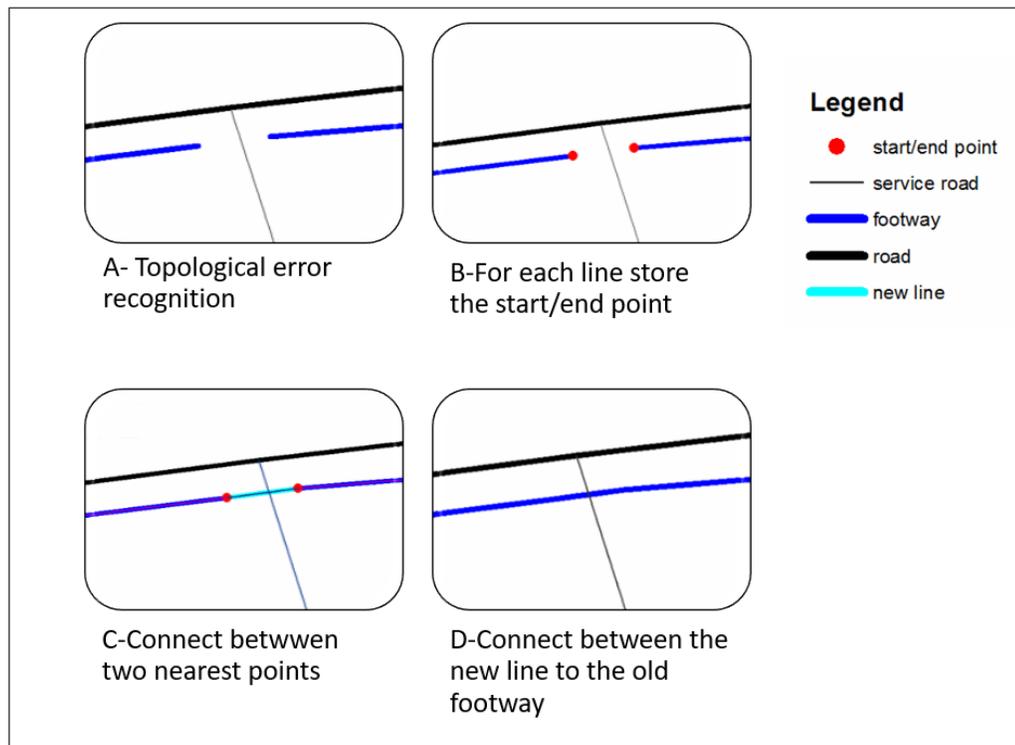
<sup>13</sup> ESRI Resources: Creating Thiessen polygons-  
[http://resources.esri.com/help/9.3/arcgisdesktop/com/gp\\_toolref/coverage\\_toolbox/creating\\_thiessen\\_polygons.htm](http://resources.esri.com/help/9.3/arcgisdesktop/com/gp_toolref/coverage_toolbox/creating_thiessen_polygons.htm)

```

pointsList = empty list
newLines = empty list
//Figure11: B
For each line in graphWays FC
{
    add to pointsList(start point of line)
    add to pointsList(end point of line)
}
//if two or more points with same location, leave only one in the pointsList
dissolve(pointsList)
//Figure11: C
For each point in pointsList
{
    //find the nearest point to point in pointsList
    nearestPoint = near( point, pointsList)
    if distance( point,nearestPoint) <7
        //7 relates to 7 meters avarage width of two urban lanes road in Israel
        {
            line = create line(point,nearestPoint )
            add to newLines(line)
            delete from pointsList( point,nearestPoint )
        }
}
//Figure11: D
append(newLines, graphWays FC)

```

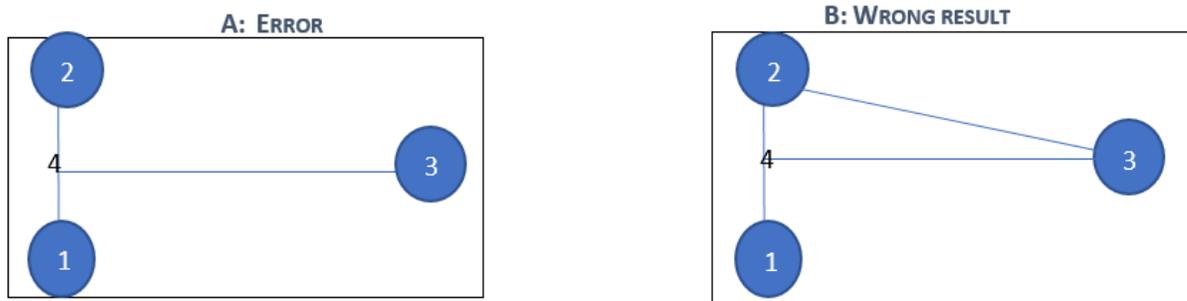
**FIGURE 10. PSEUDO CODE TO FIX DISCONTINUITY**



**FIGURE 11. FIX DISCONTINUITY ERRORS WORKFLOW**

Figure 12:A depicts the location of a horizontal line end (4) at the middle of the vertical line (1-2), which means the location is not a network intersection. Consequently, searching for the shortest route from node 1 to node 3, the Dijkstra algorithm ignores intersection 4, resulting in an error since no such route exists. Figure 12:B depicts three lines and two intersections with a similar problem of intersection 4. This time, Dijkstra algorithm will calculate a longer route than the desired one. In OSM, it is not rare that line can start/end in a middle of another line without an intersection, as a result of various users that can edit the map or updates being inserted at the time - to name a few.

To solve this problem, I have developed a topology rule that: a) retrieves this type of intersections using ArcGIS system toolbox that recognizes all the lines that are crossed by other lines, and store them as new intersection points; b) for each line intersected with one (or more) intersection points, split line at intersection location to two lines, and store in database.



**FIGURE 12. AN EXAMPLE OF A WRONG GRAPH – MISSING INTERSECTION ELEMENTS.**

### 3.4.5 Generation of Sidewalks and Crossings (optional)

Commonly, data on sidewalks and crossings are missing in OSM, but critical here. If for a given area one cannot ascertain all roads have sidewalks and crossings, an algorithm was developed that automatically generates these, and adds the new elements to the graph (Figure 13). This is achieved by: a) buffering all roads and store them as polygons; b) convert buffered polygons to line sidewalks; c) split the new line sidewalks in each intersection point to change short line segments representing crossings between adjacent sidewalks.

A-No sidewalk, alongside the road.



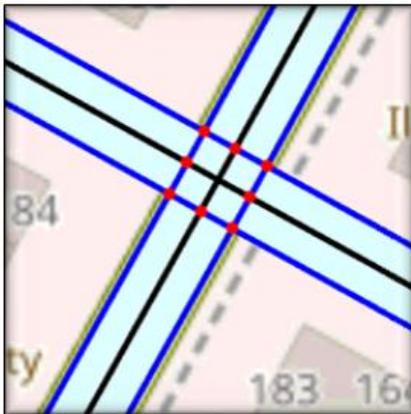
B-Apply buffer of 5 meters to each side of the road



### Legend

-  crossings
-  sidewalks
-  roads
-  intersection points
-  buffers

C-Convert the buffer polygons to polylines, and split polylines at each intersection



D-For each new polyline, if its length is less than 15 meters than it crossing, else it sidewalk.



FIGURE 13. GENERATION OF SIDEWALK NETWORK IN MANHATTAN, NYC

### 3.4.6 Implement the Four Criteria

Now that ways (GraphWays FC) are geometrically and semantically correct, criteria costs are implemented. Each way is examined by analysing its attributes and executing geoprocessing tools to obtain costs regarding each criterion. The costs will be stored as new attributes added to the GraphWays FC. The Length criteria cost is automatically calculated by ArcGIS, and stored as a geometric attribute.

#### Landmarks criterion

To apply cost regarding landmark criterion, for each line in GraphWays FC the number of landmarks is calculated (node features stored as described in paragraph 3.4.2) based on the threshold of 1.5 meters. The result value is stored as a new attribute (field) named 'LM near' and added to the GraphWays FC.

For landmarks near decision points (intersections) more stages were made: 1) new temporary FC was created to store the start and end nodes of each line with the line ID they belong to; 2) for each node in the temporary FC the number of landmarks within the threshold was calculated and stored as new attributes in the temporary FC; 3) the results of stage 2 were passed into new attributes named 'LM\_Dpnt' by comparing the line ID of the temporary FC with these of the GraphWays FC. Finally, another attribute was added, named 'LM\_w', which stores the cost regarding this criterion, by summing 'LM\_near' + 'LM\_Dpnt' values.

Figure 14 illustrates how the cost of Landmark criterion is implemented. Two landmarks were found near the examined footway: one crossing and one street lamp. Accordingly, the value in 'LM\_near' field is -2. In addition, the crossing landmark is also near a decision point, so the value in 'LM\_Dpnt' field is -1, thus the overall way cost in the 'LM\_w' field is -3 ('LM\_near' + 'LM\_Dpnt').

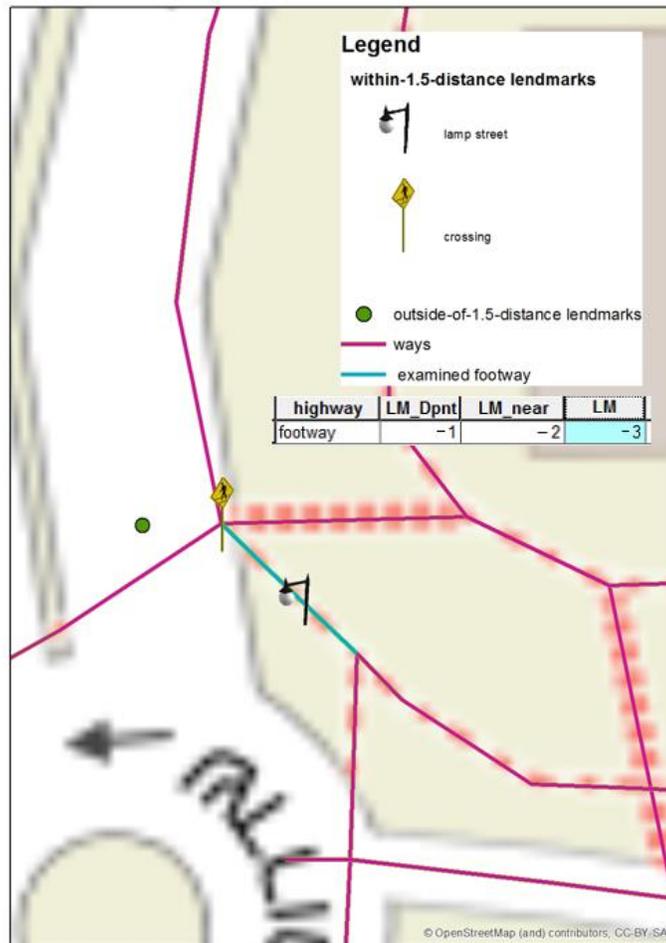


FIGURE 14. AN EXAMPLE OF LANDMARK CRITERION IMPLEMENTATION.

### Complexity criterion

Complexity counts the number of substantial curves, defined by an angular threshold of  $45^\circ$ . Figure 15 and Pseudo code in Figure 16 illustrate the idea of the complexity measure by calculating the angle between the azimuth values of two consecutive segments. If the angle minus  $180^\circ$  is larger than  $45^\circ$ , the way cost will increase by +1.

