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Participatory Sensing and Crowdsourcing in Urban Environment

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Abstract

Participatory Sensing and Crowdsourcing in Urban Environment

by Catia Prandi

With an increasing number of people who live in cities, urban mobility becomes one of the most important research fields in the so-called smart city environments. Urban mobility can be defined as the ability of people to move around the city, living and interacting with the space. This ability can be strongly affected by those architectural obstacles that represent a physical impediment to the exercise of citizenship for people with special needs, as people with disabilities and elderly people. Another barrier, that prevent and discourage some citizens in moving independently in the urban space, is represented by the lack of information about the urban environment and its accessibility. For these reasons, urban accessibility represents a primary factor to keep into account for social inclusion and for the effective exercise of citizenship.

In this thesis, we researched how to use crowdsourcing and participative sensing to effectively and efficiently collect data about aPOIs (accessible Point Of Interests) with the aim of obtaining an updated, trusted and completed accessible map of the urban environment. The data gathered in such a way, was integrated with data retrieved from external open dataset and used in computing personalized accessible urban paths. In order to deeply investigate the issues related to this research, we designed and prototyped mPASS, a context-aware and location-based accessible way-finding system.

The main research questions addressed in this thesis are: (i) Can the crowd be put to good use (via crowdsourcing and participatory sensing) to increment the density of data?; (ii) Can the user's profile be exploited in adapting and transcoding relevant information (smart data) and in providing accessible maps, interfaces and services?; (iii) Can the user's credibility and the aPOI trustworthiness be assessed on the basis of heterogeneous data sources?; (iv) Can gamification and gameplay strategies be leveraged in engaging and motivating users in collecting and validating data, by resorting to extrinsic and intrinsic motivation?.

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Chapter 1

Introduction

Many significant research issues in Computer Science come from the arising services offered and supported by Smart Cities. A Smart City is "a city well performing in a forward-looking way in six characteristics, built on the 'smart' combination of endowments and activities of self-decisive, independent and aware citizens" (Giffinger et al., 2007). A Smart City is characterized through six dimensions: Smart Enomomy, Smart People, Smart Governance, Smart environment, Smart Mobility, and Smart Living (Madakam and Ramaswamy, 2014).

With an increasing number of people living in cities, urban mobility became one of the most important research fields in the so-called Smart City environments. In this context, smart mobility is defined by four factors which reflect the most important aspects about urban mobility: (i) local accessibility; (ii) (inter)national accessibility; (iii) availability of ICT-infrastructure; and (iv) sustainable, innovative and safe transport systems (Giffinger et al., 2007). From these definitions it is clear that smart mobility, and in particular urban accessibility, is a very important element that needs to be tackled in order to improve the quality of life in cities. This is especially relevant for people with disabilities and special needs, who frequently face barriers while moving in the urban environment.

In these Smart contexts, new paradigms have been recently studied and deployed in order to design and develop participative and opportunistic Smart

City applications and services. A significant strategy is to support citizen participation by allowing them to collect data which contribute to the enhancement of their environment (Zheng et al., 2014b). Citizens are suitable to collect a large amount of data with different goals, means and types via crowdsourcing and crowdsensing (Schuurman et al., 2012; Mitton et al., 2012).

Crowdsourcing, as a voluntary activity to collect huge amount of data, has been well investigate in different Smart City contexts. Some examples are related to: mapping information about free parking spots (Chen, Santos-Neto, and Ripeanu, 2012); improving urban traffic management (Artikis et al., 2014); gathering ideas for smart apps (Mechant et al., 2011); managing queries about the status of city infrastructure and utilities (Benouaret, Valliyur-Ramalingam, and Charoy, 2013); improving safety of specific areas (Bhana, Flowerday, and Satt, 2013).

With crowdsensing, users can contribute in collecting data as gathered from sensors embedded in the users' own devices. Crowdsensing has been exploited in different projects, some examples are: to estimate the real-time bus arrivals (Zimmerman et al., 2011); to provide traffic and navigation updated information (*Waze* 2015); to create urban noise maps (Rana et al., 2015; D'Hondt and Stevens, 2011; Zheng et al., 2014a).

