Politecnico Di Milano

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Enrichment of City Accessibility Maps with Crowdsourcing Techniques

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Abstract

Currently, one in six people in the European Union – around 80 million – have a disability that ranges from mild to severe. Over one third of people aged over 75 have disabilities that restrict them to some extent. These numbers are set to rise as the EU population grows progressively older. Most of these people are all too often prevented from fully participating in society and contribute to the economy because of physical or other barriers, as well as discrimination. Whilst the European Union raises new policies regarding accessibility, creating an application which eases the life of in need people is an important step in building accessible cities.

Large cities are built and designed based on the needs of mobile people, architectural preferences and budgets. Unfortunately, this constitutes a big disadvantaged for those with mobility disabilities. Wheelchair users are regularly hindered by barriers from participating in daily life on their own.

The purpose of this thesis is to develop a set of solutions for the enrichment of geographical maps with information about the accessibility of urban pedestrian for people with mobility problems. The Maps for Easy Paths project (MEP), of which the thesis is part of, aims in creating a system able to detect automatically non-accessible features in an urban environment in order to compute a new accessible path to reach a destination. The system makes use of a smartphone or tablet which will guide the users with disabilities throughout the city by visualizing the accessible path inside the application.

The research work presented in this thesis aims in solving this problem by means of crowdsourcing and street view images. The process consists of street view images which are sent to users via crowdsourcing platform and

are marked as accessible and non-accessible based on their feedback. These images focuse on specific points (crossings, traffic lights and intersections) and precise questions are being asked in order to determine the accessibility of these points.

Sommario

Oggigiorno, una persona su sei nell'Unione europea - circa 80 milioni - ha una disabilità che varia da lieve a grave. Oltre un terzo delle persone di età superiore ai 75 anni hanno disabilità che li limitano in qualche modo. Questi numeri sono destinati ad aumentare in quanto il numero di persone anzioane dell'UE cresce progressivamente. La maggior parte di queste persone sono troppo spesso impossibilitate a partecipare pienamente nella società e contribuire alla sua economia, a causa di barriere fisiche o altro, così come la discriminazione. L'Unione Europea solleva nuove politiche in materia di accessibilità, creando così un'applicazione che facilita la vita delle persone in stato di bisogno, il che e' un notevole miglioramento per la costruzione di città accessibili.

Le grandi città sono state costruite e progettate in base alle esigenze delle persone senza problemi di mobilità, così come in base alle preferenze architettoniche e il relativo budget. Purtroppo, ciò costituisce un grosso svantaggio per le persone con disabilità motorie. Le sedie a rotelle sono regolarmente ostacolate da barriere architettoniche, problema che rende difficile la vita quotidiana e lo spostamento dei disabili per conto proprio.

Lo scopo di questa tesi è quello di sviluppare un set di soluzioni per l'arricchimento di mappe geografiche con informazioni sull'accessibilità di percorsi pedonali urbani per le persone con problemi di motorietà. Le Maps for Easy Paths, progetto (MEP) di cui la tesi fa parte, mira a creare un sistema in grado di rilevare automaticamente le caratteristiche non accessibili in un ambiente urbano, al fine di calcolare un nuovo percorso accessibile e di raggiungere più facilmente una destinazione. Il sistema si avvale di uno smartphone o tablet che guideranno gli utenti con disabilità motorie in tutta la città, visualizzando il percorso accessibile all'interno dell'applicazione.

Il lavoro di ricerca, presentato in questa tesi, mira a risolvere questo problema tramite crowdsourcing e immagini di Google Street View. Il

processo consiste nelle immagini di Street View che vengono inviate agli utenti tramite piattaforma di crowdsourcing e contrassegnate come accessibili e non accessibili, in base al loro feedback. Queste immagini si concentrano su punti particolari (incroci, semafori e intersezioni) e richieste specifiche in modo da definire l'accessibilità di questi punti.

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Chapter 1

Introduction

Historically, disability has been viewed as a static process, reflecting more or less enduring functional impairments that were the consequences of illness and injury. Increasingly, motivated by a combination of political and intellectual critiques, disability has come to be viewed as the result of complicated and sometimes unstable processes. Disability is thought to result from interactions between individuals and environments, which, in turn, consist of complicated arrays of social, cultural, political, climatic, topographic, architectural, and technologic components [16].

In their daily lives wheelchair users are confronted with many obstacles once they leave the security of their homes. As a consequence city centers are often paved with cobblestone, many subway entrances are only accessible by stairs or escalators and often shops, public facilities or even public toilettes can only be reached by stairs. Unfortunately, this constitutes a big disadvantaged for people with mobility disabilities. Wheelchair users are regularly hindered by barriers from participating in daily life on their own. As people without disability are mostly unaware of the impact of these barriers and cities have hardly any recorded data on street and sidewalk pavements, curb boarder heights, sidewalk widths, street inclines, construction sites etc. there is an imperative need to address, locate and reduce barriers in cities. In addition to that, popular modern navigation systems on the market (TomTom, Garmin, Nokia Maps, and Google Maps Navigation) do not support any features for wheelchair users and handicapped people. Some of these products just recently enhanced their feature portfolio with pedestrian navigation. Unfortunately none of these enhancements include or support data sets that are able to capture important street condition parameters such as incline, pavement etc. which would all be necessary for efficient and accurate wheelchair and handicapped navigation [14].

Currently, one in six people in the European Union – around 80 million – have a disability that ranges from mild to severe. Over one third of people aged over 75 have disabilities that restrict them to some extent. These numbers are set to rise as the EU population grows progressively older. Most of these people are all too often prevented from fully participating in society and contribute to the economy because of physical or other barriers, as well as discrimination. Whilst the European Union raises new policies regarding accessibility, creating an application which eases the life of in need people is an important step in building accessible cities.

1.1 Thesis goal

The purpose of this thesis is to develop a set of solutions for the enrichment of geographical maps with information about the accessibility of urban pedestrian for people with mobility problems [12]. The Maps for Easy Paths project (MEP), of which the thesis is part of, aims in creating a system able to detect automatically non-accessible features in an urban environment in order to compute a new accessible path to reach a destination. The system makes use of a smartphone or tablet which will guide the users with disabilities throughout the city by visualizing the accessible path inside the application (Figure A.1, Appendix A shows a possible representation of an accessible path).

The research presented aims in solving this problem by means of crowdsourcing and street view images. The process consists of street view images which are sent to users via crowdsourcing platform and are marked as accessible and non-accessible based on their feedback. These images focuse on specific points (crossings, traffic lights and intersections) and precise questions are being asked in order to determine the accessibility of these points.

The work done was developed based on the following objectives:

- Download of images containing accessibility features which need to be marked as accessible or non-accessible
- Evaluation of images with crowdsourcing techniques
- Enrichment of map with accessibility and non-accessibility info

1.2 Structure of the thesis

The structure of the thesis is as follows:

- In Chapter 2, an *Overview* of the thesis is given by introducing the MEP project, which this thesis is a contribution to. The goals of the MEP project are presented, the main scenario is described and the target users of the project are defined. Besides these, the thesis work phases are also described at a high level of details together with the selected papers used for research.

- Chapter 3 contains the *State of the Art*, in which the focus will be on the three main aspects used in the development of the thesis: OpenStreetMap, Google Street View Image and Crowdsourcing. For each of them I am offering the amount of details needed for a better understanding of the future chapter.

- Chapter 4 presents the *Requirements Analysis*, in which I will mainly focus on the process of designing the questions related to the accessibility of our points of interest.

- In Chapter 5 I am presenting the *Design Phase*, more precisely the high level implementation of the process: the OpenStreetMap tags and bounding box used, details related to the Google Street View Image link and the accessibility questions.

- Chapter 6 offers the low level *Implementation* by highlighting the most important pieces of Java software developed for downloading the images required for the crowdsourcing platform.
- In Chapter 7 I will present the *User Interface*, the end part with which the users will interact in order to provide their feedback .
- In Chapter 8 the *Conclusion* of the current thesis are presented.
- Chapter 9 presents several suggestions as possible *Future Works*.
- In *Appendix A*, I offer additional images to better highlight the development of the thesis.
- In *Appendix B*, I offer the entire developed software.

Chapter 2

Overview

2.1 MEP Project

„Maps for Easy Paths", or MEP, is a Polisocial project (a program of social responsibility of Politecnico di Milano) that aims to develop an automated system to enrich a public map with information about accessibility of city routes (roads, sidewalks, walkways, etc.) through the active contribution and participation of the following target users:

- Users with mobility impairments: for the moment the focus is on people with manual or electric wheelchairs but it can be extended to elder people with or without mechanical support, injured or in temporary situations of reduces mobility. Users can take part actively by contributing to enrich the accessibility information or by notifying any problems related to the paths.
- Municipalities, local governments and organizations that might be interested in this type of information to better plan interventions and help in creating accessible cities. With respect to location, the solutions presented in this thesis were designed for Como City.

The entire scenario of the project can be described given Figure 2.1:

Figure 2.1: MEP Project

Implicit Data (no intervention required by the user): The application installed on the users' smartphone or tablet will track the routes that they follow throughout the city. Even though these routes can be marked as accessible there are still plenty of obstacles a wheelchair user can encounter. To track the user, the application sends GPS and data of sensors (and optionally pictures taken by the embedded camera of the smartphone) to the server, which uses fusion techniques to reconstruct the route.

Explicit Data (requires contribution from user): Users actively participating in the process by taking pictures of the problems and barriers they face in the city; these pictures together with sensor information will be uploaded to the server.

After receiving the implicit and explicit data, the server constructs or updates a 3D geographical map and in the same time it records the accessible routes and the corresponding information received from the users.

The goal of the project is to offer support to people with motor impairments in finding the accessible paths throughout the city and to help them be able to move freely in the urban context without the limitations of architectural barriers. The *Final Users* can range from people with manual or electric wheelchair, elder people with or without mechanical support and people in temporary situations of reduced mobility (injured or with small children). By using this application, the users request an accessible path to reach their destination; the server will be able to suggest them one based on the collected data.

The aim of the application is not only for people with motor impairments, but also for *Public Institutions, Associations and Entities* which focus and deal with these aspects. It is desirable that these collected data will improve not only the users' life but also the urban design leading to accessible cities.

The contribution brought by this thesis stands in the *Explicit Data* category and focuses on determining what obstacles can people with motor disabilities encounter on the streets by means of crowdsourcing. More precisely, images from different key points in the city (intersections, crossings, sidewalks) where accessibility problems can be encountered will be collected and sent to users via crowdsourcing platform. Each image will have several questions and based on the answers received we can determine if we have an accessible or non-accessible situation and consider it in the configuration of the accessible path.

The accessibility features considered were mostly related to crossings and sidewalks: dropped kerbs, high curbsides, potholes, surface, drains and many more. Since the images were retrieved using the Google Street View Image API, one major rollback was the presence of people on the sidewalks and cars on the crossings which were blocking the view (besides the fact that some images were not offering a good view or were not having a good quality).

2.2 Thesis Work Phases

The work can be divided into three phases:

- Download images of interest from Google Street View – images containing accessibility features which need to be marked as accessible or non-accessible
- Evaluation of images with crowdsourcing techniques
- Enrichment of map with accessibility and non-accessibility info

As it can be seen from Figure 2.2, by processing OpenStreetMaps tags together with several features of the Google Street View Image API in a Java software, the images of interest can be downloaded and inserted in a crowdsourcing platform. These images in conjunction with specially selected questions, will mark as accessible or non-accessible the points of interest based on the feedback given by the user, feedback which later on will be used in the creation of the accessible paths.

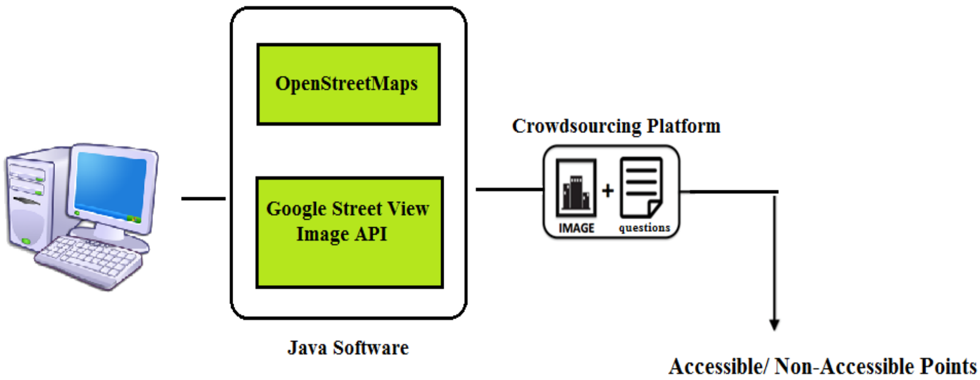


Figure 2.2: Thesis Work Phases

2.3 Literature Analysis

In order to better understand the needs of people with disabilities and to design important features of the application, specialized literature has been reviewed. The following list presents the papers used for research together with a short description of each:

- *Lorena de Freitas Pereira, Mariana Silva de Albuquerque, Licínio da Silva Portugal, „Access of wheelchair users in sportive mega events: the case of Confederation Cup" , E340XVIII Congreso Panamericano de Ingeniería de Tránsito, Transporte y Logística (PANAM 2014)* - This article aims to evaluate the access conditions for wheelchair users in sporting mega-events. It will show the characterization of some attributes related with the walk, as the variables that express them, showing the studied group particularities. The data collect was made in June, 2013 by questionnaire application during the competitions of The World Confederation Cup realized in Rio de Janeiro on the Maracanã Stadium.

- *Rosemary D.F. Bromley , David L. Matthews and Colin J. Thomas, „City centre accessibility for wheelchair users: The consumer perspective and the planning implications"* – The research presented in this paper is drawn from 150 detailed interviews with wheelchair users, to investigate and reassess current city centre accessibility 10 years after the introduction of the Disability Discrimination Act, 1995 in the UK. It shows that aspects of the built environment, public transport, and current levels of shopper activity continue to present a range of difficulties for wheelchair users, which restrict their physical mobility in the city centre.

- *Hugh Matthews, Linda Beale, Phil Picton and David Briggs, „Modelling Access with GIS in Urban Systems (MAGUS): capturing the experiences of wheelchair users"* - This paper describes a project undertaken with wheelchair users, which has developed, tested and applied a Geographic Information System model. This model acts both as a navigational device for wheelchairs users - enabling them to make informed route choices through urban places - and as a decision support and planning tool for urban planners - making visible the ways in which built environments are often distorted and hostile spaces for wheelchair users.

- *Christian Menkens, Julian Sussmann, Miriam Al-Ali, Emanuel Breitsameter, Jelena Frtunik, Tobias Nendel, Tobias Schneiderbauer, „EasyWheel - A Mobile Social Navigation and Support System for Wheelchair Users", Eighth International Conference on Information Technology: New Generations, 2011* – The research work presented in this paper tries to solve different problems faced by wheelchair users by providing EasyWheel, a mobile social navigation and support system. EasyWheel allows them to access accessibility information for all sorts of points of interests (POI) such as public transport, shops, etc and helps them navigate throughout a city while following the ideal route and avoiding all barriers and obstacles. To connect EasyWheel with the whole community of wheelchair users and helpers, EasyWheel includes a social community system including reputation and reward features leveraging Facebook.

- *Carlos Cardonha, Diego Gallo, Priscilla Avegliano, Ricardo Herrmann, Fernando Koch, and Sergio Borger, „A Crowdsourcing Platform for the Construction of Accessibility Maps"* - This article presents a crowdsourcing platform that enables the collaborative creation of accessibility maps. The platform provides means for integration of different kind of data, collected automatically or with user intervention, to augment standard maps with accessibility information.