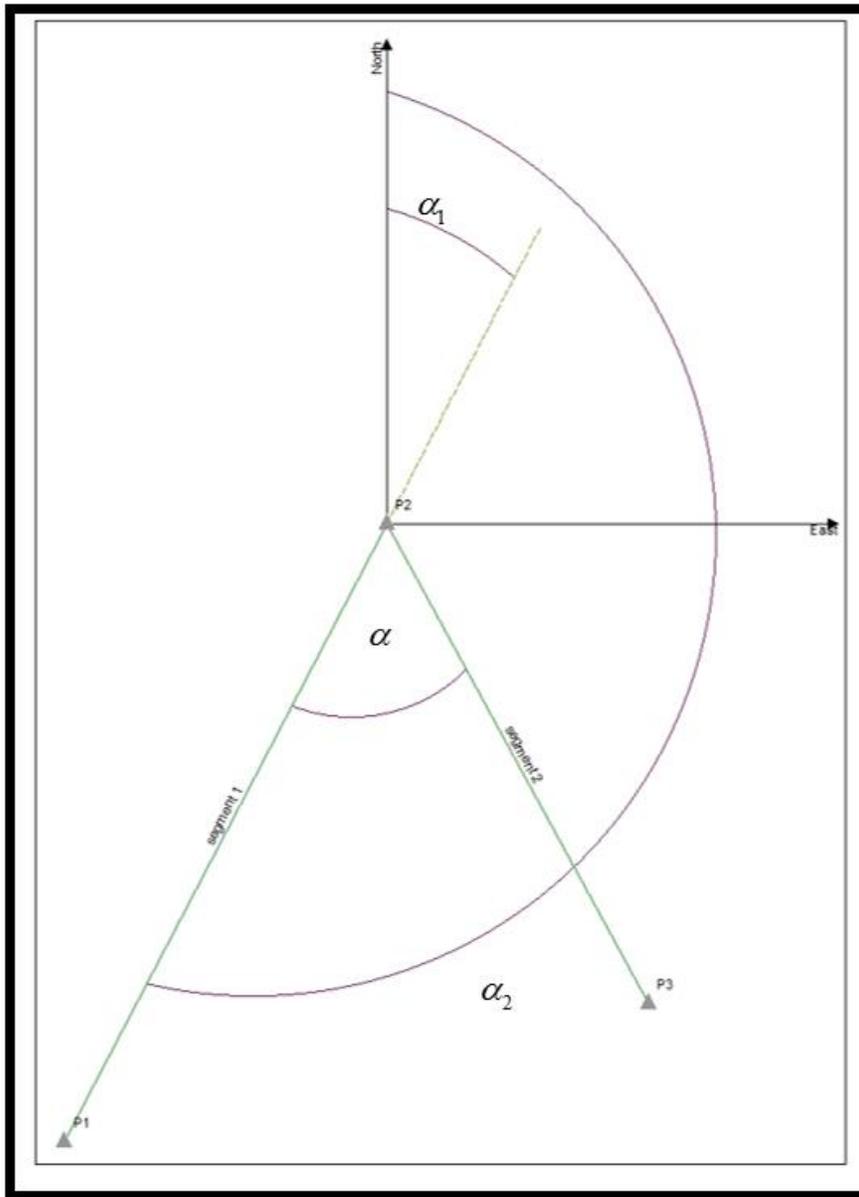


FIGURE 15. CALCULATE COMPLEXITY ANGLE BETWEEN TWO WAY SEGMENTS

```

Foreach line in the graph:
{
  If #segment > 1:
  {
    Foreach two consecutive segments:
    {
      
$$\alpha_1 = \tan^{-1} \left( \frac{\Delta E_{p1 \rightarrow p2}}{\Delta N_{p1 \rightarrow p2}} \right)$$

      
$$\alpha_2 = \tan^{-1} \left( \frac{\Delta E_{p2 \rightarrow p3}}{\Delta N_{p2 \rightarrow p3}} \right)$$

      
$$\alpha = \text{mod}(180^\circ - \alpha_1 + \alpha_2, 360^\circ)$$

      If  $|180^\circ - \alpha| > 25^\circ$ :
      {
        score by complexity ++
      }
    }
  }
}

```

**FIGURE 16. PSEUDO CODE OF COST BY COMPLEXITY CRITERION**

#### Way Type criterion

Traffic\_signals: sound/vibration attribute is not part of GraphWays attributes but an attribute of traffic light node features; therefore, I need to join this data attribute to the GraphWays attributes precede to the calculation of Way Type cost. To that end, I add two new empty attributes: 'traffic\_signals' and 'traffic\_signals: sound/vibration' to GraphWays FC, then search for each crossing line in GraphWays FC the nearest traffic light node feature with tolerance of one meter (the average stripe of zebra crossing is between 40 to 60 centimetres, but the traffic light used to be near and not on the crossing, so the tolerance is one meter). If for a certain crossing line, a traffic light node is found, the value of 'traffic\_signals: sound/vibration' attribute is copied from the given traffic light node to that of crossing line, also its traffic\_signals attribute received 'traffic\_signals = Yes'. When this process is completed, all the required attributes are ready to be examined for the cost calculation, which will be stored in a new attribute 'way\_w'.

Table 7 depicts an example, showing all attributes relevant to the Way type criterion and the cost ('way\_w') based on that attributes according to the considerations detailed in stage 3.2. For instance, way ID 410 with tags: 'highway=footway', 'OSM footway='crossing', 'OSM tactile paving=yes', 'Traffic signals=NULL', and 'Traffic signals: sound/vibration=NULL', hence based on Table 2 the cost in 'way\_w' is 4.

**TABLE 7. EXAMPLE OF WAYS FEATURES WITH RELEVANT FIELDS FOR WAY TYPE CRITERION AND FINAL WEIGHT**

OBJECTID	highway	OSM handrail	CALCULATED (WAY_W)					way_w
			OSM surface	OSM footway	OSM tactile paving	Traffic signals	Traffic signals: sound/vibration	
1	steps							4
2	service							6
18	unclassified							6
29	footway							1
47	steps	yes						3
95	path							3
139	footway			crossing				3
349	footway			crossing				3
410	footway			crossing	yes			4
445	footway			crossing	yes			4
548	footway			crossing	no			3
723	footway		1					3
741	footway		0					3
751	steps	no						4
778	open_area							6

### 3.4.7 Calculate the Final Weight

The final task required for a weighted graph is calculating the final weight for each way feature based on the accumulative costs given for all criteria. Equation (1) defines all the variables in that set.

$4 = \# \text{criterion}$   
 $n = \# \text{lines}, i = \text{line } i$

$$\begin{aligned}
 s_1^i &= \text{score based on criterion 1} \\
 &\vdots \\
 s_4^i &= \text{score based on criterion 4}
 \end{aligned} \tag{1}$$

$w = \text{normalized score}$   
 $W = \text{the final weight}$

Equation (2) depicts the normalization process required to avoid that one criterion will have more impact than others on the final weight. For example, the Length cost can be more than 100 whereas for Way Type is just 6. The obtained criterion values ( $w$ ) having the same scale between 0 and 10. Such that:

$$\left. \begin{aligned}
 w_1^i &= \frac{s_1^i}{\max(|s_1^1| \dots |s_1^n|)} * 10 \\
 &\vdots \\
 w_4^i &= \frac{s_4^i}{\max(|s_4^1| \dots |s_4^n|)} * 10
 \end{aligned} \right\} 0 \leq w^i \leq 10 \tag{2}$$

Equation (3) depicts the final calculation for obtaining the final weight for each way, where  $a_1, a_2, a_3, a_4$  are coefficients that determine the internal relations between the different criteria, which can be modified by the users. Higher value expresses a more significant criterion in the overall process.

$$W^i = a_1 w_1^i + a_2 w_2^i + a_3 w_3^i + a_4 w_4^i \tag{3}$$

Zero is a saturation value, which means blind pedestrians will be indifferent to differences between ways with a weight that is less than the saturation value. Therefore, the final weight that is less than zero for a way will be modified to zero, as shown in Equation (4).

$$\text{if } W^i < 0 \rightarrow W^i = 0 \tag{4}$$

The default coefficient values in Equation (3) are 1, meaning all criteria are of similar significance. As users might have different preferences, these values can be tuned and changed via the customized weight tool, depicted in Figure 17, where each criterion can be given a different coefficient value. For example, the figure depicts a user that prefers landmarks along a way, over way complexity.

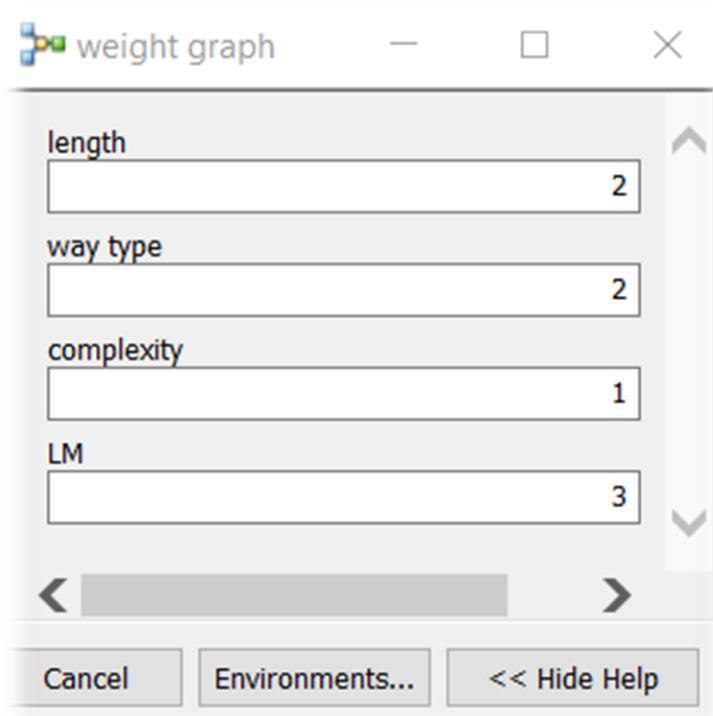


FIGURE 17. CUSTOMIZED WEIGHT TOOL.

To implement this set of equations on the ways (GraphWays FC), the following was done:

- 1) For each way, Equation (2) is calculated with values of attributes 'Shape\_Length', 'LM\_w' 'complexity\_w', and 'way\_w'; the results are stored in four new attributes: 'length\_final', 'LM\_final', 'complexity\_final' and 'way\_type\_final'.

For example, the calculation for 'way\_type\_final' in Table 8 for way ID 149 is:

$$s_4^{149} = 6$$

$$\max(s_4^1 \dots s_4^n) = 6$$

$$w_4^6('way\_type\_final') = \frac{6}{6} * 10 = 10$$

- 2) Equation (3) accumulates the values multiplied by the coefficients determined by the user (the default coefficient value is one), into 'final\_weight' attribute. For example:

$$a_i = 1$$

$$W^{149}(final\_weight) = 1.08 - 5 + 2 + 10 = 8.08$$

**TABLE 8. ATTRIBUTE TABLE OF SOME FEATURES WITH COST WITH RESPECT TO EACH CRITERION AND THEIR FINAL WEIGHT**

OBJECTID *	Shape_Length	LM_w	complexity_w	way_w	length_final	LM_final	complexity_final	way_type_final	final_weight
149	29.58	- 4	2	6	1.08	- 5	2	10	8.08
150	40.69	- 1	2	6	1.48	-1.25	2	10	12.23
269	29	0	2	3	1.06	0	2	5	8.06

Concluding this, the graph is ready to be used to find the optimal route based on the OSM network of ways, and the weights that express accessibility, preferences and safety measures designed for blind pedestrians.