Citizens can gather data also by sensing, using mobile which include not only computing and communication capabilities but also a range of sensing capabilities, such as provided by the microphone, camera, GPS, and accelerometer, among other sensors (Ganti, Ye, and Lei, 2011; Roitman et al., 2012; Mostashari et al., 2011). Community sensing orchestrates the computing, communication, and sensing capabilities of a population of mobile phones, enabling large-scale sensing purely through software running on the existing distributed hardware. A community sensing application could either be participatory, involving explicit user action, e.g., taking photographs (Benouaret, Valliyur-Ramalingam, and Charoy, 2013), or opportunistic, operating without any user involvement, e.g., detecting (Stevens and D'Hondt, 2010).

In the last years many attempts have been done to use current technologies with the aim of offering appropriate information services to citizens, involving people in collecting data about the city via crowdsourcing or crowdsensing. Despite that, different services are still far from having a significant impact on people life, due to the difficulties in collecting enough information (in terms of quantity and quality) to provide effective facilities. This is really true in offering services related to the urban environment (Song and Sun, 2010; Venanzi, Rogers, and Jennings, 2013).

The integration of data provided by crowdsourcing, crowdsensing (and, when possible, external Open Data and/or public datasets) is proposed as a solution to augment the density (i.e. limit the sparsity) of data. This approach introduces some more issues. First, the huge amount of data makes difficult to understand which data effectively have sense for user and how to visualize and to interact with them in a useful way. Second, data collected from different sources (i.e. crowdsensing, crowdsourcing, external sources) are heterogeneous from many points of view and, in particular, in terms of trustworthiness (Dai et al., 2008).

To conduct the research in the above mentioned context, we worked to a specific case study, a Smart City crowdsourcing and crowdsensing application devoted to enhance accessible smart mobility in urban environments. Urban spaces and specifically the pedestrian environments are frequently inadequate to the needs of citizens, in particular for elderly people and people with disabilities, due the presences of urban accessibility barriers (Babinard et al., 2012; Mojtahedi et al., 2008). It is important to notice that the demand of specific pedestrian paths is not necessarily limited to those citizens. Actually, the group of people who can benefit from such information is widely larger that this: from pram users to elderly people, there is a large group of citizens who can take advantage of detailed information on pathways, ramps, street lights and crossing facilities. For instance, by using this information it is possible to compute a safe pedestrian path for kids coming back from school or to avoid unsafe and unlighted areas during the night. As authors of (Quercia, Schifanella, and Aiello, 2014; Rosner et al., 2015) recently teach us, citizens are not only interested in the fastest path to reach their destination, but the more appropriate one, on the basis of the users interests, needs, preferences or mood, challenging the concept of Smart Mobility in urban environment.

1.1 Problem statement

Urban accessibility is a primary factor for social inclusion and for the effective exercise of citizenship. A lack of information about the urban environment, in fact, may seriously affect disadvantaged sectors of our society (for example, people with disabilities and elderly people), but it also worsens the quality of life of those whose daily activities are made more complex in the presence of urban barriers, like children and pregnant women, for instance. The urban built environment still represents one of the most actual examples of how people with impairments and elderly people can be disabled by barriers. Some relevant works related to this issue are: (Babinard et al., 2012; Mojtahedi et al., 2008; Taylor and Józefowicz, 2012; Deichmann, Architect, and Nyvig, 2009; Church and Marston, 2003; Walker et al., 2002a).

Moreover, the lack of information about the urban environment and its accessibility represents itself a barrier to users with disabilities who are discouraged from venturing outside known territories.

According to the World Report on disability (Organization et al., 2011) more than the 15% of the world's population is estimated to live with some form of disability. Moreover, the number of people with disabilities or reduced mobility is growing, due to ageing of populations. Improvement in urban accessibility can also benefit people who are not disabled but are "mobility impaired" by environmental barriers, which are common in the urban scenario (Carvalho, Heitor, and Cabrita Reis, 2012). For instance healthy elderly people, children, pregnant women or people with temporary health conditions. A UK based survey (Walker et al., 2002b) reported that 8% of adults recorded having difficulties moving outdoors and carrying out normal day-to-day activities.