- *Allan R. Meyers, Jennifer J. Anderson, Donald R. Miller, Kathy Shipp, Helen Hoenig, „Barriers, facilitators, and access for wheelchair users: substantive and methodologic lessons from a pilot study of environmental effects*" - A month-long intensive pilot study was undertaken on a sample of adult wheelchair-users in Boston, Massachusetts and Durham, North Carolina, USA. The study had four objectives; to: (1) measure experiences of reaching and failing to reach specific destinations; (2) measure encounters with environmental facilitators and barriers, including both those overcome and not overcome; (3) determine the frequencies of destinations, facilitators, and barriers, and (4) test for consistency between daily reports and retrospective reports. Full participation entailed baseline and exit telephone interviews, and 28 daily telephone contacts.

Chapter 3

State of the art

In this chapter I will describe the State of the Art of the application and, in particular, I will focus on three main aspects:

- Open Street Map: I will describe the tools and approaches that aim to facilitate the development of the application;
- Google Street View Image Link: I will focus on the characteristics of the link and downloading aspects;
- Crowdsourcing: I will focus on general aspects related to crowdsourcing.

3.1 OpenStreetMap

OpenStreetMap (OSM) is a collaborative project to create a free editable map of the world[1]. It represents physical features on the ground (e.g., roads or buildings) using tags attached to its basic data structures (its nodes, ways, and relations). Each tag describes a geographic attribute of the feature being shown by that specific node, way or relation.

OpenStreetMap's free tagging system allows the map to include an unlimited number of attributes describing each feature. The community agrees on certain key and value combinations for the most commonly used tags, which act as informal standards. However, users can create new tags to improve the style of the map or to support analysis that rely on previously unmapped attributes of the features.

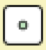
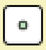
A tag consists of a 'key' and a 'value':

- The *key* describes a broad class of features (for example, highways).
- The *value* details the specific feature that was generally classified by the key (e.g. highway=motorway). If multiple values would be needed for one key the semi-colon value separator may be used in some situations[3].

Each tag describes a specific feature of a data element (nodes, ways and relations) or changesets. Both the key and value are free format text fields. In practice, however, there are agreed conventions of how tags are used for most common purposes.

The key can be modified with a prefix, infix or suffix namespace to further qualify it. Common namespaces are language specification and a date namespace specification for name keys.

The following table describes the tags which will be used further on in the development of the application:

Key	Value	Element	Comment	Rendering	Photo
highway	**traffic_signals**		**Lights that control the traffic**		
crossing	**no / traffic_signals / uncontrolled / island / unmarked**		**highway=crossing or railway=crossing**		

Tabel 3.1: OSM Tags

In order to visualize all these data on the map, OSM offers Overpass Turbo [17], a web based data mining tool which runs any kind of Overpass API query and shows the results on an interactive map.

Figure 3.1 shows all the drinking water points in the city of Como:

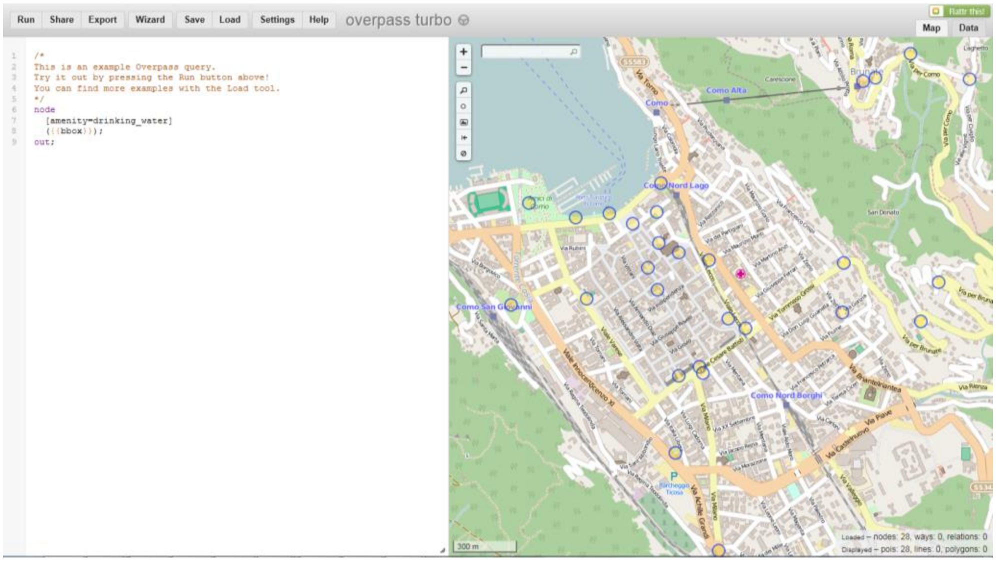


Figure 3.1: OSM Drinking Water Example

In the above example, amenity represents the key and drinking_water the value; {{bbox}} refers to the bounding box coordinates of the current map view and the circles presented on the map are the drinking water points in the city (the results of the query).

The *Export* dialog holds various export options for the query and/or data loaded by the query, where the export as *raw data from Overpass API Interpreter* will be the used one in the development as it will generate a direct link to the result of the query returned by the Overpass-API interpreter. The output for the above example will be of the following format:

```
/*****************************************************************/
<osm generator="Overpass API" version="0.6">
<note>The data included in this document is from
www.openstreetmap.org. The data is made available under
ODbL.</note>
<meta osm_base="2015-09-09T15:35:02Z" />
  <node lon="9.0884129" lat="45.8083123"
id="349815060">
    <tag v="drinking_water" k="amenity" />
  </node>
  <node lon="9.0855381" lat="45.8066350"
id="1046778326">
    <tag v="drinking_water" k="amenity" />
  </node>
  <node lon="9.0873451" lat="45.8087394"
id="1051805160">
    <tag v="drinking_water" k="amenity" />
    <tag v="yes" k="wheelchair" />
  </node>
[....]
</osm>
/****************************************************************/
```

However, in order to generate all these data, queries like the one above have to be written. *Overpass QL* is the second query language for the Overpass API and was designed as an alternative to Overpass XML. It has a C style syntax: The whole query source code is divided in *statements*, and every statement ends with a semicolon.

Returning to our points of interest, since the tags for crossings and traffic lights are already predefined, the queries needed have a simple structure as in the example above with the water drinking points. Figures 3.2 and 3.3 show the results for *highway = crossing* and *highway = traffic_signals*:

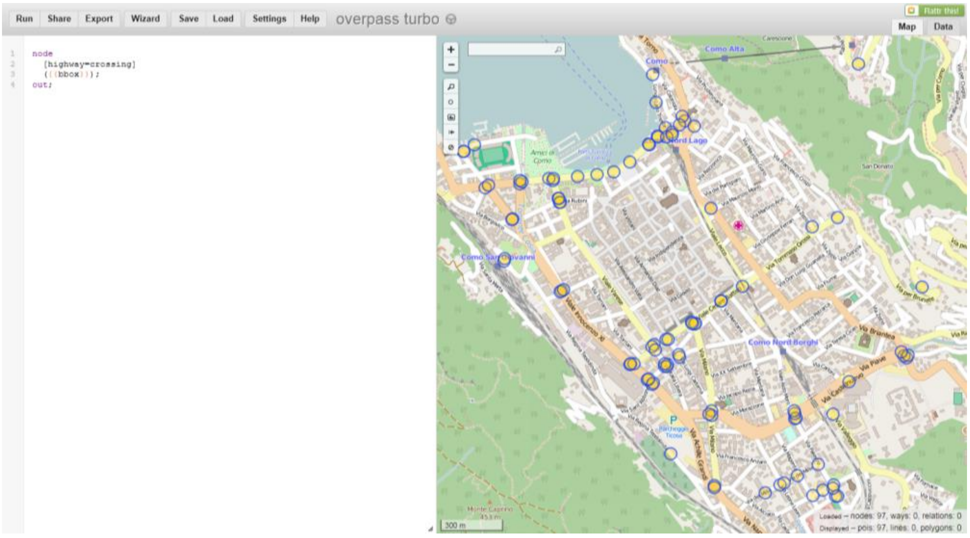


Figure 3.2: Crossings

For this region, 97 points have been tagged as crossings and 23 as traffic signals.

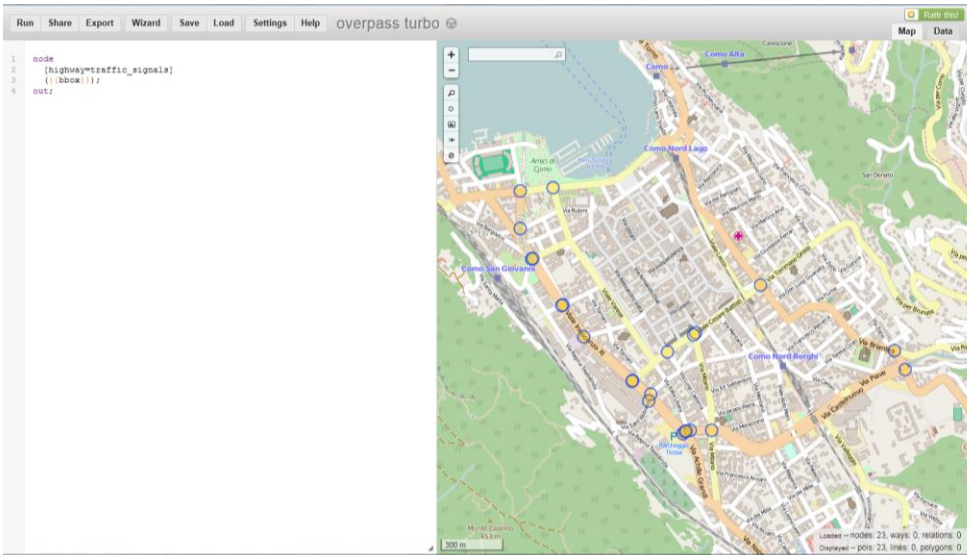


Figure 3.3: Traffic Signals

Since the queries for determining the intersections are more complex, they will be presented more into details in Chapter 6, Implementation.

3.2 Google Street View Image

The Google Street View Image API[5] lets users embed a static (non-interactive) Street View panorama or thumbnail into a web page, without the use of JavaScript. The viewport is defined with URL parameters sent through a standard HTTP request, and is returned as a static image.

A Street View Image request is an HTTP URL of the following form:

https://maps.googleapis.com/maps/api/streetview?*parameters*

For example, if we were to retrieve the street view image of the point situated at 40.720032 latitude and -73.988354 longitude, with a 400X400 size image, 235 degrees camera orientation, a zoom in of 90 degrees and the camera inclined 10 degrees up, the following request should be done:

https://maps.googleapis.com/maps/api/streetview?size=400x400&location=40.720032,-73.988354&fov=90&heading=235&pitch=10&key=API_KEY

The image is specified using request parameters. As a standard in URLs, all parameters are separated using the ampersand (&) character. Allowed parameters and their possible values are listed below.

Required parameters:

Either:

- *location* can be either a text string or a lat/lng value (40.457375,-80.009353). The Google Street View Image API will snap to the panorama photographed closest to this location. Because Street

View imagery is periodically refreshed, and photographs may be taken from slightly different positions each time, it's possible that the location may snap to a different panorama when imagery is updated.

Or:

- *pano* is a specific panorama ID. These are generally stable.

As well as:

- *size* specifies the output size of the image in pixels. Size is specified as *{width}*x*{height}* - for example, size=600x400 returns an image 600 pixels wide, and 400 high.
- *key* allows to monitor the application's API usage in the Google Developers Console; enables per-key instead of per-IP-address quota limits and ensures that Google can contact the user about the application if necessary.

Optional parameters:

- *heading* indicates the compass heading of the camera. Accepted values are from 0 to 360 (both values indicating North, with 90 indicating East, and 180 South). If no heading is specified, a value will be calculated that directs the camera towards the specified location, from the point at which the closest photograph was taken.
- *fov* (*default is* 90) determines the horizontal field of view of the image. The field of view is expressed in degrees, with a maximum allowed value of 120. When dealing with a fixed-size viewport, as with a Street View image of a set size, field of view in essence represents zoom, with smaller numbers indicating a higher level of zoom.
- *pitch* (*default is* 0) specifies the up or down angle of the camera relative to the Street View vehicle. This is often, but not always, flat horizontal. Positive values angle the camera up (with 90 degrees

indicating straight up); negative values angle the camera down (with -90 indicating straight down).

- *key* (*optional*) identifies the application for quota purposes, and enables reports in the Google Developers Console[5].

The key elements in the next phases of the development will be the *location*, the *heading*, the *fov* and the *pitch* as I will try to calculate them automatically.

3.3 Crowdsourcing

Crowdsearcher[6] is a platform for crowd management written in Javascript running on Node.js server; this is a full-fledged event-based system, which fits the need of a rule-based approach. It offers a plugin environment to transparently interface with social networks and crowdsourcing platforms and it implements the following model and process.

In general, a crowdsourcing application can be modeled with three entities: a requester, a system, and the crowd. The requester is the one who has a problem he wants to solve with the crowd. In order to do so he has to utilize the system in order to interact with the crowd.

The problem can comprehend a wide range of use cases: translating a text, transcribing an audio file, annotating images, and so on. Currently, crowdsourcing has been applied in very different scenarios like: databases, information retrieval, artificial intelligence and social science. The crowd can be very heterogeneous and can range from the anonymous worker on Amazon Mechanical Turk to a friend on Facebook or an expert on a Question Answering platform like StackOverflow. Usually the type of crowd the requester wants to involve depends on the type of problem needed to be solved.

This process allows to easily define multi-platform crowd-based applications through step-by-step specifications, where the application is initially configured and then automatically generated.

The crowdsourcing task configuration is covered by a 7-step wizard[6] that guides the task designer in the creation of a task:

- *Task Design*: The Task Design step consists in the selection of the task types that will be performed in the task. These task types are selected from an abstract model, crafted after a careful analysis of the systems for human task executions and of many applications and case studies.

- *Object Design*: Object Design consists of defining the dataset which is subject to the analysis. In particular, it entails schema definition, instance collection and data cleaning (so as to eliminate irrelevant objects and make them conforming to their schema). In this step the designer can upload the set of objects of interest (e.g., as a JSON file), possibly together with a partial ground truth, i.e. correct solutions for a subset of the objects.

- *Execution Design*: In this stage the user selects the execution platform. Execution can be performed on traditional crowdsourcing platforms (e.g., AMT), on social networks (e.g. Facebook), or on custom user interfaces, implemented ad hoc by the designer.

- *Performer Selection or Invitation Design*: In this step the user selects the invitation channel to be used to invite people to perform the task. The supported invitation platforms are:
    - Mail: the invitation is sent via email to a list of contacts provided by the user;
    - Facebook: the invitation to perform the task is posted on the wall of the user’s account;

- Twitter: the invitation to perform the task is posted as a tweet on the timeline of the user’s account.

Furthermore, a URL pointing to the task execution UI is generated by the system and can be sent manually, at any time, by the designer, through the channels of choice.

- *Adaptation Design*: The adaptation design consists in the definition of active rules that change the behavior of the system according to the status of the execution of the crowdsourcing task.

Once the task is created, the Crowdsearcher takes the specification built in this process and generates the data structure needed for its execution.