### 3.4.8 Restrictions and Added Cost

Intersection points of roads (lines with one of the tags in the red column in Table 6) with lines from the GraphWays – except crossing ways – will be considered as Restriction points, which means points blind pedestrians should avoid navigating through. For example, no crossings in the intersection, as depicted in Figure 18.

Another type of points that can play an important role in the graph are Added Cost points. These points are intersections of ways intended for pedestrians with ways intended for cars and pedestrians (e.g., entrance to parking lot). These added cost points are identified by finding all intersection points of ways of tags 'highway= Living street/ Path/ Service/ Unclassified' with ways of tags 'highway= Stairs /Footway', all from the same FC "GraphWays". Consequently, navigation through this type of points will raise the weight of the route significantly.



**FIGURE 18. AN EXAMPLE OF UNCONTROLLED INTERSECTION**

### 3.4.9 Weighted Graph

Four FCs are used to build the final graph: a) ways blind pedestrians can navigate (walk) on; b) roads they should avoid, which serve as restrictions on the graph; c) Restriction points; d) Added Cost points.

Building the final graph was implemented using the Network Dataset tool. Network Datasets are made of network elements generated from the source features where geometry helps establish connectivity that enables knowing which ways along the network are viable, in our case – GraphWays FC. Network attributes are properties of the network elements that control traversability over the network<sup>14</sup>. The network dataset is very simple without modelling of turn restrictions (more relevant to cars) or elevation. In addition, only one attribute affects the network here - ‘final\_weight’. When the network is built, the weighted graph for blind pedestrians is ready to use.

An extract of the final weighted graph of the Technion Campus generated from the OSM road network and weights calculated based on the criteria is depicted in Figure 19. The turquoise ways are the ways the blind pedestrians are ‘allowed’ to walk on, the values near each turquoise way is its corresponding weight. The red ways are roads they should avoid (not ‘allowed’) to walk on, meaning the routing algorithm will not consider. The red circles are Restriction points a route will not cross. The yellow circles are Added Cost points which are locations preferred to avoid passing through.

Some attributes of two way features are detailed to realize how they receive their weights. The left feature is shorter than the lower feature, although it has higher weight because it is a highway of type ‘service’, which means higher cost regarding way type criterion, and it is also more complex when compared to the right feature. On this network graph, the user can choose an origin and destination points, and retrieve the optimal route in terms of the needs and preference of blind pedestrians.<sup>15</sup>

---

<sup>14</sup> ESRI- What is a network dataset? <http://desktop.arcgis.com/en/arcmap/latest/extensions/network-analyst/what-is-a-network-dataset.htm>

<sup>15</sup> <https://www.youtube.com/watch?v=0hN5dB8moEM>

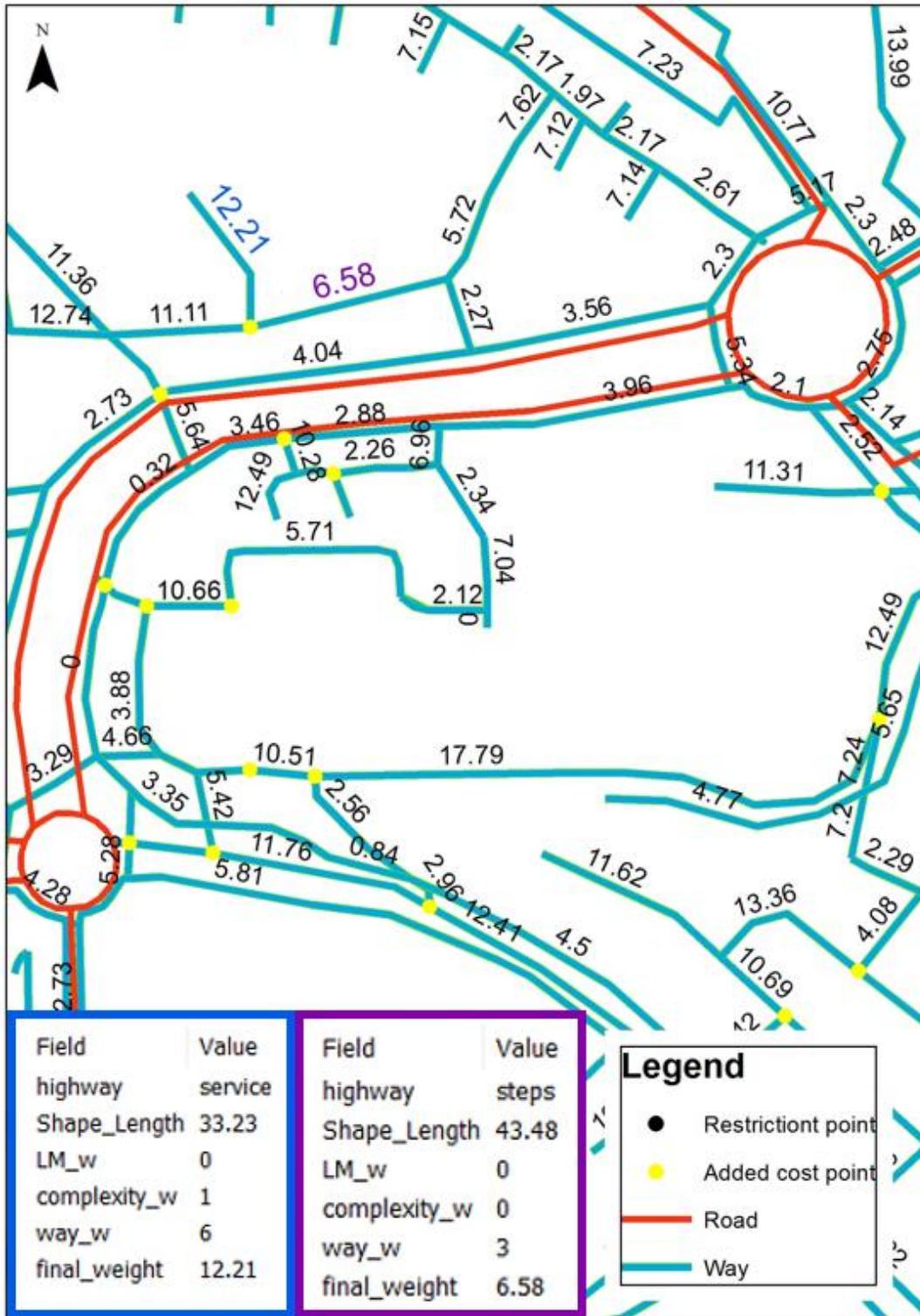


FIGURE 19. AN EXTRACT OF THE FINAL GRAPH BASED ON THE OSM ROAD NETWORK OF THE TECHNION CAMPUS

## 4. Experimental results

In this section, the implementation and analysis of the routing algorithm are presented, along with several experiments. Experiments were carried out in various locations and scenarios to draw more robust conclusions, and point to important advantages – as well as limitations – the implemented methodology might have.

### 4.1 Quantitative Evaluation

The first scenario in the Technion Campus marked the origin of the route at the entrance of the student dormitories, depicted in Figure 20 (circled 1 on the left), with the destination a couple of hundred of meters to the right (circled 2). There exist three possible candidate routes depicted in green, blue and orange. The orange route leads directly to the dormitories through a service road; the green and blue routes detour the service road by running through sidewalks, footways and staircases to the dormitories.

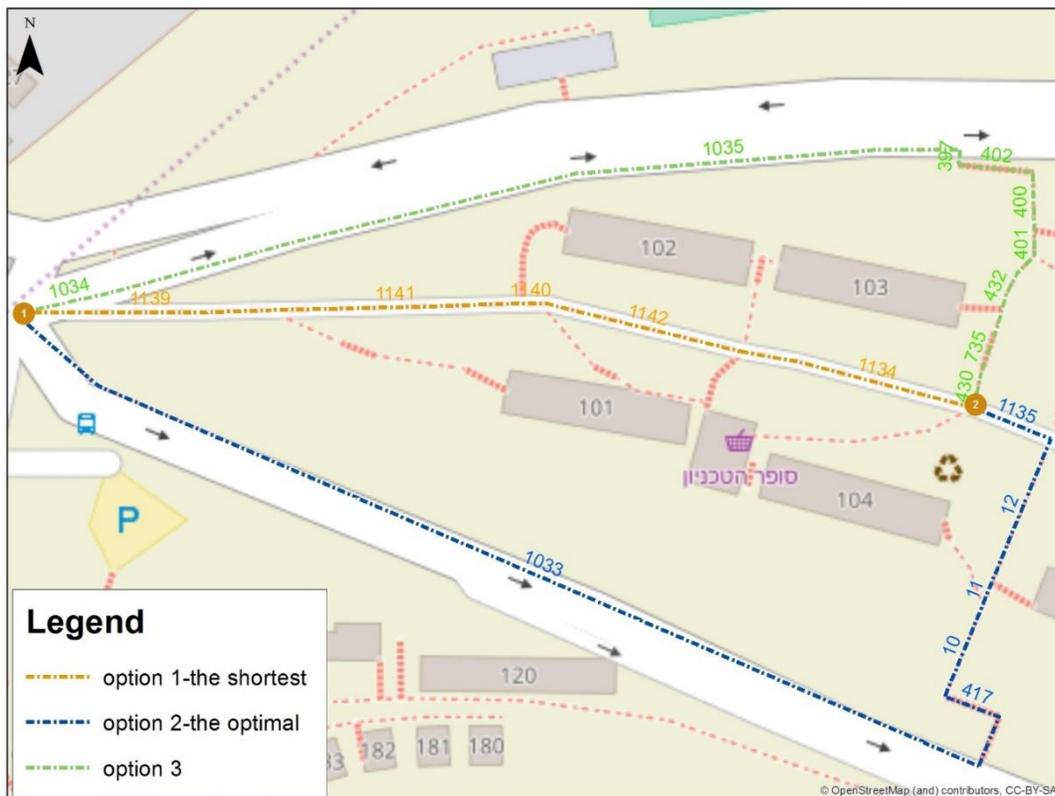


FIGURE 20. SCENARIO 1: DIFFERENT ROUTES BETWEEN ORIGIN (POINT 1) AND DESTINATION (POINT 2).

Observing Table 9, that presents all criteria and weights of different options, we can see that the algorithm finds the blue route as the optimal route, although the orange one is the shortest. For sighted pedestrians, the orange route is optimal since it is the shortest, not complex and has several landmarks along it. However, the route goes through a service road, meaning it is used also by vehicles, thus eventually it gains the highest weight among all routes and should be avoided by blind pedestrians. The optimal blue route, which although has a short segment of a service road way, is still preferred over the green route since it is composed of fewer lines (road segments), thus it is less complex. Moreover, way ID 1033 has many landmarks alongside, which decreases its weight close to zero, thus is chosen by the algorithm as the optimal route. In case users would prefer to avoid at all cost service roads, then the green route option would have been preferred over the blue one.