Unfortunately, the availability of information about urban accessibility and security is very limited if compared with other location-based and ubiquitous data and a multiple-source gathering seems to be the only effective mean to collect an adequate set of information (Biancalana et al., 2013).

Different systems have been designed and developed so as to provide appropriate maps and navigations services to users with special needs and preferences but they are still not effective because they are not able to reach the critical mass needed to provide effectively services.

1.2 Research hypothesis and research issues

This thesis in the result of the investigation of some research issues related to crowdsouce and crowdsense data employed in improving urban accessibility maps and accessible personalized paths. More precisely, our overall research hypothesis states that:

H1. Given a community who is highly impacted by credibility/availability of urban accessibility information and who by nature has a sporadic mass, we can rely on crowdsourcing/sensing techniques to provide them with the needed services.

In validating our hypothesis, we went through four research questions.

R1. Density of data. Can the crowd be put to good use (via crowdsourcing and participatory sensing) to increment the density of data?

R2. User profiling and contents adaptation. Can the user's profile be exploited in adapting and transcoding relevant information (smart data) and in providing accessible maps, interfaces and services?

R3. Data trustworthiness. Can the user's credibility and the aPOI trustworthiness be assessed on the basis of heterogeneous data sources?

R4. Crowd engagement. Can gamification and gameplay strategies be leveraged in engaging and motivating users in collecting and validating data, by resorting to extrinsic and intrinsic motivation?

1.2.1 R1. Density of data

In order to offer an effectively service, information about urban accessibility (in general, about pedestrian facilities) should be dense enough:

(i) to effectively decide about a path. In fact, the presence of an undetected barrier could seriously affect the effectiveness of the service;

(ii) to avoid errors about a specific barrier or facility. If the dataset contains incorrect detected or classified barriers, the user could take wrong decisions in taking decision.

In this above mention context, our first research question was related to the issue to design and model a system that aims to maximize the density of data using different data sources. In particular, we investigated how to filter and mush up data gathered from different source, such as crowsourcing, participative sensing, Open Data, georeferenced social networks, and VGI (Volunteered geographic information) in order to effectively map urban accessibility.

1.2.2 R2. User profiling and contents adaptation

To address the first research questions, we needed to consider and aggregate heterogeneous data retrieved via different data sources. As a consequence, information became too much to actually makes sense and this leads to an increasing demand of smart data: information obtained by large data and extracted by intelligent algorithms to meet people needs. This concept easily matches with well-known accessibility issues, solutions and techniques. For this reason, we exploited smart data as an emerging solution to prevent the large amount of data from becoming a new challenge in the e-accessibility field.

In this context, our research was devoted to apply smart data to improve e-accessibility in a mobile crowdsourcing and sensing application designed to support users with disability in avoiding urban accessibility barriers. Moreover, together with smart data, also maps and computed paths, needed to be adapted and rendered/transcoded to fit the user needs and preferences, focusing to the interaction with complex information in a mobile context.

1.2.3 R3. Crowd engagement

On the one hand to provide useful services we needs to collect a sufficiently dense, detailed and trustworthy amount of data. On the other hand, the community interested in obtaining accessible paths is not big enough to reach the critical mass of information needed by a system in order to provide effective services.

To overcome this problem, we investigated gamification and gameplay strategies in designing mobile applications targeting young adults walkers. In particular, we exploited intrinsic motivation and extrinsic motivation with the aim of enlarging the data contributors community and recruiting a sufficiently large group of users to reach critical mass engagement.

1.2.4 R4. Data trustworthiness

Another interesting topic to investigate is related to the trustworthiness of reports gathered from different sources via crowdsensing and crowdsourcing. It is important to design a trustworthiness system with the aim to decrease the number of non-existing facilities detected (false positive) and of undetected barriers (false negative).