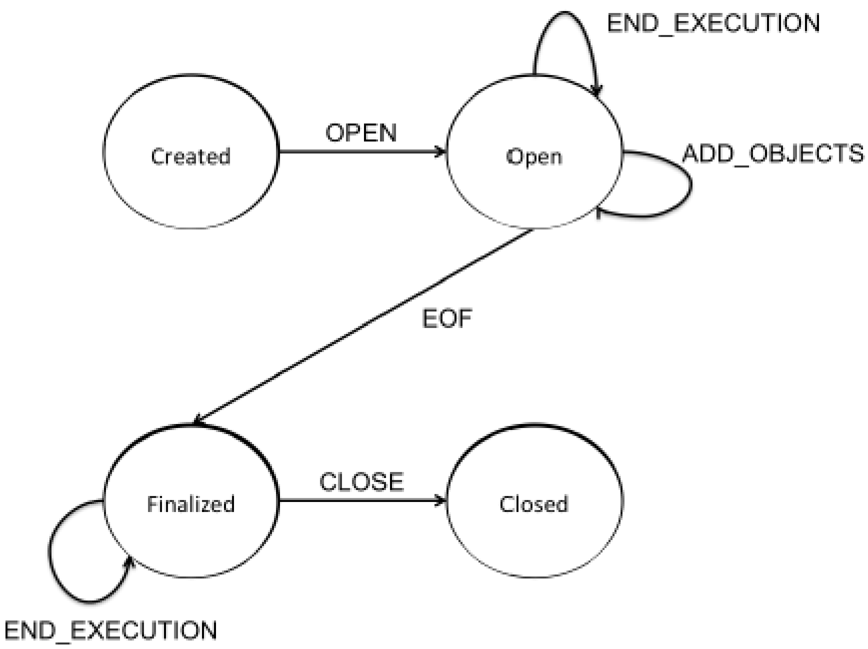


Figure 3.4: Task Life Cycle

Figure 3.4 shows the life cycle of a task in the system. The circles are the states, while the arrows represent the internal events that occur in the reactive environment. Once a task is created it only exists as a persistent object in the database; in order to be executed by the workers it needs to be deployed to the platforms through the opening phase. In this phase the system instantiates the reactive rules and the data structure required for the task control (the control mart) and deploys the task on the correct platform; afterwards it creates the post on the social networks or the HIT on Amazon Mechanical Turk. While the task is in the OPEN state, the system receives and aggregates the answers given by the performer (represented by the END_EXECUTION arrows). Once the EOF event is sent, no more objects are accepted, but the answers are still collected. When, according to some control rules, the evaluation is completed, the task is closed.

The following figure shows the architecture of the system:

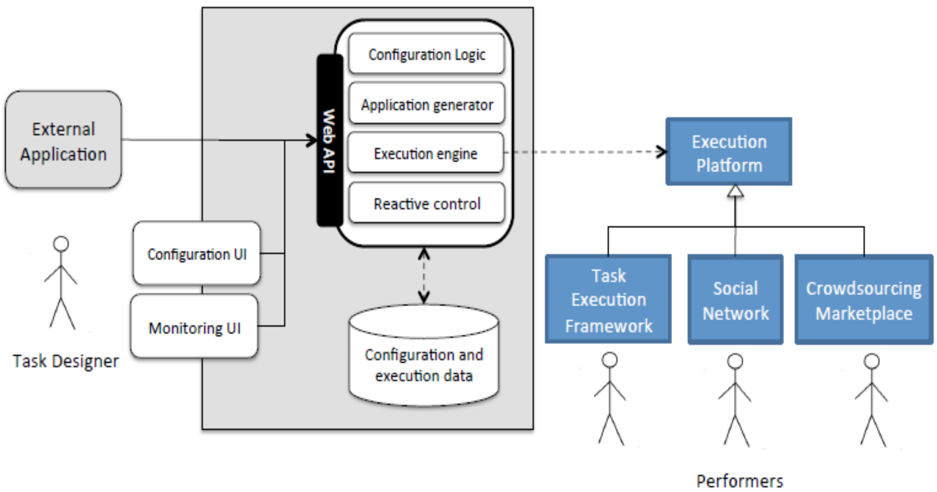


Figure 3.5: System Architecture

The core of the system is a Node.js application, integrating the data structures stored in a non-sql data source (namely a MongoDB instance) connected to the reactive control engine, and offering a set of APIs to support integration with external applications. The Task Designer can create and manage tasks either through the CrowdSearcher web interface or through a custom application invoking the API. The application generator takes the task model and generates the data structure, the rules and the objects required for the task execution and control; finally, it deploys the task on the execution platform of choice. Reactive rules are translated into scripts, whose triggering is modeled through internal platform events. Precedence between rules is implicitly obtained by defining the scripts in the proper order.

CrowdSearcher offers also a dashboard that allows designer to continuously monitor crowd-based applications[6]. For our purposes, the results generated by the platform will influence the future street view images and the level of accessibleness for a specific point.

Chapter 4

Requirements Analysis

In this chapter I will present the requirements phase, a phase which plays an important role as it is the starting point in designing the proper solutions for the question: „How to identify street-level accessibility problems by involving users?”. Within this, the answer lies in combining crowdsourcing with Google Street View.

Street View Images focusing on several accessibility features will be sent to users via a crowdsourcing platform and will be marked by them as accessible or non-accessible based on different aspects, which will be detailed later in Chapter 5.

Google Street View offers the possibility to download up to 25.000 images per day and, together with OpenStreetMap, these images can be customized in such a way to represent only the points of interest strictly related to our question. Even though the list of accessibility features which can be analyzed is long, for the time being the project limits itself to only two major features: crossings and pedestrian areas.

Downloading the images is realized by software written in Java programming language, Eclipse platform. Java, a general-purpose computer programming language that is concurrent, class-based, object-oriented, and specifically designed to have as few implementation dependencies as possible[7], was the first choice because of its free and open-source software and good execution speed.

Since the purpose is to download all these images in an automatic way, we need to have the precise location of the crossings, traffic lights and intersections. The output of the Overpass turbo queries presented in Chapter 3 is an xml file containing the geographical position of the points (latitude and longitude); by inserting these two in the Google Street View Image link, we will be having an automatic downloading process.

With respect to the accessibility features part, specialized literature has been reviewed. According to [8], accessibility is defined by the ease with which the locales and activities may be accessed by individuals, considering their diversity (Aguiar, 2010; Kwan & Weber, 2008). For Vasconcellos, "(...) it can be measured by the number and nature of the destinations (desired) that are reachable by a person." (Vasconcellos, 2000. p. 27). In depth, in terms of accessibility and traffic safety, the following aspects are sought:

Attributes	Variables
Accessibility	Existence of sidewalks, sidewalk surface material, width of pavement, quality of sidewalks, maintenance of surface longitudinal profile of the pavement, bumps, ramps, slopes (topography), barriers, proximity to crossings, adequacy of crossings, elevated tracks to traverse, accessibility, accessible routes, alternate routes, overall walk ability, orientation (boards and signage), length of the walking trail, distance to the trailhead, overall quality of the neighborhood to walk, index physical composition of the environment, residential density, mixed land use, access to commerce and services, access to leisure

	(beaches, rivers etc.), access to open areas, facilities, access by car and public transport, multimodal facilities, parking.
Traffic Safety	Nearby traffic (volume), traffic speed, traffic interference with walking, sense of safety around adjacent traffic, road width, number of crossings, ease to cross, safe crossings, signage, lowering of sidewalks, view of approaching vehicles, traffic flow at intersections, roadway separation between pavement with grass or flower beds, unsafe sidewalks (holes), difficulty walking, low walking speed, drivers who respect the law, visibility.

Table 4.1: Accessibility Features

The following table points out the the variables associated with the results of the questionnaires conducted in [8]:

Attributes	Responses	Related Variables
Accessibility	Correction of unevenness	Longitudinal profile of the pavement, ramps, slopes.
	Distance (to cover)	Accessible routes, alternate routes, overall walk ability, length of the walking trail, and distance to the trailhead.
	Sidewalks	Existence of sidewalks, sidewalk surface material,

		width of pavement, quality of sidewalks, maintenance of surface.
	Plantings and sidewalks (discontinuity between ground and grass)	Barriers.
	Adequacy of crossings	Proximity to crossings, adequacy of crossings, elevated tracks to traverse.
Traffic Safety	Adequacy of crossings	Number of crossings, ease to cross, safe crossings,signage, lowering of sidewalks.
	Sidewalks	Unsafe sidewalks (holes), difficulty walking, low walking speed.

Table 4.2: Framework of responses on attributes

According to the interviews conducted in [9], people on pavements, getting into shops and the lack of dropped kerbs were considered ‘major’ or ‘prohibitive’ obstacles; the next most serious group of obstacles all fall within the public realm, and include high kerbs, steps, and uneven surfaces (including the deliberately planned cobbled areas). Other problems noted by smaller but still substantial proportions of respondents derive from vehicle traffic and narrow pavements outside the pedestrianized core. From the in-depth interviews and focus groups, it is apparent that many users need a keen knowledge of how to get around, often involving long detours in order to avoid some of the identified obstacles and to minimize inconvenience.

As documented in [10], long inclines without a resting place, high kerbs, steps or uneven surfaces may prove to be insurmountable obstacles for wheelchair users. Road crossing represents a big problem; together with very busy main roads and the nature and positioning of the dropped kerb can make a difficult maneuvering. Narrowness of main access roads or even bustling shopping streets can cause considerable frustration. Uneven and poorly maintained pavements, temporary street obstacles together with slippery and difficult to negotiate cobbles can cause pain and discomfort. Last but not least, other problems noticed by users are uphill journeys without resting places and inaccessible toilets.

Taking all these issues into consideration and as it will be seen in Chapter 5, proper questions have been composed in order to determine the accessibleness of several street features.

Based on the research conducted, the following aspects have been selected for questioning:

- Existence of sidewalks
- Sidewalk surface material
- Quality of sidewalks
- Quality of streets
- Adequacy of crossings

Since accessibleness is determined by visualizing street view images, aspects such as traffic speed, access to open areas, accessible toilets cannot be evaluated; even the questions for the five criteria presented above have been carefully selected in order to target features which can be analyzed by image viewing.

Chapter 5

Design Phase

In this chapter I will be describing the high level implementation of the entire process in which I will be focusing on several aspects of Open Street Map and Google Street View Image together with the accessibility features considered for the crowdsourcing platform.

I would like to remember the most common problems wheelchair users can encounter when moving around the streets of a city:

- Long inclines/ Uphill going without a resting place
- High kerbs
- Position and nature of dropped kerbs
- Pavements in bad state / Uneven surfaces
- Crowdedness – especially for narrow streets
- Temporary obstacles
- Cobbles
- Gratings and drains
- Potholes
- Inaccessible shops
- Inaccessible toilets

Since the purpose of the project is to determine accessibility via images, aspects such as street crowdedness, inaccessible shops and toilets will not be taken into consideration as they cannot be analyzed from images.

The procedure of selecting the proper questions is split into three main steps as follows:

Step A

The image offers a good visibility of sidewalks or zebra?

Yes No There are ways to be improved

The first step is to determine whether the image offers a good view over the points of interest (sidewalks and zebras); in this way, we can distinguish three sub-cases:

- **Yes** – in this case the process will continue with questions regarding streets and sidewalks

  Yes

  Questions about the street Questions about the sidewalk

  Step B Step C

- **No** – no method of improving the images would work (e.g., cars or people on the zebra, crowded places); in this case the image will be discharged
- **There are ways to be improved** – the user can select from the following possibilities which best fit the case:
  - Zoom In
    - Yes
    - No

- Zoom Out
  - Yes
  - No
- Higher Pitch
  - Yes
  - No
- Lower Pitch
  - Yes
  - No
- Rotate Right
  - Yes
  - No
- Rotate Left
  - Yes
  - No

For example, an image such as Image 5.1 stands in the category of „There are ways to be improved” as, by performing a zoom out, it can offer a proper vision over the street.

Image 5.1: There are ways to be improved

Instead, an image such as Image 5.2 will not be offering a proper vision over the street as it is blocked by a bus. In both cases the images will be discharged and new ones will be selected. In cases where improvements can be done, they will be applied based on the user's feedback while in the other case a new image will be generated. All the new images will be subject to questioning, ending up in a loop until they get to be marked as „Yes" – they offer a good visibility over the points of interest.

Image 5.2: No proper vision

If the image offers a good view such as Image 5.3, steps B and C will be applied:

Image 5.3: Proper vision

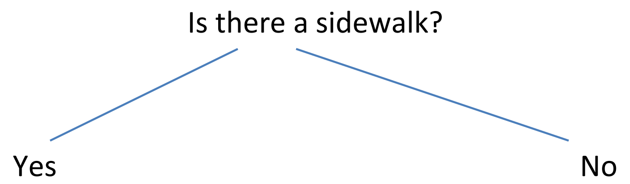
Step B

In step B, the first question aims in identifying what elements can be encountered in the image; afterwards it proceeds with questions related to the accessibility of the street:

- What elements can be encountered?
  - One zebra and possibly sidewalks
  - Two zebras and possibly sidewalks
  - No zebra
- Does the street have potholes?
  - Yes
  - No
- Does the street have tramlines?
  - Yes
  - No
- Does the street have bumps?
  - Yes
  - No
- Are there any traffic lights?
  - Yes
  - No
- Is there an intersection?
  - Yes
  - No

Step C

Step C starts by identifying whether there is a sidewalk present in the image or not:



In case a sidewalk is reported, then we proceed with questions related to it:

- Does the sidewalk have potholes?
    - Yes
    - No
- Does the sidewalk have bumps?
    - Yes
    - No
- Is the surface of the sidewalk made of cobbles?
    - Yes
    - No ->
        - Is the surface of the sidewalk made of gravel?
            - Yes
            - No
- Is the sidewalk narrow?
    - Yes
    - No
- Does the sidewalk have gratings?
    - Yes
    - No
- Does the sidewalk have drains?
    - Yes
    - No
- Can you encounter other obstacles such as:
    - Arches Bollards
        - Yes
        - No
    - Chains
        - Yes
        - No
- Does it have a dropped kerb?
    - Yes
        - Is it positioned correctly with respect to the zebra?
            - Yes

        - No
      - Is the surface neat?
        - Yes
        - No
      - Does it have a proper inclination?
        - Yes
        - No
  - No
      - Does the sidewalk have high curbsides?
        - Yes
        - No

It is considered that a dropped kerb will always be correlated to a sidewalk even though there are exceptions from the rules as it can be seen in Image A.2, Appendix A.

If no sidewalk is reported, which can be valid as there are places where the sidewalk is part of the street (Image A.1, Appendix A), then we proceed with additional questions related to the street:

- Is the surface of the sidewalk made of cobbles?
  - Yes
  - No ->
    - Is the surface of the sidewalk made of gravel?
      - Yes
      - No
- Is the sidewalk narrow?
  - Yes
  - No
- Does the sidewalk have gratings?
  - Yes
  - No
- Does the sidewalk have drains?
  - Yes
  - No

- Can you encounter other obstacles such as:
    - Arches Bollards
        - Yes
        - No
    - Chains
        - Yes
        - No

For each question Yes/No answers are accepted since they represent the easiest way to answer and at the same time it is forcing the users to answer all the questions (there will not be an answer set by default).

In addition, the questions related to potholes, bumps, cobbles, gratings and gravel will be set as mandatory while the ones related to narrow streets, drains, arches bollards and chains as optional.

One question will be sent to each user having also the possibility to write additional comments. Each question will be closed based on the following majorities:

- Step A – „No” case: 2 out of 3
- Step A – „There are ways to be improved” – no majority as we accept multiple answers
- Step B – 2 out of 4
- Step C – 2 out of 3

This means that, if two users out of three users state that the image offers poor visibility, it will be marked as „No”.