Explained in stage 3.1, blind pedestrians could have different preferences, so that some criteria will be preferred over the others, which can lead to the selection of a different route as the optimal one. Table 10 and Table 11 illustrate how different relations between the criteria affects the selected route among the three options depicted in Figure 20. Table 10 shows a case where the Length criterion is the most important over the others and Landmarks are an unnecessary criterion (Landmarks=0). In this case, the algorithm computes the green route as the optimal route; its weight ('total weight=45.92') is lower than the orange route ('total weight=66.02') and the blue route ('total weight=48.36'). The blue route obtained higher weight this time since landmarks cannot compensate long segments such as for way ID 1033 (its 'final weight=19.43' as compared to its 'final weight=0.55' beforehand). Table 11 presents a case where the Length is still the most important criterion, but now the Way Type criterion has no significance. The algorithm selects the orange option as the optimal route, since it is the shortest one and this time navigation through a service road does not affect the weight.

This analysis proves that the algorithm works properly and is adjustable, taking into consideration the environmental criteria selected here, producing qualitative and logical calculations that rely on all parameters used.

**TABLE 9. THREE OPTIONAL ROUTES: ATTRIBUTES, WEIGHTS AND FINAL WEIGHT**

Blue route-The Optimal							
ID	Highway	Handrail	Way Type	LM	Complexity	Shape Length	Final Weight
10	footway		1	0	0	22.43	2.48
11	footway		1	0	0	5.90	1.88
12	footway		1	0	0	35.68	2.97
417	steps	yes	3	0	1	25.68	6.94
1033	footway		1	-8	0	243.80	0.55
1135	service		6	-2	0	19.26	8.20

**Total length**            **352.757 m**

---

**Total weight**            **23.02**

---

Orange route-The Shortest							
ID	Highway	Handrail	Way Type	LM	Complexity	Shape Length	Final Weight
1134	service		6	-4	0	54.43	6.98
1139	service		6	-3	0	55.12	8.26
1140	service		6	0	0	3.93	10.14
1141	service		6	-2	0	58.28	9.62
1142	service		6	-3	0	48.14	8.00

**Total length**            **219.90 m**

---

**Total weight**            **43.01**

---

Green route							
ID	Highway	Handrail	Way Type	LM	Complexity	Shape Length	Final Weight
397	footway		1	0	0	3.40	1.79
400	footway		1	0	0	13.54	2.16
401	footway		1	0	0	5.92	1.88
402	steps	yes	3	0	0	17.24	5.63
430	footway		1	0	0	8.65	1.98
432	footway		1	0	0	14.71	2.20
433	footway		1	0	0	5.27	1.86
735	steps	yes	3	0	0	9.45	5.34
1034	footway		1	-1	1	19.66	2.13
1035	footway		1	0	0	198.50	8.90

**Total length**            **296.36 m**

---

**Total weight**            **33.88**

---

**TABLE 10. THE OPTIONAL ROUTE WEIGHTS WHEN COEFFICIENTS CRITERIA ARE:**

**WAY TYPE=1, LANDMARK=0, COMPLEXITY=1, LENGTH=2**

The blue route		The orange route		The green route	
ID	Final Weight	ID	Final Weight	ID	Final Weight
10	3.30	1134	13.97	397	1.91
11	2.10	1139	14.02	400	2.65
12	4.27	1140	10.29	401	2.10
417	7.87	1141	14.25	402	6.26
1033	19.43	1142	13.51	430	2.30
1135	11.40			432	2.74
				433	2.05
				735	5.69
				1034	4.10
				1035	16.13
<b>Total weight</b>	<b>48.36</b>		<b>66.02</b>		<b>45.92</b>

**TABLE 11. THE OPTIONAL ROUTE WEIGHTS WHEN COEFFICIENTS CRITERIA ARE:**

**WAY TYPE=0, LANDMARK=1, COMPLEXITY=1, LENGTH=2**

The blue route		The orange route		The green route	
ID	Final Weight	ID	Final Weight	ID	Final Weight
10	1.63	1134	0.00	397	0.25
11	0.43	1139	0.27	400	0.99
12	2.60	1140	0.29	401	0.43
417	2.87	1141	1.75	402	1.26
1033	7.76	1142	0.00	430	0.63
1135	0.00			432	1.07
				433	0.38
				735	0.69
				1034	1.18
				1035	14.46
<b>Total weight</b>	<b>15.29</b>		<b>2.30</b>		<b>21.34</b>

Scenario two at the Technion Campus aims to provide more qualitative results, mainly safety and accessibility measures that are expressed in the selected optimal route. This time, the main navigation issue involves crossing a main road. Figure 21 depicts how the algorithm suggests a longer yet safer and more accessible route: it crosses a road through a crossing that has APS.

From origin point 1 to destination point 2 (both circled in green), two optional routes are computed: (1) the orange route that goes south on the sidewalk and then turns left to crossings

that has no APS traffic light, ending in point 2; (2) the blue route that goes north on the sidewalk, and then turns right to crossings having APS traffic light, and then back south ending in point 2. The algorithm selects the blue route as the optimal one, although it is longer, since its total weight is smaller than of the orange route (routes' values depicted in Figure 21). The crossings having no APS traffic light (ways IDs 1195 and 1185) have a weight that is more significant than for both the long ways (ways IDs 704 and 723) and the crossings having APS traffic light (ways IDs 197, 199 and 1185).

The difference between these routes with respect to their weights is relatively small (1.37), which means that if origin point 1 will be moved to the intersection 724-1195, the optimal route will become the shortest one, although it means passing through crossing having no APS. That is because length is also an important criterion that raises the orange route's weight, while decreasing the blue route's weight. This means that choosing weights, as well as coefficients, is very important. For example, as in this case, if safety measures are mandatory, then raising the weight of crossings having no APS should be considered to avoid blind pedestrians crossing there.

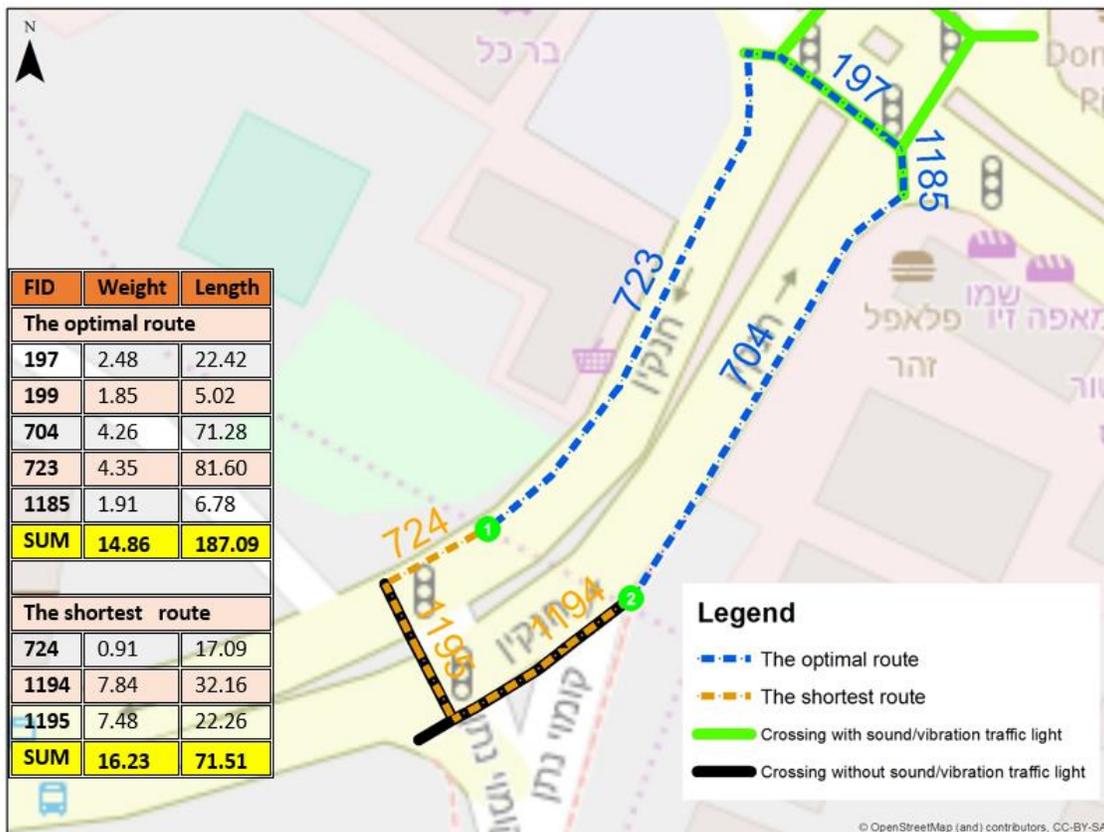


FIGURE 21. SCENARIO 2: ROUTE WITH TRAFFIC LIGHT CROSSING

Figure 22, is another example in the Technion Campus, where the algorithm does not select the shortest route but instead a longer - yet safer - route that avoids passing through added cost points. Origin point 1 is near a small intersection that people usually cross, although it has no pedestrian crossings, which is very dangerous to blind pedestrians, and thus being modelled with added cost points. The yellow route goes through this intersection to destination point 2, thus its weight is raised by 10, and the total weight accumulated to 15.77. Consequently, the algorithm prefers a route having lesser weight (14.71), the turquoise route, which, although longer, it avoids the dangerous intersection by going west to an intersection nearby that has a crossing, and then back to destination point 2. This kind of an intersection can be also customized by increasing or decreasing the added point cost, or entirely exclude these ways from the graph.