The validity of crowdsourcing reports depends on user's credibility and reputation. The validity of external source is often unknown and, in any case variable and defined by a third party. Information obtained by analyzing sensors data suffer from different problems: (i) it has different degree of accuracy (due to the sensor precision); (ii) the noise level is related to the activity performed by the user and the context; (iii) the resulted information depends on the algorithm used.

Furthermore, it is difficult to compare accuracy, validity and credibility levels in computing the trustworthiness value of a single data in the system.

1.3 Thesis Structure

This thesis details the state of the art and original works related to each of the mentioned research questions, investigating in deep our approach. The reminder of this thesis is structured as follows:

Chapter 2 introduces mPASS (mobile Pervasive Accessiibility Sensing System), a system designed to support citizens in mapping urban accessibility via crowdsourcing and participatory sensing. It first describes the data model, the user profile and architecture of mPASS. Finally, it presents, as case study, a multimodal way-finding system obtained from the integration in mPASS of a open dataset related to the public transport in Bologna. This Chapter intends to address the first research question on effectively mapping urban accessibility in a Smart City context.

Chapter 3 details the mechanisms implemented by mPASS to perform adaptation and personalization of the maps, routes and interaction modalities on the basis of the user's profile. We conclude the Chapter describing a case study involving a profile of a wheelchair user. This Chapter wants to answer the second research question about adapting and personalizing accessible maps and interface.

Chapter 4 illustrates how we employed gamification and gaming techniques to involve and motivate urban walkers in mapping urban accessibility via crowdsourcing and crowdsensing. In particular, it details the design process and some interesting field trial results of different game applications exploiting intrinsic and extrinsic motivation. This Chapter is the answer to the research question how engaging and involving communities.

Chapter 5 describes the trustworthiness model implemented to assess the trustworthiness value of the crowdsourced and crowdsensed data. It reports results obtained from a set of multi-agent simulations by exploiting OSM data, with the aim to witness the feasibility of our approach. The aim of this Chapter is to address the research question on assessing users credibility and trustworthiness.

Chapter 6 concludes the thesis by summarizing the obtained results and by outlining future research and research vision.

Chapter 2

Urban accessibility: the case study of mPASS

This Chapter presents mPASS (mobile Pervasive Accessiibility Sensing System), a system designed and developed to provide people with specific needs with personalized geo-referenced information and routing services related to urban accessibility. The system uses data produced automatically by sensors (participatory sensing and crowdsensing) as well as data voluntarily provided via crowdsourcing by users. It combines its own data with the ones available from other sources to maximize density of information and to offer users an effective service. It also permits to organizations responsible of authoritative expert reviews to add information and to fix data gathered by others in order to improve their validity. The set of aPOIs (accessibility Points Of Interest) collected by the system can be used to ask customized routing services or to have a personalized map of main accessibility barriers and facilities in a specific area. Personalization is performed on the basis of a user's profile to better meet his/her preferences and needs.

The remainder of this Chapter is organized as follows. Section 2.1 details the motivations related to the need of using data integration and data fusion techniques to improve the data quality and the data validity. Section 2.2 presents main related works and compares them with the mPASS system. 2.3 presents the Data Model, focusing on outdoor accessibility points of interests, while 2.4

introduces the User Profile. Section 2.5 illustrates the prototype development. Section 2.7 described a case study, resulted from the integration of mPASS with municipal open data related to public transportation to provide multimodal accessible way-finding. Finally, Section 2.8 concludes the Chapter, summarizing the main concepts of the presented approach.

2.1 Background and motivation

As mentioned in Chapter 1, urban spaces and specifically the pedestrian environments are frequently inadequate to the needs of elderly people and people with disabilities. The demand of specific pedestrian paths is not necessarily limited to those citizens. Examples are the requirement of safe pedestrian paths for kids coming back from school or the preference to avoid unsafe areas at night.