Regarding the OpenStreetMap aspects, as described in Chapter 3, the tags considered are crossings, traffic lights and intersections. Even though at the beginning the entire region of Como city was considered, due to a high number of images, I have limited the searches to a smaller region:

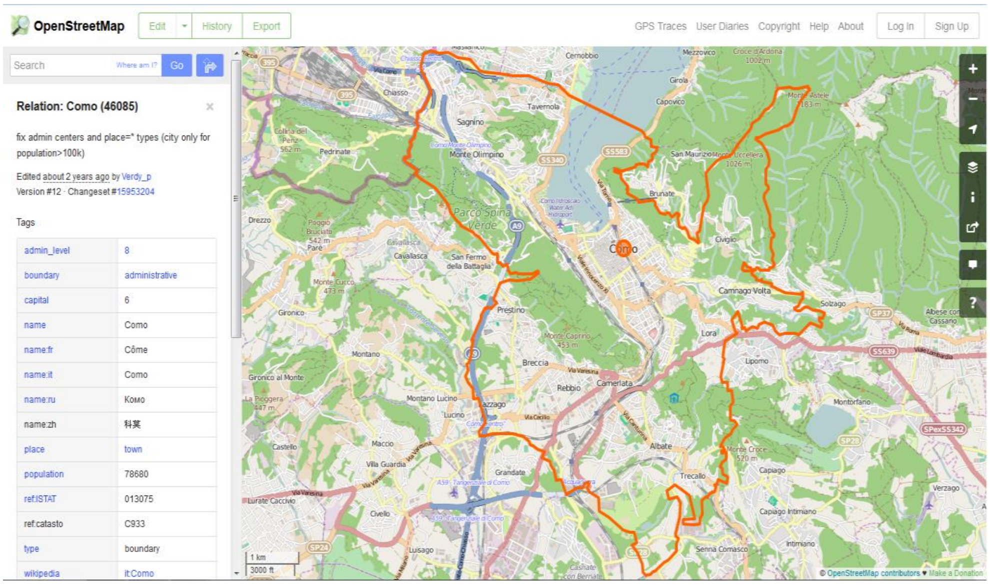


Figure 5.1: Como City – Entire region

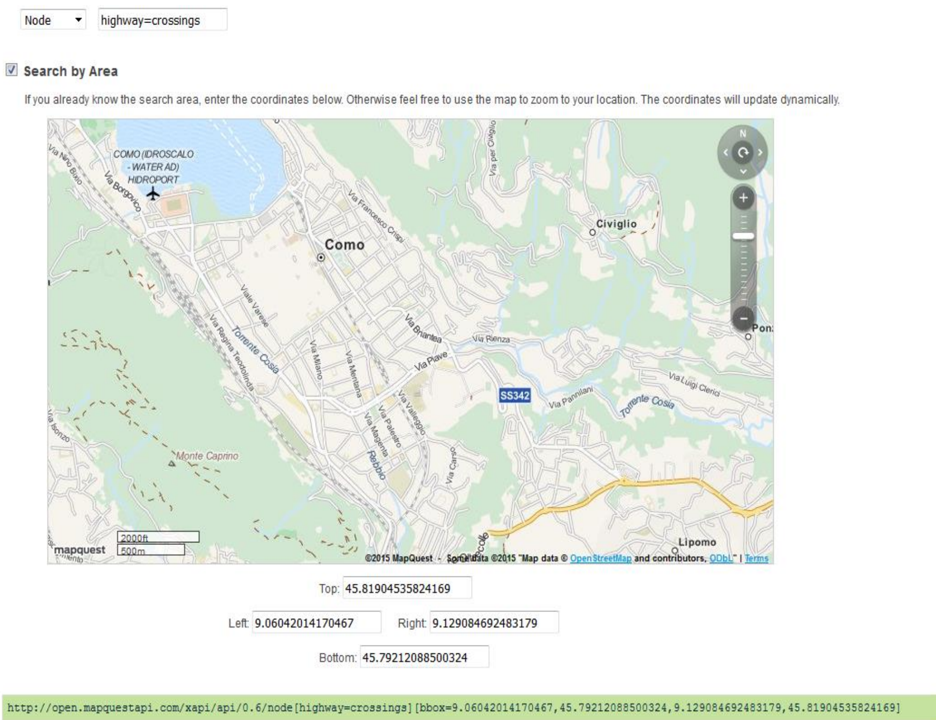


Figure 5.2: Como City – Considered region

After manually analyzing several Google Street View images, it has been decided that the parameters *fov* and *pitch* can be set as fixed (fov = 90; pitch = 10) while only the *heading* needs to be calculated (in the case of crossings and traffic lights it is manually set to 0 while for the intersections it is calculated based on several method as shown in the next chapter).

Chapter 6

Implementation

In this chapter I will describe the low level implementation process, more precisely, I will try to explain the Java code used to download the images for the crowdsourcing platform. The best way to describe the behavior of the process is by means of sequence diagrams; a sequence diagram shows the interaction among objects by highlighting the temporal flow of the messages exchanged between actors.

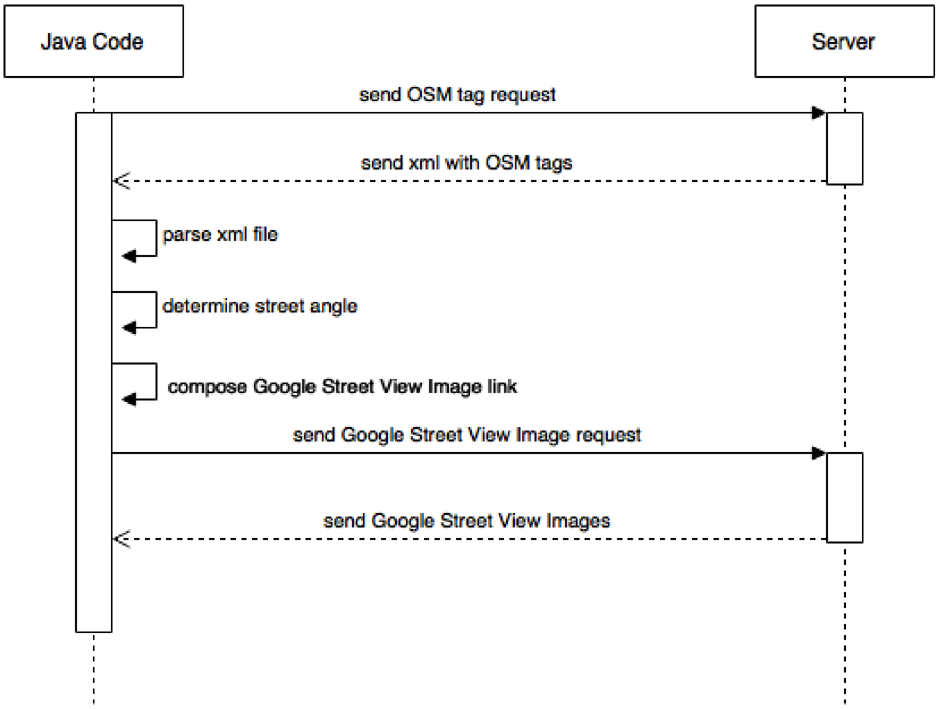


Figure 6.1: Sequence Diagram

The Java Code and the Server represent the two main actors which exchange messages between them; these messages are mostly requests being sent to the Server and answers coming from its side.

As it can be seen from Figure 6.1, the first step of the process is to determine all the Open Street Map tags automatically. Since there are already predefined tags in Open Street Map, for crossings and traffic lights they can be obtained straightforward by using a XAPI request:

```
/*****************************************************************/
String url_crossing = 
"http://open.mapquestapi.com/xapi/api/0.6/node%5Bhighway=crossings%5D%5Bbbox=8.9904,45.7581,9.1175,45.8428%5D";
String url_traffic_lights = 
"http://open.mapquestapi.com/xapi/api/0.6/node%5Bhighway=traffic_signals%5D%5Bbbox=8.9904,45.7581,9.1175,45.8428%5D";
/*****************************************************************/
```

Xapi is a read-only OpenStreetMap Extended API that provides enhanced search and querying capabilities for nodes, ways and relations. The query can be defined by OSM tags and/or a bounding box and will return all current data that match the entered search terms[11].

The key elements of the XAPI request are the tags and the bbox; the following table describes the selection predicates that may be included in the request[11]:

Predicates	Description
tags	Features with the specified OSM tags will be returned. Format must be in the form [*key=value*]. • **node** - node[*key=value*] • **way** - way[*key=value*] • **relation** - relation[*key=value*]

bbox	Bounding box used to limit the extent of the result document. Usage of bbox is currently limited to 10 square degrees. Must be in the following order: • [bbox=*left*,*bottom*,*right*,*top*]

Table 6.1: XAPI Request Elements

For our case the tags required are highway = crossings and highway = traffic_signals while the bbox=8.9904,45.7581,9.1175,45.8428 corresponds to the city of Como.

The response of the XAPI request will be an xml file of the following format:

```
/**************************************************************/

<node id="152649789" version="10" timestamp="2012-11-
25T20:19:42Z" uid="668137" user="ilGianlu"
changeset="14036107" lat="45.8021613" lon="9.0863774">

    <tag k="highway" v="traffic_signals"/>

  </node>

/**************************************************************/
```

Where the latitude and longitude attributes represent our point of interest as they will be later used in the composition of the Google Street View Image link.

Downloading the intersection tags is not that straightforward as a XAPI request cannot be used. The issue can be solved instead by using queries in Overpass turbo, as follows:

```
/**************************************************************/

[out:xml][timeout:3600];

// filter ways

way[highway][highway!~"footway|cycleway|path|service|tr
ack"](45.7581,8.9904,45.8428,9.1775)->.hw;
```

```
// for each way
foreach.hw->.eachw(

// get ways which share the same nodes minus current
way into .otherws

node(w.eachw)->.ns;
way(bn.ns)[highway][highway!~"footway|cycleway|path|ser
vice|track"]->.w2;
(way.w2; - way.eachw;)->.otherws;

// get shared nodes
node(w.otherws)->.n2;
node(w.eachw)->.n3;

(((node.n2; node.n3;) -(node.n2; - node.n3;);) -
(node.n3; - node.n2;););->.shrdnodes;

// ways which are in junction
way(bn.shrdnodes)->.outways;

// union ways and nodes
(way.outways; node.n2.n3); out geom;
);
/*******************************************************************/
```

The flowchart presented in Figure 6.2 presents the steps of the algorithm.

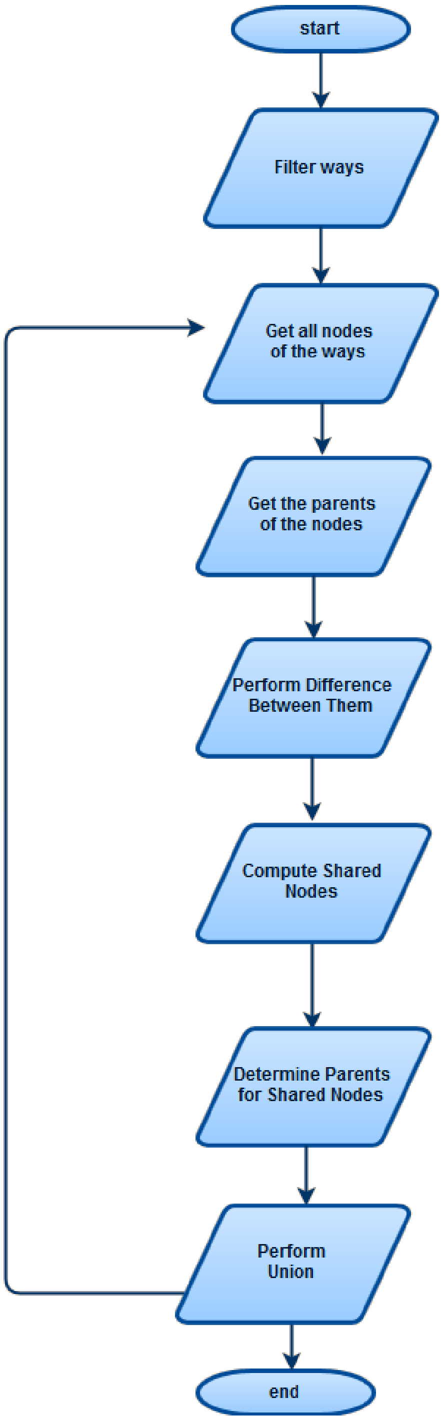


Figure 6.2: Flowchart

I start by filtering out the ways, meaning i am selecting the *key* highway from which i exclude the *values* footway, cycleway, path, service and track.

Given the entire list of values[21] associated to the highway key, Table 6.2 shows a description of the values which were excluded to better highlight the decision taken.

Key	Value	Element	Comment	Photo
highway	service		For access roads to, or within an industrial estate, camp site, business park, car park etc. Can be used in conjunction with service=* to indicate the type of usage and with access=* to indicate who can use it and in what circumstances.	
highway	track		Roads for mostly agricultural or forestry uses. To describe the quality of a track, see tracktype=*.	
highway	footway		For designated footpaths; i.e., mainly/exclusively for pedestrians. This includes walking tracks and gravel paths. If bicycles are allowed as well, you can indicate this by adding a bicycle=yes tag. Should not be used for paths where the primary or intended usage is unknown. Use highway=pedestrian for pedestrianised roads in shopping or residential areas and highway=track if it is usable by agricultural or similar vehicles.	

highway	path		A non-specific path. Use highway=footway for paths mainly for walkers, highway=cycleway for one also usable by cyclists, highway=bridleway for ones available to horses as well as walkers and highway=track for ones which is passable by agriculture or similar vehicles.	
highway	cycleway		For designated cycleways. Add foot=* only if default-access-restrictions do not apply.	

Table 6.2: Excluded Key Values

The core of the query lies in the loop (*foreach*) where the shared nodes (between streets) are being calculated; it puts the element to loop over into the variable *eachw*.

Now, by using *node (w);* (w - forward from ways) , I select the child nodes from all the ways of the input set:

```
/*****************************************************************/
node(w.eachw)->.ns;
/*****************************************************************/
```

Will save all the child nodes of the ways into ns.
Proceeding to *way (bn);* (bn - backward from nodes), I select the parent ways for all nodes from the input set.

```
/*****************************************************************/
way(bn.ns)[highway][highway!~"footway|cycleway|path|ser
vice|track"]->.w2;

/*****************************************************************/
```

Meaning that I am selecting the parents of the nodes determined with one step above.

At this moment, if we were to stop here, by applying the difference between them, I get all the junction nodes and the junction ways but without their other child nodes:

```
/****************************************************************/

(way.w2; - way.eachw;)->.otherws;

node(w.otherws)->.n2;

node(w.eachw)->.n3;

/****************************************************************/
```

In order to get also the other points of the ways, a union needs to be applied between the shared nodes and the ways they belong to.

```
/****************************************************************/

(((node.n2; node.n3;) -(node.n2; - node.n3;);) -
(node.n3; - node.n2;););)->.shrdnodes;


// ways which are in junction

way(bn.shrdnodes)->.outways;


// union ways and nodes

(way.outways; node.n2.n3); out geom;);

/****************************************************************/
```

Where node.n2.n3; calculates the intersection of the input set .n2 and .n3

The three differences to determine the shared nodes stand for the following: (all the nodes from n2 and n3 together) – (all the nodes from n2 which are not in n3) – (all the nodes from n3 which are not in n2).

The idea of the query can be better highlighted using the street network shown in Figure 6.3 where we have the main street (number II) and additional streets with which it forms intersections.

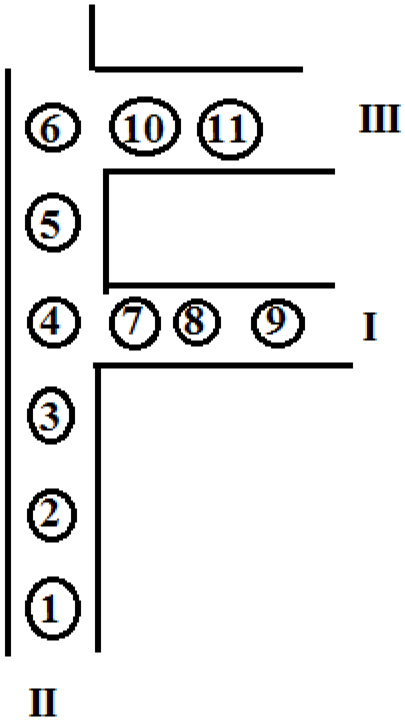


Figure 6.3: Street Network

I start by selecting all the child nodes for street II: 1, 2 ,3 ,4 ,5 , 6 and 7. Now, for each node I retrieve all the parent nodes:

Node 1 -> Parent Street II

Node 2 -> Parent Street II

Node 3 -> Parent Street II

Node 4 -> Parent Street II + Parent Street I

Node 5 -> Parent Street II

Node 6 -> Parent Street II + Parent Street I

By applying now the difference between *w2* (the parents) and *eachw* (the streets determined in step 1 – meaning street II), for node 4 I will get Parent Street I. At this point, I know that node 4 is an intersection and that street II has an intersection with street I.