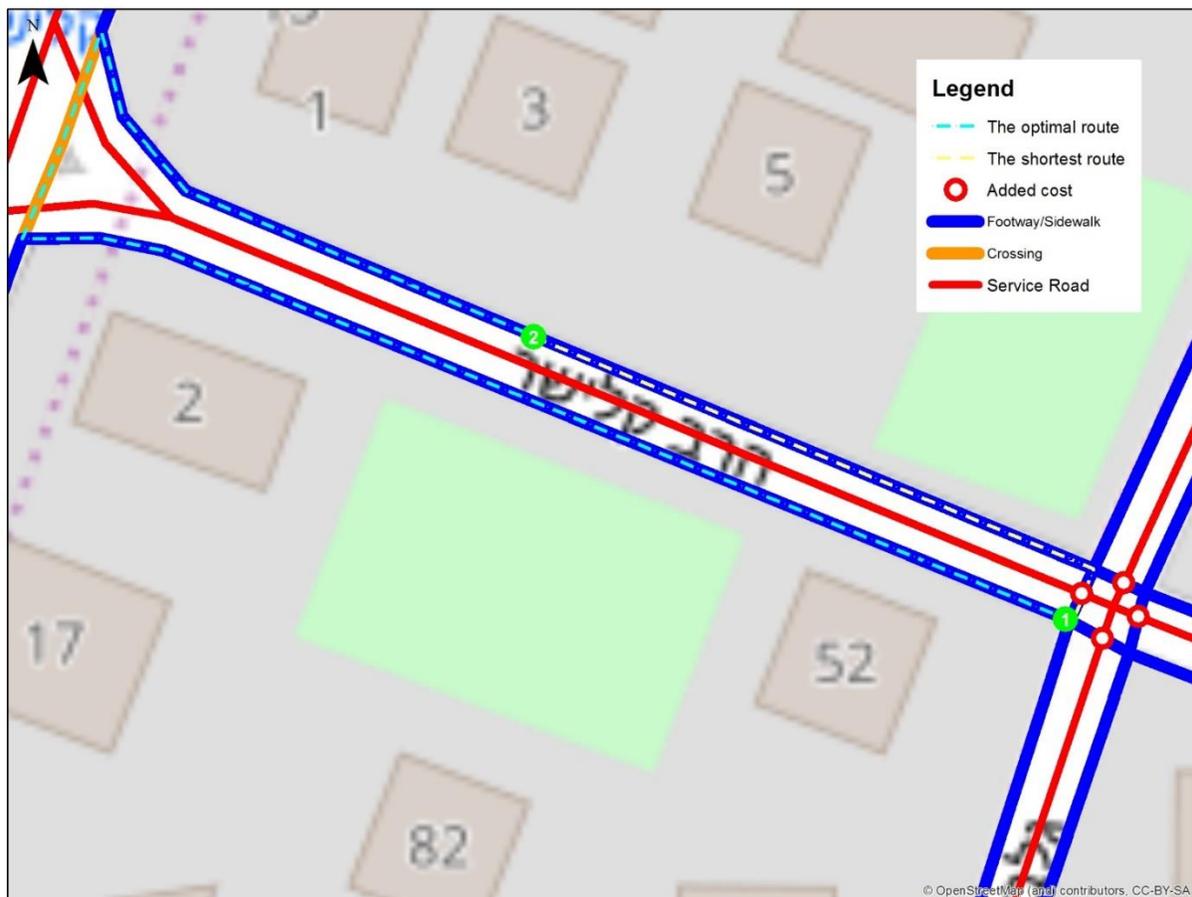


FIGURE 22. SCENARIO 3: ROUTE WITH ADDED COST.

## 4.2 Qualitative Evaluation

Several scenarios with volunteers were carried out to try and extract general qualitative measures from the participants regarding the generated optimal routes. Five blind participants (see Table 12) in Haifa, Israel, and NYC, U.S.A., have participated, varied in age, gender and assistance aid (guide dog or white cane). This evaluation had three parts:

1. Blind participants were navigating in a route that was selected by the algorithm, and reflect their insights during the walk. This part aims to identify the pros and cons of the selected optimal route, as well as analyse the reasons blind pedestrians prefer this route, and compare these to those used in the algorithm.
2. Blind participants walked two routes: one that was selected by the algorithm, and one that was the shortest route. At the end of the navigation, the participants shared their experiences and insights on both routes. This part evaluates whether the optimal route was preferred by the users over the shortest one.
3. Blind participants answered a short questionnaire about the criteria set. This part aims to validate the criteria with respect to the participant answers.

During the navigation and the questionnaire, I recorded the participant comments with voice recorder app.

**TABLE 12. PARTICIPANTS INFORMATION**

Pseudonym	Location	Age/Gender	How he/she walk?
Dana	Haifa	40's/F	White cane
Nir	Haifa	20's/M	White cane
Andy	NYC	20's/M	Guide dog
Beth	NYC	40's/F	Guide dog
Dev	NYC	20's/F	White cane

### 4.2.1 Optimal Route

#### Haifa Pilot Study

Testing in The Technion Campus, Haifa, was made with two participants - Dana and Nir. The route that was selected by the algorithm, depicted in Figure 23, originated at a pedestrian zone, followed by a sidewalk to a staircase, and then crossing an open area, ending in a park entrance. This route is less complicated and shorter compared to other options. It goes through sidewalks and stairs having handrails, and a short navigating in an open area. Due to a construction work, which is not updated in OSM and thus not considered by the algorithm, participants were forced to deviate from the original route to a less accessible route that extends navigating in open area.

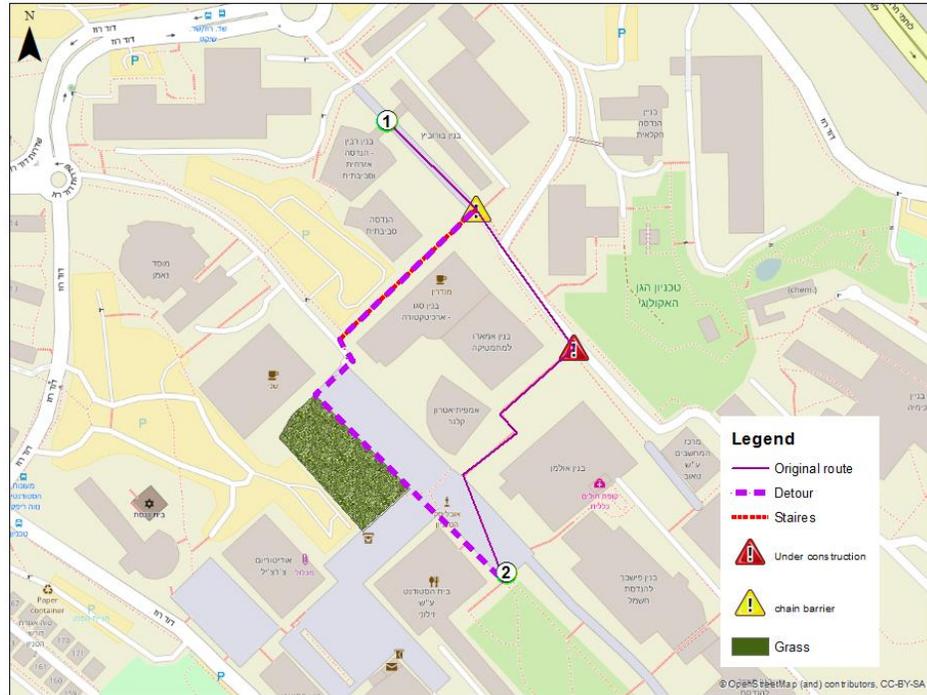
The testing validates some assumptions made when the graph was built:

- Customized tool - Dana emphasized that she did not use to navigate on long and difficult routes, mostly uphill. The route length was 420 meters, but shorter than NYC (733 meters). Nevertheless, participants did not mention the length as a challenge. This is one evidence of many that show differences among the users, thus the importance of Customized weight tool.
- Handrails stairs - The staircase in the route had handrails; as expected (and implemented in the algorithm), handrails helped participants to step up the staircase easily, also making them feel more confident about the route.
- Open area as challenging zone - The participants felt lost there because there was almost nothing in the vicinity to support their wayfinding (except for one part that they could track on a line that separated a grass zone from the main path).

The testing revealed some additional ideas that should be considered for integration into the criteria and database graph:

- Slope - slope criterion should be considered for formulation, instead of a simple length criterion, consisting of slope and length measures combined from start to end segments.
- Landmarks - entities that separate different ways might be also considered as landmarks. In the testing, for instance, a chain barrier connects the pedestrians zone to a service road (and the sidewalk alongside), or the line in an open area that separated a grass zone from the main path.

- Constriction zone – In the case of long-term construction (and other significant temporal phenomenon), it should be mapped and inserted into OSM and considered by the routing algorithm to avoid routes passing through this type of zones.



**FIGURE 23. HAIFA OPTIMAL ROUTE, TOTAL LENGTH 420 METERS.**

### NYC Pilot Study

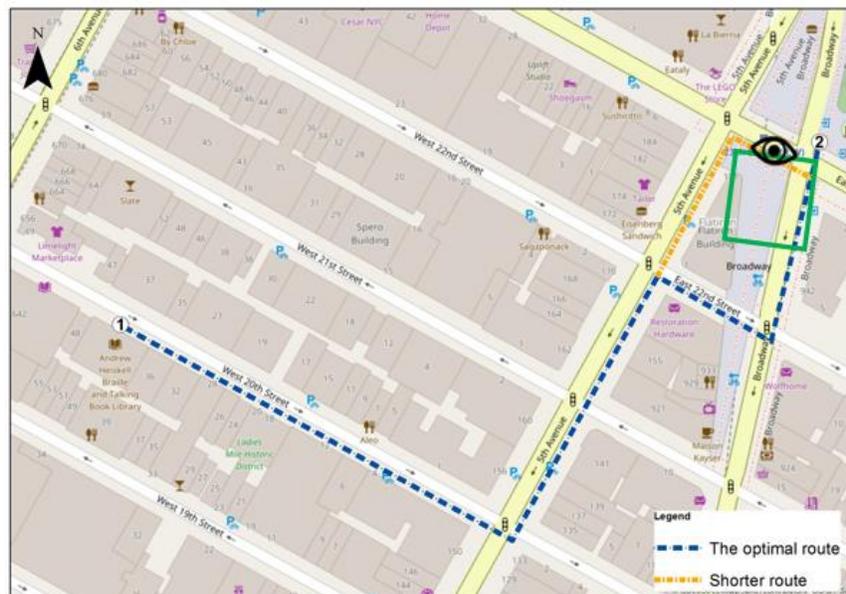
Testing in NYC lasted two days, each testing took two hours. On the first day, Andy and Beth navigated with a guide dog, and on the second day, Dev navigated with a white cane. The route, depicted in Figure 24, originated in Andrew Book Library and finished in Madison Square Park. The optimal route is a combination of a short and simple route that goes through helpful landmarks (e.g., subway entrance). The algorithm preferred a slightly longer route that avoided the pedestrians open area road (depicted in Figure 24 and Figure 25), which was considered as a more complex surrounding for blind pedestrians to navigate through (as described in section 3.2).

Another evidence for the importance of the customized weight tool was gained in this testing. Along the way to the destination, two options to cross Broadway street exist: one is the optimal route, which crosses the street without APS traffic light, and the second (the shorter route in Figure 24) is through the pedestrian road following crossing having APS traffic light. Dev said she preferred the optimal route, unlike Beth that said she would have preferred the second (shortest)

option. Beth explained that when she walks with her guide dog, pedestrian roads are not considered challenging since the dog avoids all the obstacles, such as cars or people, walking straight ahead; in crossings, however, the dog cannot make the decision for her when and where to cross, thus she preferred safer crossing.

All participants pointed out that their earlier knowledge of the area helped them to do the navigation without a mental effort, especially when it comes to the grid structure that helps them to know exactly where they are. In respect to Complexity criterion, all the route ways obtained: 'complexity=0'. Participants also noted that the navigation alongside 5<sup>th</sup> avenue was very easy, since it was not crowded like typical streets in Manhattan, so they could keep their orientation with respect to the street grid easily. If statistical data about crowding along the streets during day-hours can be retrieved, the weighted graph could be based also on this data, so that the selected route would change according to the time-of-day.

Overall, the optimal routes are safe and efficient, having supportive landmarks along the way. Still, some factors that should be considered are missing in the algorithm (e.g., slope), as well as temporary conditions that might have an effect on the selected preferred route.



**FIGURE 24. MANHATTAN OPTIMAL ROUTE, TOTAL LENGTH 733 METERS (THE GREEN RECTANGLE IS DEPICTED IN FIGURE 25).**



**FIGURE 25. ENLARGED FRAME OF THE PEDESTRIANS OPEN-AREA ROAD. THE TRAFFIC LIGHT IS WITH APS.**

#### 4.2.2 Optimal and Shortest Route

Here, participants navigated from the origin point to the destination point – and back. In both cases, the shortest route computed navigated users through a park, where the way back, according to the optimal route, was on a footway around the park; both are depicted in Figure 26 and Figure 27.