While communities are working to improve urban accessibility for all citizens, independently from age and needs, the urban built environment still represents one of the most actual examples of how people with impairments can be disabled by barriers (Hanson, 2004). Moreover, the lack of information about the urban environment and its accessibility represents itself a barrier to users with disabilities who are discouraged from venturing outside known territories.

Many attempts have been done to use current technologies with the aim of offering appropriate information services to users with unconventional needs. A list of the most interesting ones is reported in Section 2.2. To have significant impact on people life, these systems need to collect enough information (in terms of quantity and quality) to provide effective routing/mapping services, and this goal is very difficult to achieve. In order to offer a service with such characteristics, information about urban accessibility (in general, about pedestrian facilities) should be:

- *trustworthy* enough to avoid errors about a specific barrier or facility. If the dataset contains incorrect detected or classified barriers, the user could take wrong decisions in computing routes (and the same would be for routing algorithms computed by the system);

- *dense* enough to effectively decide about a path. The user (and/or the algorithm) should know about all the possible barriers and facilities. In fact, the presence of an undetected barrier could seriously affect the effectiveness of the service.

To obtain such a kind of geo-referenced database, many different sources could be used:

1. *Crowdsensing and participatory sensing*: data produced by users moving in the urban environment. Users equipped with a smartphone are obviously equipped with gyroscope, accelerator and GPS, so they can run an app to sense data about urban accessibility. While data sensed by a single user can be considered not very accurate, multiple sensing of the same barrier or facility makes the data valid.

2. *Crowdsourcing*: data produced by users interested in reviewing urban accessibility can be gathered by using a mobile app. Applications like this one can collect both textual information and multimedia (pictures, video) data. Even in this case, multiple data enforce the validity of gathered information.

3. *Authoritative reviews*: many authorities and organizations (e.g., local administrations, disability right organizations, hotels associations, etc.) do official reviews about indoor and outdoor accessibility. They ask experts to evaluate and to write structured or unstructured reviews of the actual accessibility. Usually these evaluations are too few to be significant in deciding a route, but they are surely valid.

The above mentioned data gathering systems are different in terms of validity and density and none of them seems to be a definitive solution to the problem. Moreover, mash-up should be used as a forth source of information: lots of data about urban accessibility are currently available, but they are dispersed in different systems. In particular, existing systems show one or more of the following lacks: (i) few data; (ii) data referred to specific or small places/territories; (iii) data about a limited set of barriers/facilities; (iv) data about accessibility are provided together with lots of other data, e.g. (*Foursquare* 2015).

For these reasons, we designed mPASS as a system able to provide people with specific needs with personalized geo-referenced information and routing services related to urban environments, integrating data produced by sensors (via crowdsensing) as well as data provided by users (via crowdsourcing) and open data sources.

All these data are exploited so as to provide users with paths and maps which are tailored to their special needs and/or requirements in terms of urban mobility. Examples of users who can benefit from our system are:

- wheelchair users and users with mobility impairments: they would avoid steps and stairs or uneven surfaces on their paths and they would enjoy ramps, curb cuts and similar facilities;
- blind users and users with low vision: they would prefer paths equipped with tactile paving and acoustic cues, avoiding obstacles and unsafe crossings;
- elderly people: generally they would prefer safe and comfortable paths; more specifically, they would choose paths which are personalized according to their actual abilities.

Moreover, mPASS can meet the needs of a wider variety of users, with specific requirements, such as kids coming back from school, women who prefer to avoid unsafe areas at night, people with temporary disabilities, mothers with baby strollers or tourists carrying heavy luggage (Deichmann, Architect, and Nyvig, 2009).

2.2 Related work

In analysing related work we considered four main groups of research and applications: (i) crowdsourcing platforms for urban accessibility; (ii) sensing system to detect accessibility/pedestrian barriers and facilities; (iii) routing system for users with special needs; (iv) integrated systems that include one or more of the above mentioned activities.