In order to determine the precise shared nodes and the ways they belong to, I continue by retrieving all the nodes from Street I and II and applying differences among them:

Street I: 4, 7, 8, 9

Street II: 1, 2 ,3 ,4 ,5 , 6 and 7

(all the nodes from Street I and II together) – (all the nodes from Street I which are not in II) – (all the nodes from Street II which are not in I) = (1, 2 ,3 ,4 ,5 , 6, 7, 8, 9) – (7, 8, 9) – (1, 2 ,3,5 , 6) = 4

The query can be exported as a link and, as in the crossings and traffic lights case, it is possible to download all the tags automatically as an xml file:

```
/*****************************************************************/

String url_intersections = "http://overpass-
api.de/api/interpreter?data=%0A%5Bout%3Axml%5D%5Btimeout%3A3600%5D%
3B%0A%2F%2F%20filter%20ways%0Away%5Bhighway%5D%5Bhighway%21~%22foot
way%7Ccycleway%7Cpath%7Cservice%7Ctrack%22%5D%2845.7581%2C8.9904%2C
45.8428%2C9.1775%29-
%3E.hw%3B%0A%0A%2F%2F%20foreach%20way%0Aforeach.hw-
%3E.eachw%28%0A%20%20%2F%2F%20get%20ways%2C%20which%20shares%20same
%20nodes%20minus%20current%20way%0A%20%20%2F%2F%20into%20.otherws%0
A%20%20node%28w.eachw%29-
%3E.ns%3B%0A%20%20way%28bn.ns%29%5Bhighway%5D%5Bhighway%21~%22footw
ay%7Ccycleway%7Cpath%7Cservice%7Ctrack%22%5D-
%3E.w2%3B%0A%20%20%28way.w2%3B%20-%20way.eachw%3B%29-
%3E.otherws%3B%0A%0A%20%20%2F%2F%20get%20shared%20nodes%0A%20%20nod
e%28w.otherws%29-%3E.n2%3B%0A%20%20node%28w.eachw%29-
%3E.n3%3B%0A%0A%20%28%28%28node.n2%3B%20node.n3%3B%29%20-
%28node.n2%3B%20-%20node.n3%3B%29%3B%29%20-%28node.n3%3B%20-
%20node.n2%3B%29%3B%29-
%3E.shrdnodes%3B%0A%0A%20%20%2F%2F%20ways%20which%20are%20in%20junc
tion%0A%20%20way%28bn.shrdnodes%29-
%3E.outways%3B%0A%0A%20%20%2F%2F%20union%20ways%20and%20nodes%0A%20
%20%28way.outways%3B%20node.n2.n3%29%3B%20out%20geom%3B%20%0A%29%3B
%0A%20%20%0A%20%20%0A%20%20%0A%20%20%0A%20%20%0A";

/*****************************************************************/
```

The output, containing all intersection points and the ways they belong to, will be of the following format:

```
/******************************************************************/
<node id="283338852" lat="45.7795789" lon="8.9933379"/>
<node id="676633881" lat="45.7821164" lon="8.9749494"/>
<node id="946751825" lat="45.7811333" lon="8.9895299"/>
<way id="53560605">
    <bounds minlat="45.7821164" minlon="8.9718081"
maxlat="45.7852767" maxlon="8.9754394"/>
    <nd ref="676633881" lat="45.7821164"
lon="8.9749494"/>
    <nd ref="946753392" lat="45.7822876"
lon="8.9749637"/>
    <nd ref="676633883" lat="45.7824795"
lon="8.9749256"/>
    <nd ref="946751727" lat="45.7826806"
lon="8.9748991"/>
    <tag k="highway" v="unclassified"/>
    <tag k="name" v="Via Luraschi"/>
  </way>
/******************************************************************/
```

e.g. , node 676633881 belongs to way 53560605

Figures 6.4 and 6.5 show also the representation on the map:

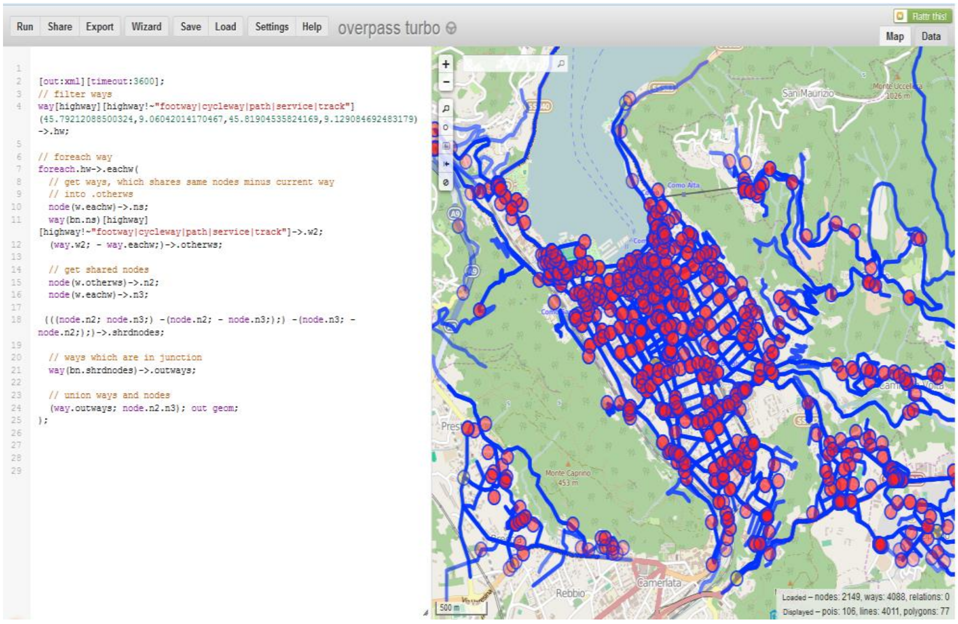


Figure 6.4: Query representation on the map – high level

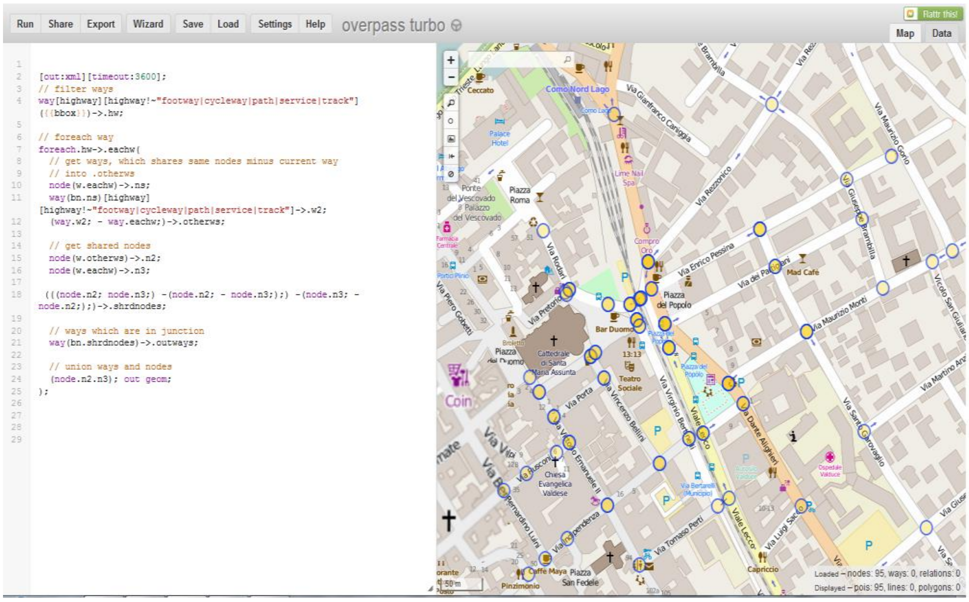


Figure 6.5: Query representation on the map – detailed level

Now that we have collected the nodes we can parse the xml file in order to retrieve only the latitude and longitude of each node (for the crossings and traffic lights cases):

```
/*****************************************************************/

    // focus only on the node and tag lists
    NodeList nList = doc.getElementsByTagName("node");
    NodeList nList2 = doc.getElementsByTagName("tag");
    for (int temp = 0; temp < nList.getLength(); temp++) {
      Node nNode = nList.item(temp);
      Node nNode2 = nList2.item(temp);
      Element eElement = (Element) nNode;
      Element eElement2 = (Element) nNode2;
    // for each element of type nNode („node”) get the id, lat and
    long
    if (nNode.getNodeType() == Node.ELEMENT_NODE) {
      writer.println("Image: image"  + temp + ".png");
      writer.println("ID: " + eElement.getAttribute("id"));
      writer.println("Longitude: " +
    eElement.getAttribute("lon"));
      writer.println("Latitude: " + eElement.getAttribute("lat"));
                                                    }
    // for each element of type nNode2 („tag”) get the tags
    if (nNode2.getNodeType() == Node.ELEMENT_NODE) {
      writer.println("Tag: " + eElement2.getAttribute("k") + ";" +
    eElement2.getAttribute("v"));
      writer.println("\n");
/*****************************************************************/
```

I start by focusing only on the „node" and „tag" lists as these are the ones that I will process later on. While scanning the entire node list (inside the *for* loop), I retrieve the node id and the latitude and longitude of the point (`eElement.getAttribute("id");eElement.getAttribute("lon"); eElement.getAttribute("lat")`).

Due to the fact that the tag list is inside the node one, by simply checking if it's a tag, we can retrieve what type of OSM tag it is (`eElement2.getAttribute("k"); eElement2.getAttribute("v")`).

The output will be of the following format:

```
/***********************************************************/
Image: image0.png
ID: 152649789
Longitude: 9.0863774
Latitude: 45.8021613
Tag: highway;traffic_signals
/***********************************************************/
```

The same code applies also for the intersection case, just that here we also want to determine the street inclination (angle) the node belongs to.

The general formula for calculating the angle (bearing) between two points, each having a latitude and longitude, is as follows:

θ = atan2(sin(Δlong)*cos(lat2), cos(lat1)*sin(lat2) – sin(lat1)*cos(lat2)*cos(Δlong))

Where Δlong = long2 - long1.

atan2 is a common function found in almost all programming languages (mostly in the Math package) which returns the angle whose tangent is the quotient of two specified numbers. The return value is the angle in the Cartesian plane formed by the x-axis, and a vector starting from the origin, (0,0), and terminating at the point, (x,y)[18]. Since it returns values in the range of -π ... +π, in order to convert the result to a compass bearing, θ needs to be multiplied by 180/π and after to use (θ+360) % 360, where % is modulus division operation returning the remainder of the division.

In Java the formula can be implemented using the below method:

```
/*****************************************************************/

static double angleFromCoordinate(double lat1, double long1, double
lat2, double long2) {
            double dLon = (long2 - long1);
            double y = Math.sin(dLon) * Math.cos(lat2);
            double x = Math.cos(lat1) * Math.sin(lat2) -
Math.sin(lat1) * Math.cos(lat2) * Math.cos(dLon);
            double brng = Math.atan2(y, x);

            brng = Math.toDegrees(brng);
            brng = (brng + 360) % 360;
            brng = 360 - brng;

            return brng;
        }
/*****************************************************************/
```

For example, the following request with the heading being calculated using the above method will give a proper output:

https://maps.googleapis.com/maps/api/streetview?size=600x600&location=45.7979860,9.0631094&fov=90&heading=187.24566002145684&pitch=10

Image 6.1: Google Street View Image Request

As it can be seen from above, the method makes use of two pairs of latitude and longitude. If the first pair is exactly one intersection point (e.g., 676633881), the second one can be any other point in the list of points belonging to that specific way (e.g., 946753392 or 676633883 or 946751727).

This can be done by comparing the node id with the ref attribute contained in the way; if there is a match, it means that the node belongs to that way:

```
/*****************************************************************/

      if
      (eElement.getAttribute("id").equals(childElement.getAttribut
      e("ref"))

/*****************************************************************/
```

Selecting the second node required by the *angleFromCoordinate* method means scanning the entire ways the first node belongs to and retrieve any other node from the way. In order to achieve this, some check-ups need to be performed.

Going back to the above example, we see that node 676633881 occupies the first position in the list but it can occupy any other position including the last one. Therefore, the positions need to be checked accordingly:

- If it's the first position => retrieve the second one
- If it's in the middle => retrieve any other position
- If it's the last position => retrieve the first one

```
/***********************************************************/
NodeList nList2 = doc.getElementsByTagName("way");
for (int  i = 0; i < nList2.getLength(); i++) {
Node nNode2 = nList2.item(i);
Element eElement2 = (Element) nNode2;
Node childNode = eElement2.getFirstChild();
Element childElementFirst= null;
Element childElementSecond= null;
if (nNode2.getNodeType() == Node.ELEMENT_NODE) {
      int count=0;
      while( childNode.getNextSibling() !=null ){
       count++;
       childNode = childNode.getNextSibling();
       if (childNode.getNodeType() == Node.ELEMENT_NODE) {
           Element childElement = (Element) childNode;
            if(count <= 3){
                  childElementFirst=(Element) childNode;
                        }
            if
      (eElement.getAttribute("id").equals(childElement.getAttribut
      e("ref")) &&
```

```
(!(eElement.getAttribute("id").equals(childElementFirst.getA
ttribute("ref"))))){
            writer.println("WAY ID: " +
        eElement2.getAttribute("id"));
            writer.println("first: ID:
"+childElementFirst.getAttribute("ref") + " ; Lat: "+
childElementFirst.getAttribute("lat") +" ; Lon:"+
childElementFirst.getAttribute("lon"));
                                                }


            else if
(eElement.getAttribute("id").equals(childElement.getAttribute("ref"
)) &&
(eElement.getAttribute("id").equals(childElementFirst.getAttribute(
"ref")))){
            writer.println("WAY ID: " +
eElement2.getAttribute("id"));
            String[] rnd_pos =
arr_get_one(reflist,childElementFirst.getAttribute("ref"));
            writer.println("next position: id: "+ rnd_pos[0] + " ;
        lat:" + rnd_pos[1] + " ; lon:" + rnd_pos[2]);;}}
/*****************************************************************/
```

While count <= 3 means the first position in the way; it goes until 3 because, while scanning all the siblings, it takes into consideration also the elements above the first "nd" – e.g. bounds.

```
/*****************************************************************/
(eElement.getAttribute("id").equals(childElement.getAttribute("ref"
)) &&
(!(eElement.getAttribute("id").equals(childElementFirst.getAttribut
e("ref")))))
/*****************************************************************/
```

If the node id == ref and it is not the first position => give me the first one.

```
/*****************************************************************/
(eElement.getAttribute("id").equals(childElement.getAttribute("ref"
)) &&
```

```
((eElement.getAttribute("id").equals(childElementFirst.getAttribute
("ref"))))
/****************************************************************/
```

If the node id == ref and it is the first position => give me the second one.

The array rnd_pos refers to an ArrayList containing all the childNodes of the way from which we can retrieve the second position:

```
/****************************************************************/
ArrayList<String[]> reflist = mychild_refs(childNode);
public static String[] arr_get_one(ArrayList<String[]> str_array,
String str_remove) {
            String[] tmp_array;

            for (int i = 1; i < str_array.size(); i++) {
                  tmp_array = str_array.get(i);
                  if (tmp_array[0] != str_remove) {
                        return tmp_array;
                  }
            }
            return null;
      }
public static ArrayList<String[]> mychild_refs(Node childs) {
            ArrayList<String[]> my_array = new
ArrayList<String[]>();
            while (childs.getNextSibling() != null) {

                  if ((childs.getNodeType() ==
Node.ELEMENT_NODE)) {
                        Element childElement = (Element) childs;
                        String[] str_myrefs =
{childElement.getAttribute("ref"),
                        childElement.getAttribute("lat"),
                        childElement.getAttribute("lon") };
```

```
                    my_array.add(str_myrefs);
                }
                childs = childs.getNextSibling();
            }
            my_array.removeAll(Collections.singleton(null));
            return my_array;
        }
/*****************************************************************/
```

Using the mychild_refs() method I save all the children of the way list in my_array. Here i recall that the output of the Overpass turbo query has the following format:

```
/*****************************************************************/
<way id="53560605">
    <nd ref="676633881" lat="45.7821164"
lon="8.9749494"/>
    <tag k="highway" v="unclassified"/>
    <tag k="name" v="Via Luraschi"/>
  </way>
/*****************************************************************/
```

That is why the elements added to our ArrayList are `childElement.getAttribute("ref")`, `childElement.getAttribute("lat")` and `childElement.getAttribute("lon")`.