##### Haifa Pilot Study

Participants said that the optimal route, which avoided walking through a park, was simpler and easier to navigate in, without any obstacles and problems; also, walking along the road, as suggested by the optimal route, assisted them since they could listen to sound and could sense the direction of going vehicles for orientation. Moreover, Nir pointed out that the optimal route felt ‘shorter’ when compared to the shortest route. However, Dana said that even though a park is considered as a difficult surrounding to navigate through, since one might unintentionally lose his/her orientation quite easily, it is a very relaxing and calm to navigate in. In fact, the routing did not plan to consider emotional or psychological parameters, and therefore mostly will avoid entering parks.

##### NYC Pilot Study

The participants in NYC mentioned the same advantages as participants in Haifa related to navigating around the park instead of crossing it, also indicating the positive mood when walking inside the park. Apparently, Madison Square Park is even more challenging, because it is more crowded having several fountains, in addition to musicians and carts that might interrupt blind pedestrians’ sense of orientation. Still, Dev mentioned that these obstacles can be used as landmarks, since they have distinct voices and smells (although to some extent are considered as temporal, thus not always possible to model). Andy noted that he tracks the line that separated the path from the grass (barrier) while walking inside the park to improve his orientation. This

practice is similar to the one participants in Haifa do when they walked in the open area (4.2.1). Navigating around the park is still the preferable route even though blind pedestrians like the positive mood while walking inside it; distinct landmarks and clear boundaries along the park would lead to being the optimal route that has a positive effect on blind pedestrians.

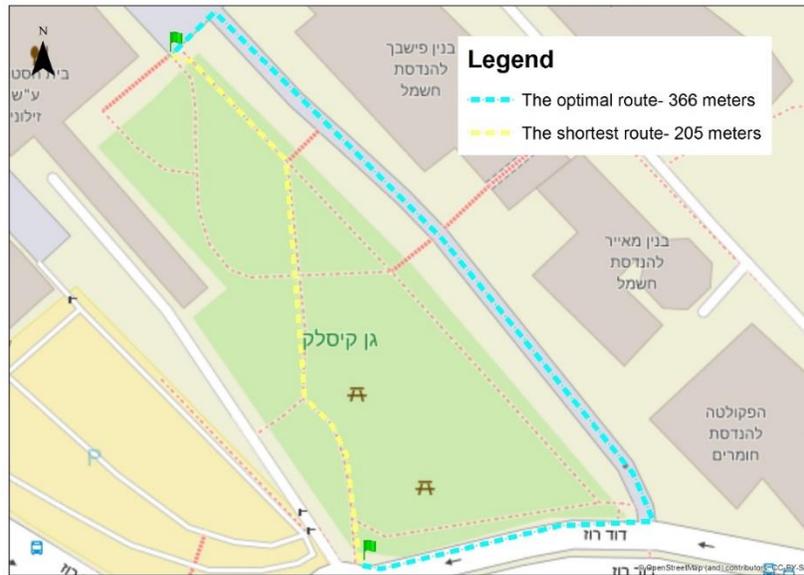


FIGURE 26. OPTIMAL AND SHORTEST ROUTES IN HAIFA



FIGURE 27. OPTIMAL AND SHORTEST ROUTES IN NYC

### 4.2.3 Questionnaire about the Criteria Set

Testing finished with a short questionnaire about the criteria set, mainly to evaluate it with respect to participants' insights. The questionnaire includes four questions, as shown in Figure 28. Question 1 relates to the previous section (4.2.2) and examines how much the easiness of orientation and wayfinding processes is important over safety. Question 2 validates the criteria set by examining whether any criterion is unnecessary. Question 3 continues the analysis of the criteria set, where unlike question 2, it does not specify the criteria, but displays two alternatives, each one expresses high cost with respect to one criterion, and it examines whether the findings will be as same as Question 2 findings. Question 4 evaluates the correlation between participants' ranking of some landmarks to those determined by the algorithm as usable for blind pedestrians. In this way, some landmarks may be eliminated and removed from the algorithm, and vice versa - others may be added and considered by the algorithm.

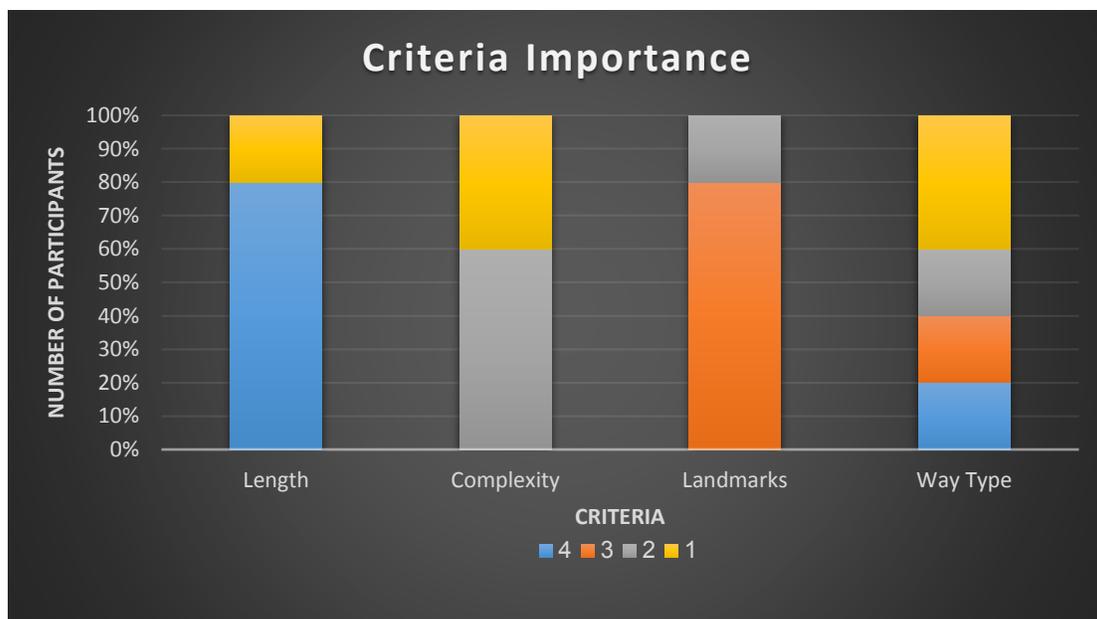
1. Rank the following options of route from point A to point B (grade 3 is preferred):
  - a. Walking through the park
  - b. Sidewalk with many crossings
  - c. Bad surface sidewalk (holes, crack, debris)
2. Rank the following parameters in term of importance for you when you plan to walk from one place to another: (grade 4 is preferred):
  - a. Length.
  - b. turns and curves
  - c. landmarks
  - d. Attributes relate to the way itself (e.g. shared lane, sidewalk, path, surface condition act.)
3. Which route is preferred?
  - a. Sidewalk with many crossings
  - b. Sidewalk with many curves
4. Rank the following landmarks between 1 to 10(1 is obstacle and 10 is outstanding landmark)
  - a. Bus stop/ Subway
  - b. Traffic light
  - c. Bicycle rental/Parking
  - d. Waste basket/Bench
  - e. cluster of trees
  - f. Supermarket
  - g. Restaurant/Bakery

**FIGURE 28. QUESTIONNAIRE QUESTIONS**

## Questionnaire Findings

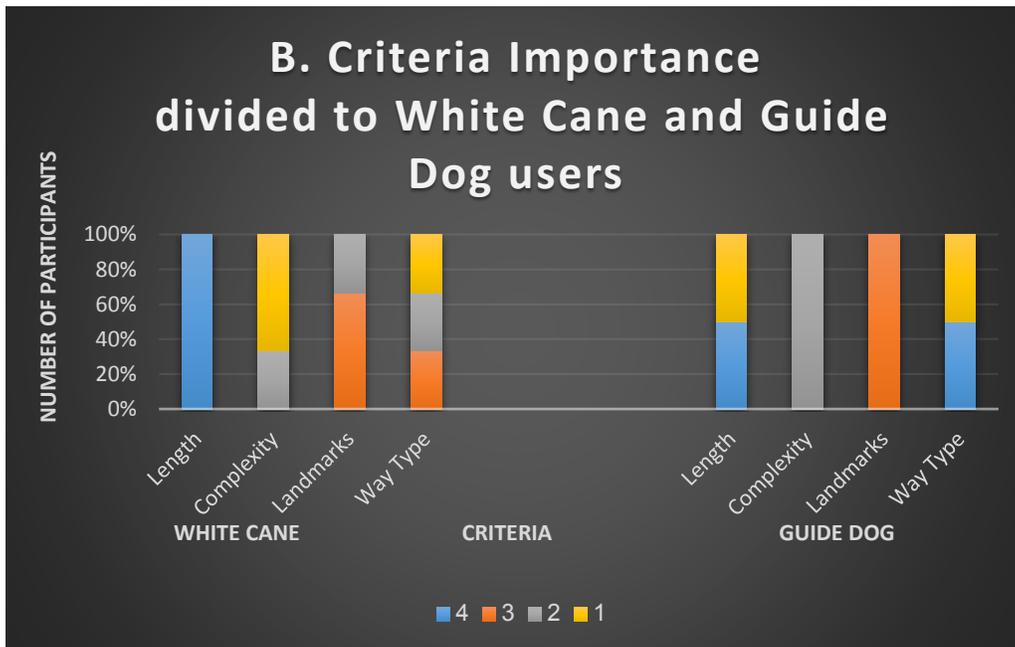
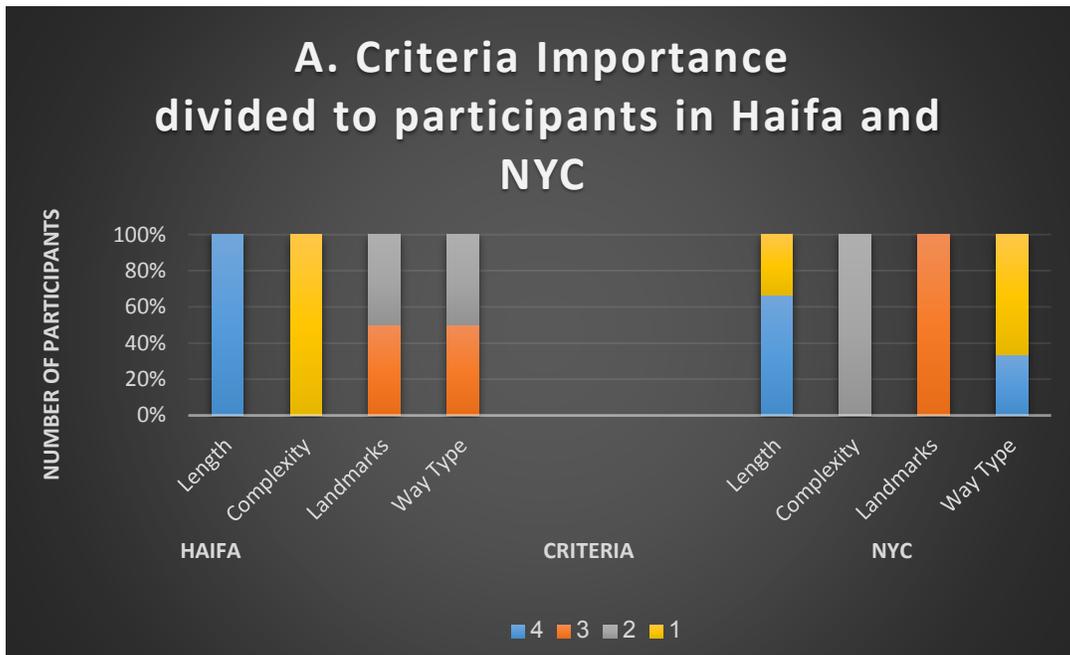
**Question 1** - All users preferred a route that enables them to orient and navigate through easily over a 'safe' route (i.e., not to navigate inside the park) in spite the fact the alternatives involved the crossing of many roads, navigation in uneven surfaces, and as it is shown before, longer route.