In the last few years, several crowdsourcing applications (apps) have been developed that allow citizens to collaborate in improving the quality of life in their urban environment (Zambonelli, 2011; Bicocchi et al., 2013). A part of these apps are devoted to collect data about urban accessibility, on the basis of surveys about indoor and outdoor places. The goal of (*Weel Map* 2015) and (*Weel Mate* 2015) is to review the accessibility of specific type of POIs (Points of Interest) considering the special needs of wheelchair users. In (*Weel Map* 2015) it is possible to review and to find wheelchair accessible toilets and parking spaces while in (*Weel Mate* 2015) users can rate the accessibility of a service (e.g., related to tourism, sport, education, etc.). In (*Weel Mate* 2015) POIs are displayed with icons of different colors (green, yellow and red) based on the accessibility level (accessible, partially accessible and not accessible). Moreover the app shows the particular type of service. In both apps (*Weel Map* 2015; *Weel Mate* 2015) there are no clues about the specific barrier or facility that impacts on the POI accessibility level. The application presented in (*Access Together* 2015) is available both via browser and as mobile app, developed directly inside the Foursquare app (*Foursquare* 2015). It allows users to answer to a long survey with very detailed questions about the accessibility of a POI. On one hand the review asked to users is very accurate. On the other hand it could confuse novice users and it could become boring or difficult to complete. A mobile app that permits to add photos and comments related to barriers and obstacles on sidewalks is presented in (Cardonha et al., 2013a). All the above mentioned systems rate accessibility by means of user's opinions, without involving experts in review process. An example of official reviews (done by professionals) is available in (*ingresso libero* 2015), which reports a collection of reviews related to indoor accessibility of POIs located in Bologna (Italy), done both by users and by accessibility experts working for a disability right organizations. Note that these data are not geo-referenced, not structured and they delivered only via web.

Many sensing apps have been developed to monitor human activities and a part of them could be effectively used to detect accessibility/pedestrian barriers (such as stairs) and facilities (such as zebra crossing). This research presents sensing architectures and algorithms studied to be used in different contexts, so they need to be adapted in order to be exploited in detecting barriers and facilities, see for example (Choi, LeMay, and Youn, 2013; Anjum and Ilyas, 2013; Ronao and Cho, 2014).

In (Bujari, Licar, and Palazzi, 2012a), the authors (by using data obtained by a smartphone accelerometer) aim to recognize the position where a pedestrian stops and crosses a street ruled by a traffic light. Some barriers and facilities could be recognize more easily by using cooperative sensing, working on detecting movement of groups of people (Kjærgaard et al., 2012).

Routing algorithms for people with special needs are based on geo-referenced data about barriers and facilities that are usually collected by crowdsourcing. In (Kurihara, Nonaka, and Yoshikawa, 2004), the authors describe a system that use GIS and GPS to support the creation and the use of network based barrier-free street maps, using specific hardware. RouteCheckr (Völkel and Weber, 2008) is a client/server system for collaborative multimodal annotation of geo-referenced data. It provides personalized routing to mobility impaired pedestrians thought the configuration of a user profile. U-Access (Sobek and Miller, 2006) is a Web-based application developed in the specific context of the University of Utah campus for identifying the shortest accessible route on the basis of three physical ability levels (peripatetic, aided mobility or wheelchair user). This classification requires users to choose one of these three levels, avoiding any further personalization. Finally, some works are devoted to find route for elderly people (Kawamura, Umezu, and Ohsuga, 2008; Umezu, Kawamura, and Ohsuga, 2013). In particular, in (Umezu, Kawamura, and Ohsuga, 2013) the authors present a barrier notification service running on cellular phones equipped with GPS sensor.

Two examples of complex systems, that integrate different data sources and provide multiple geo-referenced services are describe in (Cardonha et al., 2013b) and (Menkens et al., 2011). The authors of (Cardonha et al., 2013b) propose to mix data gathered by sensing with data from crowdsourcing in order to compute accessible routes. In (Menkens et al., 2011), a system called EasyWhell is described. It is mainly devoted to support wheelchair users and it encourages people to write reviews providing reputation and rewards via Facebook.