The arr_get_one() method processes the above ArrayList in such a way to return the second element in the list. By using the following calls, the method receives as an input the list of child nodes and it will return the second child node in the list:

```
/*****************************************************************/
ArrayList<String[]> reflist = mychild_refs(childNode);
String[] rnd_pos = arr_get_one(reflist,
childElementFirst.getAttribute("ref"));
/*****************************************************************/
```

The output is the following:

```
/*****************************************************************/
Image: image0.png
ID: 283338852
Latitude: 45.7795789
Longitude: 8.9933379
WAY ID: 81257578
next position: id: 283338853 ; lat:45.7792718 ;
lon:8.9929288
WAY ID: 126101807
first position: ID: 676633881 ; Lat: 45.7821164 ;
Lon:8.9749494
WAY ID: 180358158
next position: id: 1908029109 ; lat:45.7809515 ;
lon:8.9952597
WAY ID: 126101807
first position: ID: 676633881 ; Lat: 45.7821164 ;
Lon:8.9749494
WAY ID: 81257578
next position: id: 283338853 ; lat:45.7792718 ;
lon:8.9929288
WAY ID: 126101807
first position: ID: 676633881 ; Lat: 45.7821164 ;
Lon:8.9749494
WAY ID: 180358158
next position: id: 1908029109 ; lat:45.7809515 ;
lon:8.9952597
WAY ID: 180358158
next position: id: 1908029109 ; lat:45.7809515 ;
lon:8.9952597
/*****************************************************************/
```

Node 283338852 belongs to the way 81257578 where it occupies the first position so I will retrieve the second one. In way 126101807 it is not the first one, so i will retrieve the first.

After having all the required latitudes and longitudes, the only remaining step is to call the *save_Image_Tags()* method which will process the Google Street View Image link and will download the images for each point:

```
/*****************************************************************/

	public static void save_Image_Tags(String imageUrl, String
destinationFile)
			throws IOException {
		URL url = new URL(imageUrl);
		InputStream is = url.openStream();
		OutputStream os = new
FileOutputStream(destinationFile);

		byte[] b = new byte[2048];
		int length;

		while ((length = is.read(b)) != -1) {
			os.write(b, 0, length);
		}

		is.close();
		os.close();
		System.out.println("end");
	}
/*****************************************************************/
```

The method receives as input an URL from where to download the images and a destinationFile in which it is specified the location where to save the images. The calls for crossings/traffic lights can be done as follows:

```
/*****************************************************************/

String imageUrl =
"https://maps.googleapis.com/maps/api/streetview?size=600x600&locat
ion="+eElement.getAttribute("lat") + ","
+eElement.getAttribute("lon") + "&fov=90&heading=0&pitch=10";

String destinationFile =
"/Users/Salai/workspaceEclipse/DownloadImagesForCrowdSourcing/cross
ings/image" + temp + ".png";

save_Image_Tags(imageUrl, destinationFile);

/*****************************************************************/
```

While for the intersections:

```
/*****************************************************************/

String imageUrl =
"https://maps.googleapis.com/maps/api/streetview?size=600x600&locat
ion="+ eElement.getAttribute("lat")+ "," +
eElement.getAttribute("lon") + "&fov=90&heading=" +
angleFromCoordinate(
Double.parseDouble(eElement.getAttribute("lat")),
Double.parseDouble(eElement.getAttribute("lon")),Double.parseDouble
(childElementFirst.getAttribute("lat")),Double.parseDouble(childEle
mentFirst.getAttribute("lon"))) + "&pitch=10";

/*****************************************************************/
```

And

```
/*****************************************************************/

String imageUrl =
"https://maps.googleapis.com/maps/api/streetview?size=600x600&locat
ion="+ eElement.getAttribute("lat")+ "," +
eElement.getAttribute("lon") + "&fov=90&heading=" +
angleFromCoordinate(
Double.parseDouble(eElement.getAttribute("lat")),
Double.parseDouble(eElement.getAttribute("lon")),Double.parseDouble
(rnd_pos[1]),Double.parseDouble(rnd_pos[2])) + "&pitch=10";

/*****************************************************************/
```

At this point we have downloaded all the images required which now can be passed over to the crowdsourcing platform.

Chapter 7

User Interface

The User Interface occupies a very important part in the thesis as it represents the end point by which the users will interact with the project itself. The goal of this interaction is to allow effective operation and control of the process/machine from the human end, whilst the process/machine simultaneously feeds back information that aids the operators' decision making process[19].

Generally, the goal of user interface design is to produce a user interface which makes it easy (self explanatory), efficient, and enjoyable (user friendly) to operate a machine in the way which produces the desired result. This generally means that the operator needs to provide minimal input to achieve the desired output, and also that the machine minimizes undesired outputs to the human[19].

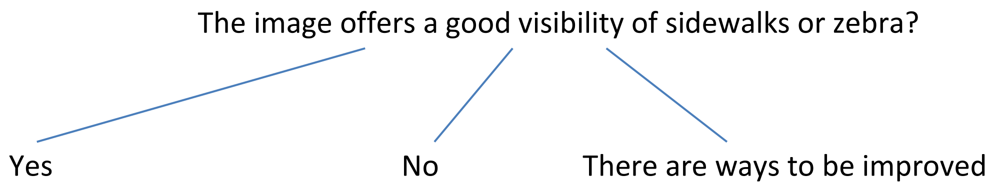
Even though the user interface can arguably include the total "user experience," which may include the aesthetic appearance of the device, response time, and the content that is presented to the user within the context of the user interface[20], for the time being, these aspects have not been taken into consideration. If the users will be actively participating and will provide an increased number of feedbacks (leading to a real success of the platform) then, in addition to all future works presented in Chapter 9, web and mobile accessibility features can be introduced. For the moment the platform has been mostly designed as a web application but it can also be extended to a mobile one. The accessibility features which can be considered for both cases refer to the following major categories of disability:

- Sensorial disabilities
    - Visual disabilities: complete/partial blindness, low vision, color blindness
    - Auditory disabilities: complete/partial deafness
- Motor
    - Inability to use a mouse, slow response time, limited fine motor control
- Cognitive impairments
    - Learning disabilities, distractibility, inability to remember or focus on large amount of information
- Seizure disorders
- Ageing

The platform addresses itself to any kind of user described in Chapter 1; the questions can be answered by users with mobility impairments, local governments and organizations and even volunteers. Therefore, these aspects are perfectly valid and worth taken into consideration due to the fact that a wheelchair user (and not only) can suffer from additional diseases as the ones mentioned above.

Returning to the user interface, the following figures represent the implementation of the questions presented in Chapter 5.

Figure 7.1 represents Step A, in which the image visibility is evaluated:



The first image can be improved and therefore the user will have the possibility to choose the appropriate improvement methods (multiple answers). These answers are displayed only after the user has clicked on the „can be improved" button; as it can be seen from the figure, it is highlighted in a different way from the other two buttons. The second image does not offer any proper visibility over the sidewalks and zebras and it will be removed; the image will not be completely deleted as it represents a strategic point in the configuration of the accessible path. Instead, a new image will have to be generated, from the same location but having a different orientation (the *heading*, *fov* and *pitch* elements in the Google Street View Image link will have different values). The third and the fourth images offer a good visibility over the sidewalks and zebras and therefore it can be proceed to steps B and C.

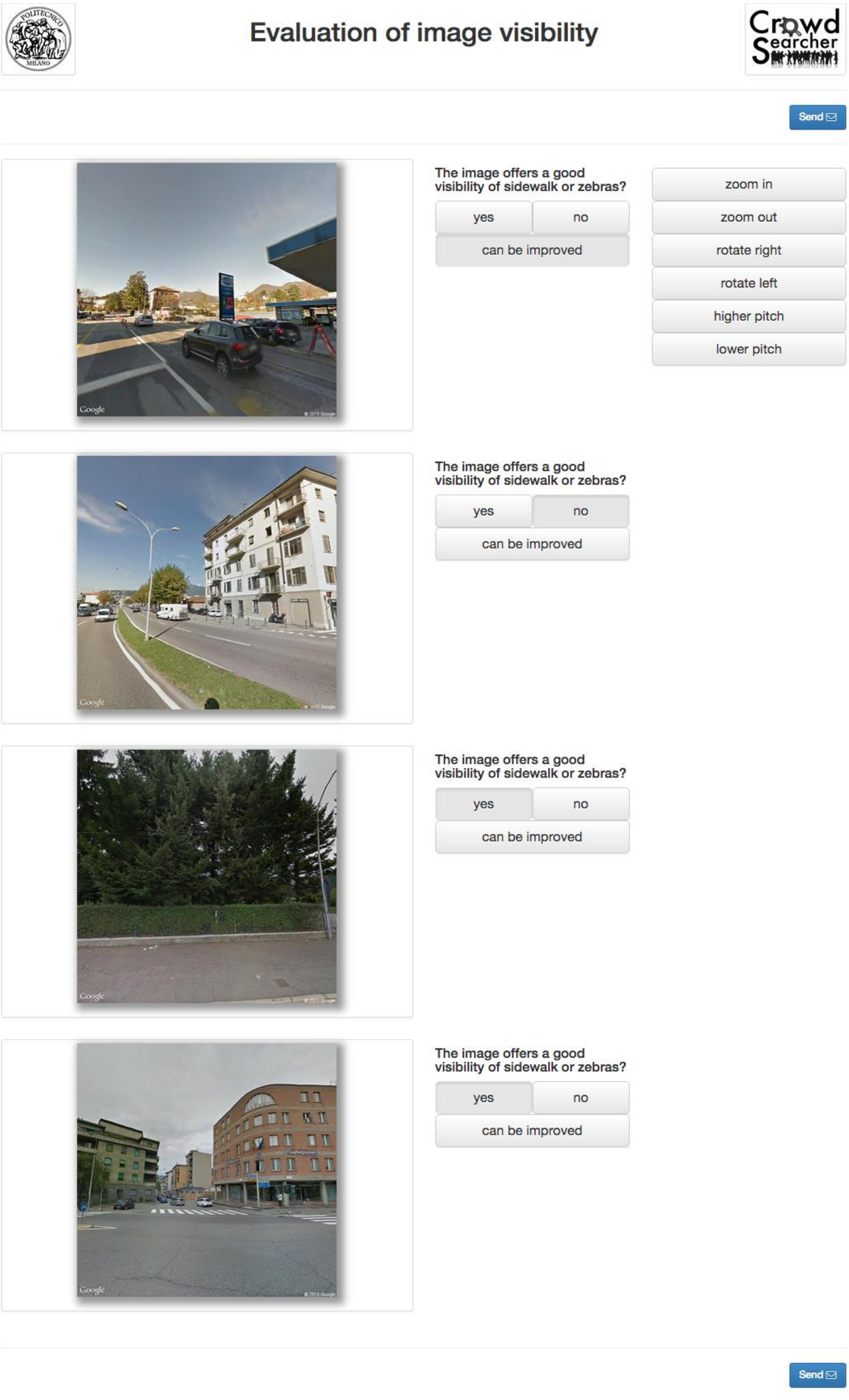


Figure 7.1: Evaluation of image visibility

Figure 7.2 is related to the street questions in Step B. The image presented was selected as „it offers a good visibility of sidewalk and zebras" in Step A and now it continues with questions regarding the sidewalk and zebras.

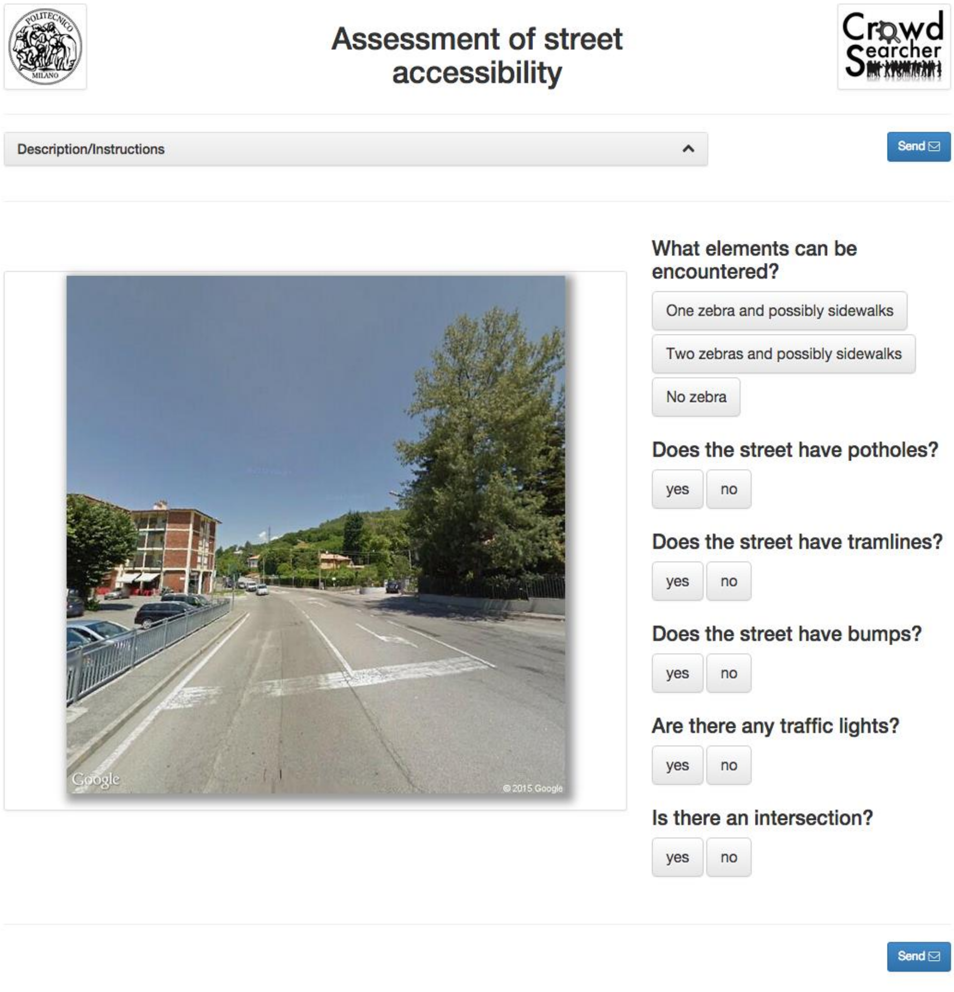


Figure 7.2: Evaluation of street accessibility

Figure 7.3 shows the case of an image which falls into Step C – questions related to the sidewalk. Since the surface of the sidewalk is not made of cobbles, the question if it is made of gravel will rise. Additionally, a dropped kerb cannot be spotted in the image and therefore it will be asked if the sidewalk has high curbsides (if the curbsides have a low height then it is considered that users can cross).