**Question 2** - Figure 29 depicts the importance of each criterion, expressed by its grade values (1 up to 4) according to participant answers. Based on the answers received, Length is the most important criterion (except Beth, all others rated Length with 4), followed by Landmark. Complexity is the least important criterion (but not distinct as length: two participants rated it as 1, and three as 2).



**FIGURE 29. CRITERIA IMPORTANCE BASED ON PARTICIPANTS ANSWERS**

When answers are divided into groups – Haifa and NYC participants (Figure 30A), and white cane and guide dog users (Figure 30B), Haifa and white cane groups' answers were even more explicit: Length gains the maximum possible grade, whereas for Complexity the minimum possible grade. However, observing the answers in NYC and guide dog users' groups show that every criterion has roughly the same importance. The results of Length can be explained in terms of the mental work blind pedestrians do during the wayfinding process—the grid structure in NYC or guide dog assistance require less mental work while navigating, when compared to Haifa or using a white cane.



**FIGURE 30. THE IMPORTANCE OF EACH CRITERION DIVIDED TO GROUPS: HAIFA AND NYC (TOP) AND WHITE CANE AND GUIDE DOG USERS (BOTTOM).**

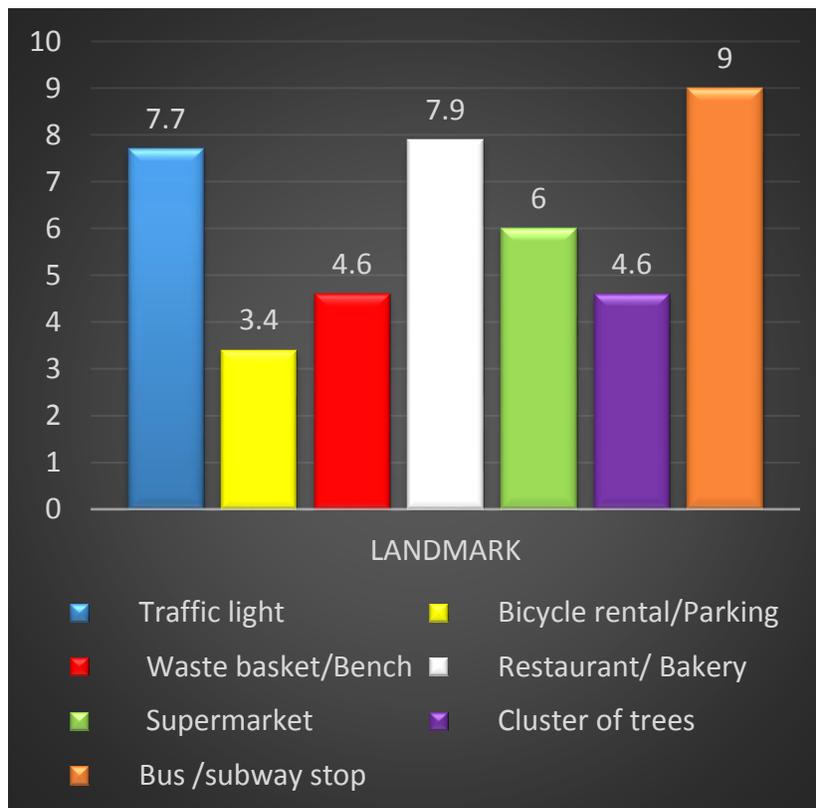
**Question 3** - While the guide dog users’ answers show that the Way Type and Complexity criteria have roughly the same importance (matched the findings of question 2), the white cane users’ answers showed a different picture about Complexity criterion. They said that they would prefer to cross many roads rather than to navigate a complex route (“Curves are disturbing”, “many

curves might cause lose your orientation.”); therefore, it will be a mistake to conclude that the Complexity criterion is less important when compared to the others.

**Question 4** - Figure 31 shows that Bus stop/subway, Traffic light and Restaurant/bakery are considered as good landmarks, while Waste basket/Bench, Bicycle rental/Parking and Cluster of trees are not, exactly as the implemented routing algorithm considers. Supermarket is the only landmark that is considered as an effective landmark to blind pedestrians by the routing algorithm that did not have a similar importance by the participants. Table 13 might explain this difference, where in NYC a supermarket is considered as a very good landmark (grade=9), whereas in Haifa it is considered as a poor landmark (grade=1.5), i.e., considered more as an obstacle. On one hand, the participants in NYC explained that a supermarket has a distinct smell and sounds/voices, but on the other hand, the participants in Haifa explained that a supermarket has many obstacles around, such as carts or cars that park on the sidewalk.

Subway stops in NYC (Bus/subway landmark) are rated as 10, whereas in Haifa, the corresponding transportation stop, a bus stop, is rated only a 7.5, yet it has the highest grade in Haifa. Table 14 shows that there exists a large difference between White cane to Guide dog users regarding Cluster of trees landmark grade. Guide dog users prefer to avoid such clusters, thus they cannot play as a landmark, since the path becomes narrower, and thus it is more likely to be an obstacle for them. For white cane users, a cluster of trees can be good landmarks since they are able to recognize it along the route with their cane.

The questionnaire findings show that assumptions made in building the routing criteria set are backed by users' preferences. Generally, all the criteria are relatively equally necessary to gain the optimal route, and in case different weights are required (as showed by the diverse groups' preferences), these can be tailored to be customized to user's demands. Also, according to the values extracted, it appears that the routing algorithm makes use of the valuable landmarks that should assist the navigation process. However, differences were found among users from different locations, therefore the algorithm needs also to enable the selection of specific landmarks that are more important to a certain area (user's community) to improve the overall effectiveness of the route.



**FIGURE 31. THE AVERAGE GRADE (1 TO 10) OF LANDMARKS**

**TABLE 13. THE AVERAGE GRADE DIVIDED TO GROUPS - HAIFA AND NYC**

Landmark	Haifa	NYC
Traffic light	6.5	8.5
Bicycle rental/Parking	4.5	2.7
Waste basket/Bench	4.5	4.7
Restaurant/ Bakery	7	8.5
Supermarket	1.5	9
Cluster of trees	6	3.7
Bus/subway stop	7.5	10

**TABLE 14. THE AVERAGE GRADE DIVIDED TO GROUPS - WHITE CANE AND GUIDE DOG USERS**

Landmark	White Cane	Guide Dog
Traffic light	7	8.8
Bicycle rental/Parking	5	1
Waste basket/Bench	4	5.5
Restaurant/ Bakery	7.5	8.5
Supermarket	4	9
Cluster of trees	6.7	1.5
Bus/subway stop	8.3	10

## 5. Conclusions and Future Work

My research presented a methodology that uses OSM data (maps and database - elements and attributes), and a specifically tailored set of criteria for the generation of optimal route intended for blind pedestrians, where the focus was given to safety and easy factors (in term of wayfinding and navigation). Main ideas identified in the course of this research in relation to blind pedestrians navigation are: (1) OSM data has the potential to serve as a mapping infrastructure used as an input for the computation of a tailored weighted graph, (2) in general, the proposed criteria set expresses correctly blind pedestrians needs and preferences while navigating, (3) a reliable and effective weighted graph can be built to generate the optimal route.

The findings show that this research has the potential to improve the quality of life of blind pedestrians by enhancing their independency, allowing them the capacity to wayfind in urban environments. The developments, implementations and the new insights gained from this research could be used by navigation systems for blind pedestrians. Additionally, this research provides insights in support of accessible wayfinding for blind pedestrians planning of the built environment. The methodology developed during this research can be expanded to other groups and communities. Additionally, the criteria system developed to support the creation of a weighted graph used in the routing algorithm could be used as an analysis tool to other research that involves blind users in general, and pedestrians in particular.

OSM was found to serve as an efficient and valuable database for this research, at least in urban cities in developed countries. High volume and detailed set of objects can be easily retrieved and used, and in case data are still missing, the community can step up and easily complete and insert it into the OSM map database. In addition, the free and full access to the updated OSM database allows everyone to download the required data to a local machine for use and analysis. However, considering OSM data, it has some shortcomings that required specific handling:

- OSM data lacks strict data regulation and inspection, specifically validation, in terms of location, topology and semantics. Although OSM is considered nowadays accurate and complete, its heterogeneous nature imposes some limitations that might present difficulties and ambiguities when used and analysed. Therefore, the development of

several procedures to automatically fix problems were developed and implemented, mainly to solve topologic and geometric data ambiguities and errors.

- As shown in the literature review section, and illustrated in stage 3.3, data regarding objects and attributes essential to blind pedestrian navigation in OSM are to some extent still missing. The OSM data in Haifa pilot study area was completed by local mapping (3.3), whereas in NYC pilot study area no updates to OSM database were made, but still several pre-processing stages were required to make data usable. I believe that with time, as public awareness continues to grow more users will continue to contribute valuable data, serving OSM map's completeness and reliability.

Qualitative evaluations made illustrate how the algorithm selects a safer and easier route to navigate—avoid dangerous locations and prefer more accessible ones— although in some cases the generated route might be longer when compared to the default routing. In addition, blind pedestrians could have different preferences, so that some criteria will be preferred over the others, which can lead to the selection of a different route as the optimal one.

Qualitative evaluation illustrates how the optimal routes were generally more effective and usable for blind pedestrians, providing the OSM data in the given area are comprehensive and updated. The questionnaire showed that in spite of the revealed differences among various locations and users, generally the criteria used should be involved in the weighted graph construction, leaving it to the user to choose the preferred ones. However, the questionnaire included 5 participants only, which means that I cannot perform any reliable statistical evaluation, thus bigger population should be considered in future work to draw more concrete conclusions.

The routing graph formulation designed to find the optimal route that is safe and efficient is presented in this research, has a potential to be integrated into a navigation process considered as one of the biggest challenges for blind people. The literature review showed that blind pedestrians must acquire travel skills, and use sources of nonvisual environmental information, which is cognitively demanding, and often require conscious moment-to-moment problem solving. Moreover, an unsafe and inaccessible route increases the stress levels of blind pedestrians. The literature also discuss which information should be provided. On the one hand,

a good solution should attempt to convey a rich image of the environment, while on the other hand, it should provide a simple presentation that provides only the most critical information for safe and efficient navigation. Both are addressed in this research, and its findings suggest that building an effective navigation system is prior to convey a rich image of the environment.