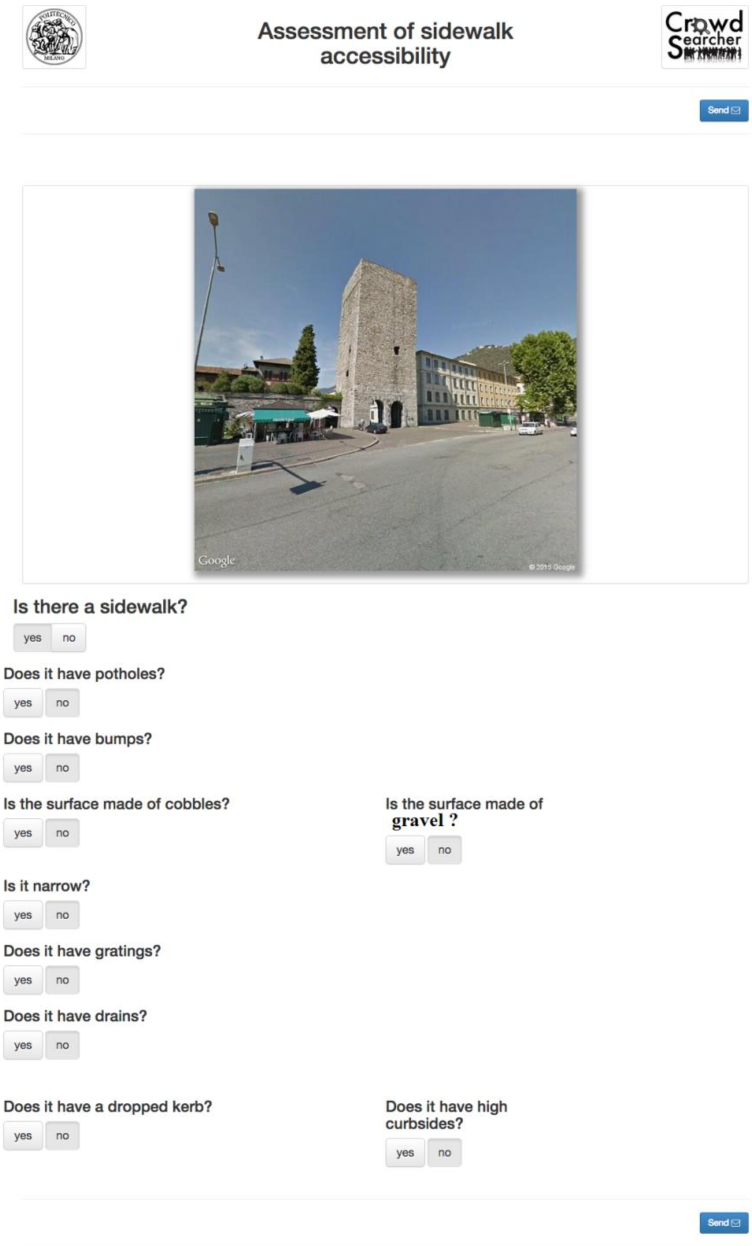


Figure 7.3: Evaluation of sidewalk accessibility

Chapter 8

Conclusion

Large cities are built and designed based on the needs of mobile people, architectural preferences and budgets. Unfortunately, this constitutes a big disadvantaged for those with mobility disabilities. Wheelchair users are regularly hindered by barriers from participating in daily life on their own. The research work presented in this thesis aims in solving this problem by means of crowdsourcing and street view images. The process consists of street view images which are sent to users via crowdsourcing platform and are marked as accessible and non-accessible based on their feedback. These images focus on specific points (crossings, traffic lights and intersections) and precise questions are being asked in order to determine the accessibility of these points.

I first started by analyzing the best way to collect the images; this can be done by combining OpenStreetMap with Google Street View Image. OpenStreetMap offers pre-defined tags for crossings and traffic lights; for intersections, instead, special queries in Overpass Turbo were needed. The requests for these tags give as an output an xml file containing geographic points, more precisely the latitude and longitude of the points which are crossings, traffic lights and intersections. By parsing these xml files in a Java software, only the latitude and longitudes are extracted which later on are used in constructing the Google Street View Image link, a link which provides the images needed for the crowdsourcing (images focusing on the three points of interest).

In the meantime I was also focusing on the accessibility questions. By analyzing and reviewing specialized literature, I tried to determine the most important problems a wheelchair user can encounter by going on a street. Even though the list is long, I focused only on aspects related to zebras and sidewalks which can be determined by analyzing the images:

- High kerbs
- Position and nature of dropped kerbs
- Pavements (Cobbles, Gratings and drains, Potholes, etc.)
- Temporary obstacles

As it is described in Chapter 7, there are several features which can be added to the application. If the adoption of the platform reaches a level where accessibility issues are reported with high frequency, then all these can lead to a big help for wheelchair users (and not only) and hopefully in the near future to accessible cities.

Chapter 9

Future Work

In this chapter I will be suggesting future aspects which can expand my part of the thesis – work which can be added to complete it - and to the application in general - by focusing more on the accessibility part, I will try to show how the application can be customized in order to satisfy a wider number of users.

9.1 Thesis Future Contributions

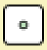
In this section I am presenting several improvements which can be added to the thesis in order to reach a higher level of completeness:

- Expand work to the entire region of Como

As stated in Chapter 5, even though at the beginning the entire region of Como city was considered, due to a high number of images, work has been limited to a smaller region. Considering the entire region as in Figure 5.1 means getting to know accessibility problems on a wider area and thus, more users helped. On the other hand, a drawback of this point would be that more users are needed to answer the accessibility questions and a longer time is required to collect the feedbacks.

❖ Include more OSM tags

For the time being the application has limited itself to only three OSM tags (crossings, traffic signals and intersections) but the list can increase. Table 9.1 shows the possible street level tags which can be included[2]:

Key	Value	Element	Comment	Photo
barrier	block		A large, solid, immobile block that can be moved only with heavy machinery or great effort. Typically big solid things made of concrete for stopping larger vehicles. Sometimes natural boulders are used for the same purpose.	
barrier	bollard	 	solid (usually concrete or metal) pillar or pillars in the middle of the road to prevent passage by some traffic.	
barrier	bus_trap		A bus trap is a metal grate placed over a ditch or depression in the road with tines spaced far enough apart that small-diameter-wheeled vehicles fall in between the tines but close enough that larger-diameter-wheeled vehicles, such as buses, may pass.	
barrier	cattle_grid		Bars in the road surface that allow wheeled vehicles but not animals to cross. Sometimes known as a Texas Gate, even outside of Texas	

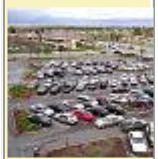
barrier	**chain**		**A chain used to prevent motorised vehicles.**	
barrier	**cycle_barrier**		**Barriers to bicycle traffic, most typically a pair of staggered steel bars perpendicular to the way itself whose gaps allow pedestrians to pass.**	
barrier	**debris**		**A road is blocked by debris with or without ground. This might be for short or long time. Often used as first step in blocking an abandoned road. The photo does not display the road after the debris because it was a slope road and the photo was taken on the top.**	
emergency	**fire_hydrant**		**A fire hydrant is an active fire protection measure, and a source of water provided in most urban, suburban and rural areas with municipal water service or other water source to enable firefighters to tap into the municipal water supply to assist in extinguishing a fire.**	
highway	**steps**		**For flights of steps (stairs) on footways. Use with step_count=* to indicate the number of steps**	
tactile_paving	**yes / no**		**A paving in the ground to be followed with a blindman's stick.**	

tracktype	grade1/ grade2/ grade3/ grade4/ grade5		To describe the quality of the surface.	
traffic_calming	yes/ bump/ hump/ cushion/ table.		Traffic calming consists of engineering and other measures put in place on roads for slowing down or reducing motor-vehicle traffic as well as to improve safety for pedestrians and cyclists.	
barrier	kerb		A (for example footway) kerb is a barrier for vehicles and wheelchair drivers. The height of the kerb is important and with this information, the usage by different groups can be determined. The height of the kerb is tagged additionally as height=*, if available. Right side is bottom, left side is top.	
barrier	wall		a freestanding solid structure designed to restrict or prevent movement across a boundary. Usually made from solid brick, concrete or stone and almost always built so that it is opaque to vision.	
bridge	yes		If the railway goes over a street, waterway or other railway.	

railway	tram		One or two carriage rail vehicles, usually sharing motor road.	

Table 9.1: Future OSM Tags

Additionaly, Table 9.2 suggests also other tags which can be taken into consideration as they represent key points in the daily destinations of a wheelchair user (more detailed into MEP Project Future Contributions section). Accessibility should also be evaluated for the following features:

Key	Value	Element	Comment	Photo
amenity	parking		Car park. Nodes and areas (without access tag) will get a parking symbol. Areas will be coloured. Streets on car parking are often tagged highway=service and service=parking_aisle.	
amenity	toilets		Public toilets (might require a fee)	
railway	funicular		Cable driven inclined railways. In many cases they serve touristic interest, giving easy access to spectacular mountain views.	
shop	supermarket		Supermarket	

amenity	**hospital**		**Often used in conjunction with emergency=* to note whether or not the hospital has emergency facilities**	
highway	**elevator**		**Elevator**	
public_transport	**stop_position**		**The position on the street or rails where a bus, tram or train stops.**	
public_transport	**platform**		**The place where passengers are waiting for the transportation vehicle.**	

Table 9.2: Additional OSM Tags

- Google Street View Image Link Improvement

As explained in Chapter 5 and 7, if an image falls down into one of the categories „No" or „There are ways to be improved" in Step A, then a new image needs to be generated; this can also be done automatically by means of Java software.

For the „There are ways to be improved" category, the Google Street View Image link can be personalized according to the feedback received. Therefore, a zoom in/out means modifying the *fov* value, higher/lower pitch means modifying the *pitch* while rotation means increasing/decreasing the value of the *heading* with 90 degrees. Further research is required in order to determine standard values for decreasing and increasing the values of *fov* and *pitch*.

Instead, if an image is marked as „No", then a new one needs to be generated from the same location but with a different heading.

The new images will also be subject to questioning, ending up in a loop until they get to be marked as „Yes” – they offer a good visibility over the points of interest.

- Profiling the users evaluating the images

For the time being, the application focuses on wheelchair users and therefore, they represent the best category of users to evaluate the images. In addition, also families and specialized volunteers suit best as they have direct contact with the problems a wheelchair user might encounter.

9.2 MEP Project Future Contributions

In addition to all features described in Chapter 4, the following are suggested:

- Application customization based on how severe the disability is:

According to [14], wheelchair users can be divided into three sub groups:

- **Active** - Are very active and athletic wheelchair users that are for example able to do certain sports, are very independent, are able to travel long distances on their own and are able to overcome many obstacles and barriers that wheelchair users from the following two groups can't. All of the active wheelchair users use manual wheelchairs.

- **Partly Help Dependent** - Are still active but not athletic and their disability does not allow them to do any sports or similar. Traveling through the city without any help is very exhausting for them, so they need help to complete certain daily tasks, to overcome obstacles and barriers and to travel longer distances. This group uses manual or electric wheelchairs.

- **Help Dependent** - Their disability does not allow them to be active or athletic and even short distances are very exhausting for them. They use electric wheelchairs which makes it very difficult to overcome any barriers or obstacles, so they are restricted most when traveling through the city. In general, even for small daily tasks like shopping they depend on help 24/7.

The group of helpers mentioned above can be divided into two sub groups:

- **Family, Voluntary Helpers, Friends** - This group has an intrinsic motivation to help their friends or family members in wheelchairs. They are looking for ways to contribute to ease the wheelchair users burden and to help them to get up to date information about barriers and obstacles so they can avoid them.

- **Organizations, Associations, Social Workers** – Professional organizations to support disabled people as well as facilities like assisted living homes or retirement homes are constantly looking for ways to support their disabled customers as well as their own employees better at regular tasks like for example organized guided wheelchair excursions through the city. These organizations need up to date data about obstacles and barriers to put more pressure on city planners. Only so, they can motivate them to renovate parts of the city, to remove barriers and to include these parameters and needs into future city plans.

The street navigation and even the design of the mobile application can be customized in order to serve the three categories presented above. In addition to this, additional applications can be created for the group of helpers; they might contain information on how to help the user in special cases, how to deal with accidents, reminders and to-do lists.

- Sentiment Analysis

This option can show how happy users are with their experience on going on the street; if the analysis can be done on specific streets/ access points in the city, then even the accessible path can be generated according to user's sentiments.

As suggested in [15], Sentiment Analysis, which aims in identifying the subjective state of human beings, such as emotions, through language processing analysis, has the benefit that more information about the state of the users can be added in an automatic way, improving the estimation of the crucial problems to be solved in the city.

Prioritization is another aspect which can be taken into consideration; based on the number of user reports addressing the same accessibility issue in the city, one can have a first evaluation of how many people are being affected by it. Nevertheless, different issues affects people in different ways. Some issues may be a simple inconvenient, while others may hinder people from reaching their destinations. Different techniques, such as Sentiment Analysis, help to give relevant insights about how severe an issue is, and what are its direct and indirect effects in people's life.

In order to assign a priority level to an urban event, all this evaluations must be aggregated to determine how negative the effect of an event is over the population. Events that are preponderantly negative must be resolved more urgently than neutral ones, thus receiving a higher priority. An Analytic Hierarchy Process may be used in order to assign weights to the criteria used to define priority levels.

- Frequency of Destinations Analysis

Based on the interviews conducted in [16], the most commonly daily destinations by 20 (80%) or more of the 25 respondents, were food stores, restaurants and bars, drug stores and other kinds of stores and shops. Destinations reported with moderate frequency (>10–19 respondents, or 40–76% of the sample) included ATMs, friends' or relatives' homes, other places for recreation or leisure, work places, doctors' offices, churches, synagogues or other religious buildings and civic buildings. Less frequently reported destinations (11 respondents, 40% of the sample) included school, movies, dentists' or other health professionals' offices, libraries, sporting events and parks.

Taking into consideration these aspects, the application can be customized in such a way to provide further assistance for the most important points (e.g., remote communication); also these data can be communicated to municipalities in order to help building more accessible cities.

- Comfort

Comfort deals with the possibility of undertaking any intended activity without more effort than the daily practice requires. It considers in this way the characteristics present in the space that may cause some discomfort. It also may expose one to outdoor urban conditions like noise and air pollution and climate protection. (Cardoso,2012; Keppe Jr., 2008; Stradling, 2007). Aspects such as air pollution, exposure to noise, degree of accessibility to route, rest areas, shade and protection against sun and rain, time length to reach a destination, effort and other external factors which can cause stress can be taken into consideration when building the accessible navigation.

- Keep the user engaged

The application should provide feedbacks to users whenever reported issues were addressed in order to keep them engaged. The concept of crowdsourcing for mapping of issues in a city stimulates citizen's engagement and in the same time helps improving the application. New ideas, an increased number of feedbacks and other daily activities can be rewarded; the only aspect that needs to be considered is the validity of the feedbacks.

Chapter 10

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Appendix A

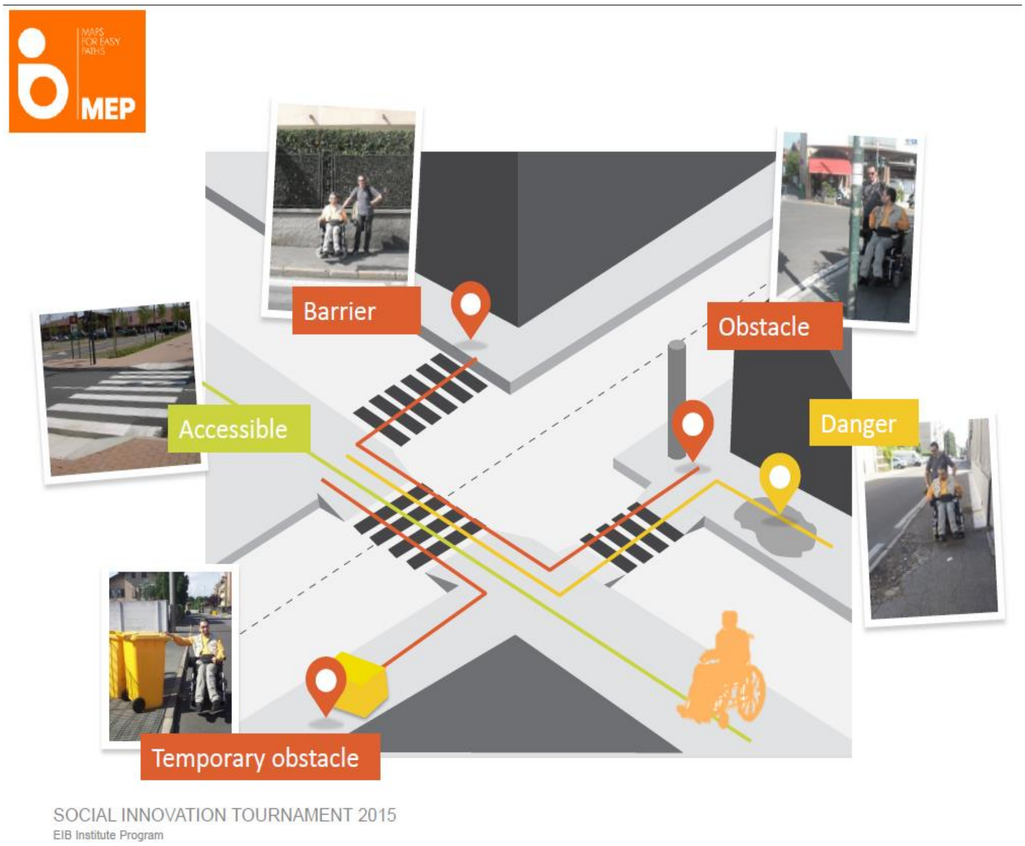

Figure A.1: Accessible Path

Image A.1: Zebra + Sidewalk without Dropped Kerb

Image A.2: Street without sidewalk

Appendix B

```
/*
 * Step 1: save all tags from OSM into xml
 *
 * Step 2: parse the xml -> retrieve id of tag, latitude and longitude
 *
 * Step 3: determine the angle of the street
 *
 * Step 4: download the images: construct the Google Static Images URL with the lat and long from step 2 and angle from step 3
 */

public class DownloadImagesForCrowdSourcing {

	public static void main(String argv[]) throws IOException,
			ParserConfigurationException, SAXException {

/******************* STEP 1 ************************/

// download nodes for crossings
String url_crossing = "http://open.mapquestapi.com/xapi/api/0.6/node%5Bhighway=crossing%5D%5Bbbox=9.06042014170467,45.79212088500324,9.129084692483179,45.81904535824169%5D";
String destination_crossing = "/Users/Salai/workspaceEclipse/DownloadImagesForCrowdSourcing/crossings/crossings.xml";

// download nodes for traffic lights
```

```
String url_traffic_lights = "
http://open.mapquestapi.com/xapi/api/0.6/node%5Bhighway=traffic_signals%5D%5Bbbox=9.06042014170467,45.79212088500324,9.129084692483179,45.81904535824169%5D ";

String destination_traffic_lights =
"/Users/Salai/workspaceEclipse/DownloadImagesForCrowdSourcing/traffic_lights/traffic_signals.xml";


// download nodes for intersections

String url_intersections = "http://overpass-api.de/api/interpreter?data=%0A%5Bout%3Axml%5D%5Btimeout%3A3600%5D%3B%0A%2F%2F%20filter%20ways%0Away%5Bhighway%5D%5Bhighway%21~%22footway%7Ccycleway%7Cpath%7Cservice%7Ctrack%22%5D%2845.79212088500324%2C9.06042014170467%2C45.81904535824169%2C9.129084692483179%29-%3E.hw%3B%0A%0A%2F%2F%20foreach%20way%0Aforeach.hw-%3E.eachw%28%0A%20%20%2F%2F%20get%20ways%2C%20which%20shares%20same%20nodes%20minus%20current%20way%0A%20%20%2F%2F%20into%20.otherws%0A%20%20node%28w.eachw%29-%3E.ns%3B%0A%20%20way%28bn.ns%29%5Bhighway%5D%5Bhighway%21~%22footway%7Ccycleway%7Cpath%7Cservice%7Ctrack%22%5D-%3E.w2%3B%0A%20%20%28way.w2%3B%20-%20way.eachw%3B%29-%3E.otherws%3B%0A%0A%20%20%2F%2F%20get%20shared%20nodes%0A%20%20node%28w.otherws%29-%3E.n2%3B%0A%20%20node%28w.eachw%29-%3E.n3%3B%0A%0A%20%28%28%28node.n2%3B%20node.n3%3B%29%20-%28node.n2%3B%20-%20node.n3%3B%29%3B%29%20-%28node.n3%3B%20-%20node.n2%3B%29%3B%29-%3E.shrdnodes%3B%0A%0A%20%20%2F%2F%20ways%20which%20are%20in%20junction%0A%20%20way%28bn.shrdnodes%29-%3E.outways%3B%0A%0A%20%20%2F%2F%20union%20ways%20and%20nodes%0A%20%20%28way.outways%3B%20node.n2.n3%29%3B%20out%20geom%3B%20%0A%29%3B%0A%20%20%0A%20%20%0A%20%20%0A";

String destination_intersections =

"/Users/Salai/workspaceEclipse/DownloadImagesForCrowdSourcing/intersections/intersections.xml";


//call method to download nodes

save_Image_Tags(url_crossing, destination_crossing);

save_Image_Tags(url_traffic_lights, destination_traffic_lights);

saveImage(url_intersections, destination_intersections);
```

```
/******************** STEP 2.1 Crossings *********************/

try {

File fXmlFile = new File(
"/Users/Salai/workspaceEclipse/DownloadImagesForCrowdSourcing/crossings/crossings.xml");
DocumentBuilderFactory dbFactory =
DocumentBuilderFactory.newInstance();
DocumentBuilder dBuilder = dbFactory.newDocumentBuilder();
Document doc = dBuilder.parse(fXmlFile);

PrintWriter writer = new PrintWriter(
"/Users/Salai/workspaceEclipse/DownloadImagesForCrowdSourcing/crossings/crossings_parsed.txt","UTF-8");

doc.getDocumentElement().normalize();

NodeList nList = doc.getElementsByTagName("node");
NodeList nList2 = doc.getElementsByTagName("tag");

for (int temp = 0; temp < nList.getLength(); temp++) {

      Node nNode = nList.item(temp);
      Node nNode2 = nList2.item(temp);

      Element eElement = (Element) nNode;
      Element eElement2 = (Element) nNode2;
      if (nNode.getNodeType() == Node.ELEMENT_NODE) {
            writer.println("Image: image" + temp + ".png");
            writer.println("ID: " + eElement.getAttribute("id"));
```

```
                writer.println("Longitude: " +
eElement.getAttribute("lon"));
                writer.println("Latitude: " +
eElement.getAttribute("lat"));
                                }

                if (nNode2.getNodeType() == Node.ELEMENT_NODE) {
                        writer.println("Tag: " +
                        eElement2.getAttribute("k") + ";" +
                        eElement2.getAttribute("v"));
                        writer.println("\n");
                                }

String imageUrl =
"https://maps.googleapis.com/maps/api/streetview?size=600x600&locat
ion=" + eElement.getAttribute("lat") + "," +
eElement.getAttribute("lon")
+ "&fov=90&heading=0&pitch=10";
String destinationFile =
"/Users/Salai/workspaceEclipse/DownloadImagesForCrowdSourcing/cross
ings/image" + temp + ".png";

save_Image_Tags(imageUrl, destinationFile);
                        }
        writer.close();
                } catch (Exception e) {
                        e.printStackTrace();
                }

/****************** STEP 2.2 Traffic Lights ***************/

try {
```

```
File fXmlFile = new File(
"/Users/Salai/workspaceEclipse/DownloadImagesForCrowdSourcing/traff
ic_lights/traffic_signals.xml");
DocumentBuilderFactory dbFactory =
DocumentBuilderFactory.newInstance();
DocumentBuilder dBuilder = dbFactory.newDocumentBuilder();
Document doc = dBuilder.parse(fXmlFile);

PrintWriter writer = new PrintWriter(
"/Users/Salai/workspaceEclipse/DownloadImagesForCrowdSourcing/traff
ic_lights/traffic_signals_parsed.txt","UTF-8");

doc.getDocumentElement().normalize();

NodeList nList = doc.getElementsByTagName("node");
NodeList nList2 = doc.getElementsByTagName("tag");

System.out.println("----------------------------");

for (int temp = 0; temp < nList.getLength(); temp++) {

       Node nNode = nList.item(temp);
       Node nNode2 = nList2.item(temp);

       Element eElement = (Element) nNode;
       Element eElement2 = (Element) nNode2;

       if (nNode.getNodeType() == Node.ELEMENT_NODE) {
              writer.println("Image: image" + temp + ".png");
              writer.println("ID: " + eElement.getAttribute("id"));
```

```
            writer.println("Longitude: " +
eElement.getAttribute("lon"));
            writer.println("Latitude: " +
eElement.getAttribute("lat"));
                    }

            if (nNode2.getNodeType() == Node.ELEMENT_NODE) {
                writer.println("Tag: " +
eElement2.getAttribute("k") + ";"
                + eElement2.getAttribute("v"));
                writer.println("\n");
                    }

String imageUrl =
"https://maps.googleapis.com/maps/api/streetview?size=600x600&locat
ion=" + eElement.getAttribute("lat") + "," +
eElement.getAttribute("lon") + "&fov=90&heading=0&pitch=10";
String destinationFile =
"/Users/Salai/workspaceEclipse/DownloadImagesForCrowdSourcing/traff
ic_lights/image" + temp + ".png";

save_Image_Tags(imageUrl, destinationFile);
                }
            writer.close();
            } catch (Exception e) {
                e.printStackTrace();
            }

/****************** STEP 2.3 Intersections ***************/

try {

File fXmlFile = new File(
```

```
"/Users/Salai/workspaceEclipse/DownloadImagesForCrowdSourcing/intersections/intersections.xml";

DocumentBuilderFactory dbFactory =
DocumentBuilderFactory.newInstance();

DocumentBuilder dBuilder = dbFactory.newDocumentBuilder();

Document doc = dBuilder.parse(fXmlFile);


PrintWriter writer = new PrintWriter(

"/Users/Salai/workspaceEclipse/DownloadImagesForCrowdSourcing/intersections/intersection_parsed.txt", "UTF-8");


doc.getDocumentElement().normalize();


NodeList nList = doc.getElementsByTagName("node");

NodeList nList2 = doc.getElementsByTagName("way");


System.out.println("----------------------------");


// determine all nodes


for (int temp = 0; temp < nList.getLength(); temp++) {


Node nNode = nList.item(temp);

Element eElement = (Element) nNode;


Element childElementFirst = null;


if (nNode.getNodeType() == Node.ELEMENT_NODE) {

        writer.println("Image: image" + temp + ".png");

        writer.println("ID: " + eElement.getAttribute("id"));

        writer.println("Latitude: " + eElement.getAttribute("lat"));
```

```
        writer.println("Longitude: " +
eElement.getAttribute("lon"));

        // determine all ways and their nds
        for (int i = 0; i < nList2.getLength(); i++) {

                Node nNode2 = nList2.item(i);
                Element eElement2 = (Element) nNode2;

                Node childNode = eElement2.getFirstChild();

                if (nNode2.getNodeType() == Node.ELEMENT_NODE) {
                        int count = 0;
                        ArrayList<String[]> reflist =
mychild_refs(childNode);
                        while (childNode.getNextSibling() != null) {
                                count++;
                                childNode = childNode.getNextSibling();

                                if ((childNode.getNodeType() ==
Node.ELEMENT_NODE)) {
                                Element childElement = (Element)
childNode;


                                if (count <= 3) {
                                childElementFirst = (Element) childNode;}


                                if
(eElement.getAttribute("id").equals(childElement.getAttribute("ref"
)) &&
(!(eElement.getAttribute("id").equals(childElementFirst.getAttribut
e("ref"))))) {
```

```
                            writer.println("WAY ID: 
"+eElement2.getAttribute("id"));
                            writer.println("first position: ID: "+ 
childElementFirst
                            .getAttribute("ref") + ";Lat: " + 
childElementFirst
                            .getAttribute("lat") + ";Lon:" + 
childElementFirst
                            .getAttribute("lon"));

                            String imageUrl = 
"https://maps.googleapis.com/maps/api/streetview?size=600x600&locat
ion=" + eElement.getAttribute("lat") + "," + 
eElement.getAttribute("lon") + "&fov=90&heading=" + 
angleFromCoordinate(
Double.parseDouble(eElement.getAttribute("lat")),Double.parseDouble
(eElement.getAttribute("lon")),Double.parseDouble(childElementFirst
.getAttribute("lat")),Double.parseDouble(childElementFirst.getAttri
bute("lon")))+ "&pitch=10";
       String destinationFile = 
"/Users/Salai/workspaceEclipse/SaveImageFromURL/int/image" + temp + 
".png ";

                            saveImage(imageUrl, destinationFile);

                            } else if 
(eElement.getAttribute("id").equals(childElement.getAttribute("ref"
)) && 
(eElement.getAttribute("id").equals(childElementFirst.getAttribute(
"ref")))){
                            writer.println("WAY ID: 
                     "+eElement2.getAttribute("id"));

                            String[] rnd_pos = 
arr_get_one(reflist,childElementFirst
                            .getAttribute("ref"));
```

```
                        writer.println("next position: ID: " +
                   rnd_pos[0] + ";Lat:" + rnd_pos[1] + ";Lon:" +
                   rnd_pos[2]);



                        String imageUrl =
"https://maps.googleapis.com/maps/api/streetview?size=600x600&locat
ion="+ eElement.getAttribute("lat") + ","+
eElement.getAttribute("lon") + "&fov=90&heading=" +
angleFromCoordinate(Double.parseDouble(eElement.getAttribute("lat")
),Double.parseDouble(eElement.getAttribute("lon")),Double.parseDoub
le(rnd_pos[1]), Double.parseDouble(rnd_pos[2])) + "&pitch=10";


                        String destinationFile =
"/Users/Salai/workspaceEclipse/SaveImageFromURL/int/image"+ temp +
".png ";


                        saveImage(imageUrl, destinationFile);
                        }}}}}
                   }
                    writer.println("\n");
                   }
                   writer.close();
            } catch (Exception e) {
                   e.printStackTrace();
            }
      }


public static String[] arr_get_one(ArrayList<String[]> str_array,
String str_remove) {
String[] tmp_array;


for (int i = 1; i < str_array.size(); i++) {
      tmp_array = str_array.get(i);
```

```
        if (tmp_array[0] != str_remove) {
                return tmp_array;
                        }
                }

        return null;
        }



public static ArrayList<String[]> mychild_refs(Node childs) {
ArrayList<String[]> my_array = new ArrayList<String[]>();
while (childs.getNextSibling() != null) {
        if ((childs.getNodeType() == Node.ELEMENT_NODE)) {
                Element childElement = (Element) childs;
                String[] str_myrefs = {
childElement.getAttribute("ref"),

        childElement.getAttribute("lat"),

        childElement.getAttribute("lon") };
                my_array.add(str_myrefs);
                        }
        childs = childs.getNextSibling();
                }
my_array.removeAll(Collections.singleton(null));
return my_array;
        }

public static void save_Image_Tags(String imageUrl, String
destinationFile) throws IOException {
URL url = new URL(imageUrl);
InputStream is = url.openStream();
```

```
OutputStream os = new FileOutputStream(destinationFile);

byte[] b = new byte[2048];
int length;
while ((length = is.read(b)) != -1) {
       os.write(b, 0, length);
              }
is.close();
os.close();
System.out.println("end");
       }

static double angleFromCoordinate(double lat1, double long1, double
lat2, double long2) {

double dLon = (long2 - long1);

double y = Math.sin(dLon) * Math.cos(lat2);
double x = Math.cos(lat1) * Math.sin(lat2) - Math.sin(lat1)
                          * Math.cos(lat2) * Math.cos(dLon);

double brng = Math.atan2(y, x);

brng = Math.toDegrees(brng);
brng = (brng + 360) % 360;
brng = 360 - brng;

return brng;

       }
}
```