Future research is planned to:

1. **Design and implement a comprehensive open source map catalogue** – the development of a mapping infrastructure that allows editing and sharing of geospatial data that is commonly not accessible will be designed and implemented, among others: crossings, accessible traffic lights, sidewalks. In addition, it is planned to develop feature extraction algorithm designed to automatically identify and retrieve geospatial objects from photos (e.g., Google Street View or geo-tagged photos) to augment the open-source map catalogue. To this end, it is planned to use the OSM platform.
2. **Optimize routing algorithm designed for blind pedestrians** – the aim is to extend and enhance a weighted graph tailored for specifications of blind pedestrians by:
  - (1) Investigate the effects of supplementary environmental aspects, such as smell, sound and shadow.
  - (2) Study routes, which are chosen manually by O&M instructors, to optimize the routing algorithm with respect to weights and thresholds used, and other quantitative considerations.
  - (3) Investigate routing algorithms – other than the Dijkstra - which take into consideration the complete route - and not merely route segments.
3. **Develop a navigation system prototype, which is based on open-source maps** – It is planned to develop a prototype of navigation application, with the implementation of the developed routing algorithm, focusing mainly on two primary aspects:
  - (1) User Interface – study and understand the interaction between the navigation system and the needs of the blind pedestrians (e.g., verbal audio as speech capability or nonverbal audio as sound, haptic feedback, vibration).
  - (2) Navigation route instructions - besides the default route instructions (e.g., turn by turn instructions), the plan is to seek supplementary and tailored route

instruction information that will improve insight and understanding of the immediate environment to strengthen safety and independency of users.

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## תקציר

בכדי לנווט ממקום למקום בהצלחה נעזרים הולכי הרגל במיומנות טבעית הנקראת 'wayfinding' (מציאת דרך), אשר משלבת את המידע המרחבי הנראה לתוך הייצוג המנטלי של המרחב במוח. תהליך זה מתרחש בעיקרו באמצעות הערוץ הוויזואלי, ולכן איננו נגיש להולכי רגל עיוורים, כך שמידע קריטי (לדוגמא: שמות רחובות, סימני דרך וכדומה) הנדרשים להצלחת הניווט לא מגיע אל המוח. אתגרים נוספים העומדים בפני הולכי רגל עיוורים הינם: 1) דרכים משותפות להולכי רגל ואופניים - ולעיתים אף לרכבים (לדוגמה בכניסה לחניות), 2) אזורים פתוחים, כמו גם אזורים צפופים, 3) הימנעות ממכשולים פיזיים בעת הליכה על מדרכה – רכבים חונים, עבודות בנייה ותחזוקה, סדקים ובורות וכדומה. אתגרים אלה מגבילים באופן ניכר את יכולת התנועה של הולך רגל עיוור במרחב, וגורמים לו להיות תלוי באחרים או בעזרים כמו מקלות וכלבי נחייה. במחקרים קודמים הדגישו המשתתפים העיוורים כי היו שמחים לצאת יותר - אילו רק יכלו. בנוסף, נמצא קשר ישיר בין ניידות ועצמאות לבין שגשוג ורווחה.

ההתפתחות המהירה בתחום הטלפונים החכמים ('סמארטפונים') קידמה מאוד פיתוח של טכנולוגיות המיועדות להולכי רגל עיוורים. סוג אחד של טכנולוגיות משתמש בחיישן ה-GPS הקיים במכשיר בכדי להנחות את הולך הרגל העיוור במרחב, ולהזהיר אותו ממכשולים באמצעות הודעות קוליות. סוג נוסף של טכנולוגיות משתמש במצלמה הקיימת במכשיר לזיהוי ואיתור מכשולים בזמן אמת. למרות שטכנולוגיות אלה מאפשרות לאדם העיוור לנוע ביתר בטחון במרחב, הן עדיין לא מספקות מידע כולל על המרחב, כך שמלכתחילה אין למשתמש מידע בהיקף רחב יותר מסלול שעשוי להתאים לו, כזה שגם יצמצם למינימום את האינטראקציה עם מכשולים ואתגרים שעשויים להיות בדרך. לצורך, כך יש להשתמש במאגר מידע מעודכן, הכולל את כל האובייקטים במרחב עם מאפייניהם (כגון מעברי חצייה או הימצאות של סימן ייעודי להולכי רגל עיוורים).

OpenStreetMap (OSM) הוא פרויקט שפותח ע"י סטיב קואסט מבריטניה בשנת 2004, המבוסס על רעיון של מיפוי מבוסס מיקור המונים, שמטרתו למפות את העולם בעזרת נתונים וידע נתרם הנאסף מההמון. כל אחד ואחת בעולם יכול להוסיף נתונים ומידע למפה, לערוך נתון או מידע קיים, או להשתמש בנתונים ובמידע הקיימים לצרכים שלו. כתוצאה מכך, הופך OSM למאגר מידע מקיף ועדכני, שלא קיים בשום תשתית מיפוי בקנה מידה עולמי. אחד מהשירותים שניתן לקבל על-ידי OSM הינו ניתוב - קבלת המסלול הקצר ביותר בין שני מיקומים על-גבי המפה. הבעיה היא שלהולכי רגל עיוורים המסלול הבטוח או הקל ביותר להתמצאות וניווט יהיה מועדף על פני הקצר ביותר, ולכן המסלול המתקבל כיום ב- OSM איננו תמיד מתאים לקהילה זו.

מטרת המחקר היא לייצר מנגנון ניתוב, העונה על דרישות הולכי רגל עיוורים. המוטיבציה היא לפתח אלגוריתם ניתוב, המבוסס על גרף משקלים ייעודי, אשר עושה שימוש במכלול השיקולים הסביבתיים

והסמנטיים החשובים להולכי רגל עיוורים, למטרת הפקה של מסלולי הליכה המותאמים לצרכיהם. על המסלולים המחושבים להיות בטוחים יותר, נגישים וקלים לניווט. בנוסף, רשת הדרכים בה יעשה שימוש מבוססת בלעדית על נתונים ומידע מיפויי הקיים בתשתית המפות של OSM, היות והוא מאפשר גמישות במושגים של הזנת, עריכת, ניתוח ושימוש הנתונים והמידע המצטברים.

המחקר כלל למידה מעמיקה, תצפיות וראיונות בערים חיפה וניו-יורק עם מדריכות אוריינטציה וניידות, כמו גם עם עיוורים, אודות דגשים החשובים להולכי רגל עיוורים בעת ניווט במרחב העירוני. כתוצאה מאלה, הוסקו מספר מסקנות, אשר אפשרו הגדרה של סט קריטריונים, המבטאים בצורה הטובה ביותר דגשים אלו. הקריטריונים הם: אורך הדרך, סוג הדרך (לדוגמה: האם הדרך מיועדת רק להולכי רגל או גם לאופניים?), מורכבות הדרך (מבחינה גיאומטרית - האם כיוון הדרך משתנה באופן תדיר?) וסימנים בדרך (landmarks). קריטריונים אלו מאפשרים לבחון כל דרך, ולקבוע את נגישותה להולכי רגל עיוור. כמו כן, בעקבות הלמידה נקבעו הישויות המרחביות הסביבתיות הנדרשות למיפוי לטובת מימוש האלגוריתם. יישום האלגוריתם התבצע בתוכנת ArcGIS, ובפרט באמצעות ה-ModelBuilder. המודל שנבנה כולל את כל השלבים הדרושים, החל מהורדת המידע מ-OSM, דרך עיבוד מקדים, שכלל סינון מידע לא רלוונטי, מיון המידע לעבודה ותיקון בעיות טופולוגיות, וכלה בבחינת הדרכים בהתאם לסט הקריטריונים. לבסוף מתקבל גרף משקלים (רשת דרכים), שעליו ניתן להריץ לחישוב את אלגוריתם הניתוב לקבלת המסלול המיטבי להולכי רגל עיוור.

רשת הדרכים נבחנה על ידי הרצת האלגוריתם במספר מקומות, בנוסף לשני ניסויי שדה בחיפה ובניו יורק עם מספר מתנדבים עיוורים לבחינת המסלולים המתקבלים. בחלקו הראשון של הניסוי התבקשו המשתתפים ללכת במסלול שחושב על-ידי האלגוריתם, ולחוות את דעתם עליו. בחלקו השני, הלכו המשתתפים בין מוצא ליעד - פעם אחת במסלול שחושב על-ידי האלגוריתם, ופעם שנייה במסלול הקצר ביותר. כמו כן, המשתתפים ענו על שאלון אשר בוחן את התאמת סט הקריטריונים לצורכיהם האישיים. הממצאים הראו כי המתודולוגיה המתוארת במחקר מתאימה לבניית גרף המשקלים. עוד נמצא, כי ל-OSM פוטנציאל רב להוות תשתית מקיפה ומספקת לבניית רשת דרכים עבור הולכי רגל עיוורים. מצד שני, נמצא שעדיין חסר מידע רב בכל מה שקשור לאובייקטים ונגישותם ב-OSM, ודרוש כלי ולידציה אשר יתקף את האובייקטים או את העדכונים המוספים ל-OSM, ויבחן את מהימנותם ודיוקם. מתוצאות השאלון עולה כי אף על פי שבמרבית המקרים סט הקריטריונים המוצע מבטא נכון את הצרכים וההעדפות של הולכי הרגל העיוורים, קיים שוני מסוים בין העדפות המשתתפים הנגזר ממקום מגוריהם (חיפה לעומת ניו-יורק), והן הנגזר מהעזרים בהם הם משתמשים (כלב נחייה או מקל הליכה). אי לכך, ישנה חשיבות רבה לאפשר למשתמש יכולת התאמה מסוימת של רמת חשיבות הקריטריונים (מדדים) בהתאם להעדפותיו, ועל בסיס זה לבצע חישוב של המסלול המתאים לו או לה ביותר. למחקר זה תרומה אפשרית רבה לקהילת העיוורים, אשר יכול להוביל לשינוי משמעותי בנושא ניידות ונגישות בפרט של עיוורים במרחב העירוני – ועצמאות בכלל.

המחקר נעשה בהנחייתם של ד"ר שגיא דליות מהפקולטה להנדסה אזרחית וסביבתית, המסלול לתחבורה וגאו-אינפורמציה, ושל פרופסור משנה שירי אזנקוט ממכון טכניון-קורנל בקורנל-טק, אוניברסיטת קורנל. אני מודה לטכניון - מכון טכנולוגי לישראל, על התמיכה הכספית הנדיבה בהשתלמותי. תודה רבה לד"ר שגיא דליות על ההנחיה, התמיכה, העידוד והסבלנות הרבה לאורך כל הדרך. תודה מיוחדת לפרופסור משנה שירי אזנקוט על התמיכה מקרוב ומרחוק, ועל העזרה הרבה בקידום המחקר. בנוסף, אני רוצה להודות לארגון "מגדל אור", ובמיוחד לרונית לנדסמן וריטה לפיד, על עזרתן הרבה, ובכך שאפשרו לי להשתתף בפעילות הארגון. תודה ל-Ruch Exchange Grant ולחממה החברתית בטכניון על תמיכתם הכספית למחקר.

# בניית גרף משקלים מבוסס נתוני OSM לבניית אלגוריתם ניתוב המיועד להולכי רגל עיוורים

חיבור על מחקר

לשם מילוי חלקי של הדרישות לקבלת התואר מגיסטר למדעים בהנדסת מיפוי וגאו-  
אינפורמציה

אחיטוב כהן

הוגש לסנט הטכניון – מכון טכנולוגי לישראל

מרץ 2017

חיפה

אדר תשע"ז