2.3 Data Model

To defined aPOIs (accessibility Points Of Interest) we have analyzed more than 200 accessibility requirements, divided in two main classes, respectively devoted to indoor (architectural design) and to outdoor (urban design) accessibility (Holmes-Siedle, 1996; Imrie and Hall, 2003; Gray, Gould, and Bickenbach, 2003). In the smart city context, the more relevant requirements are the ones related to urban design. We sub-classified these urban elements in seven categories (as shown in Table 2.1) with the aim of simplifying and clarifying the aPOIs classification to users.

Each requirement corresponds to a type of aPOI that represents the presence (or absence) of an accessibility barrier or facility. A small but significant part of such aPOIs can be detected by sensing with smartphones (which are equipped with accelerometer and gyroscope). Examples are steps and stairs that can be detected by a single walking pedestrian, ramps and curb cuts that can be detected by wheelchair users or traffic lights and zebra crossings that can be detected by groups of users. Other aPOIs cannot be detected by sensing so that

TABLE 2.1: aPOIs categories

Category	**Description**	**Examples**
Gap	Elements that create break in continuity and facility to overcome them	Barriers: gaps, steps, stairs. Facilities: ramps, curb cuts and handrails
Crossing	Facilities related to crossing	Presence or absence of zebra crossing, traffic lights, audible traffic lights
Obstruction	Obstructions and protruding elements that can block or limit the way	Barriers only: traffic signs, trees and garbage bins
Parking	Position and type of parking spaces	Facilities only: slots reserved to people with disabilities
Surface	Descriptions of pathways and ramp surfaces that can represent an accessibility barrier	Barriers: uneven road surface. Facilities: tactile paving
Pathway	Descriptions of all the types of sidewalks	Positive/negative sidewalk characteristics: width
Bus/train stop	Contains all the facilities and barriers that can affect a bus stop	Characteristics of platform, availability of information (large-print, high-contrast, and non-glare informational signs, braille and tactile information, acoustic cues and speakers).

users are needed to identify and to add them to mPASS DB. Each aPOI and its related data can be added to our system by means of one or more reports.

Reports are classified in three different source classes, accordingly to how they are collected. The three source classes have a growing validity:

- **U-report** (report obtained by users). By using the mPASS app, users can add aPOI to the DB system. This can be done in two ways: (i) spontaneously: a user encountering a specific barrier or an accessibility facility can send a report to the mPASS; (ii) on demand: the mPASS app can ask users to improve validity of an existing aPOI (usually an aPOI reported by sensors). Since this, the system will exploit the user report instead of sensor ones and the user gets an award badge on his/her public profile.

- **S-report** (report obtained by sensors). The mPASS app running on Android (http://www.android.com) systems can automatically produce data by sensing. These reports are supposed to have a low validity, since sensors can generate false positives and false negatives.

- **A-report** (report produced by authorities/experts). Authorities are people working for organizations involved in monitoring urban accessibility (such as local administrations and municipalities or disability right organizations). Being professionally able to correctly classify and measure every kind of aPOIs, their reports are considered totally valid. Reports from authorities/expert can be added in two ways: (i) spontaneously: administrators add reports accordingly to their program of activities, sending to the mPASS system reports on barriers or accessibility facilities; (ii) on demand: the mPASS app can ask to authorities to improve validity of an existing aPOI (usually a user-added one). Since this, the system will use the authoritative report instead of user ones.

Hence, mPASS can have more reports of the same aPOI, classified with one or more different source classes. Both the map provided to users and the dataset considered by the routing algorithm are based on the more valid reports available. For example, if an aPOI is added both by sensors and by users, U-reports are used instead of S-reports, since they are considered more valid. Analogously, if an aPOI is added both by users and by authorities, A-reports are used instead of U-reports, because they are considered more valid. To populate the mPASS DB we also added some aPOIs and reports obtained by converting, filtering and mashing up existing data (see the following 2.5).

Figure 2.1 shows the gathering architecture of mPASS. Reports related to aPOIs are collected by Sensors, Users and Authorities. Data gathered by other systems are added by filtering or mashing-up. The thin dashed arrows describe the on demand mechanism set up in order to improve the validity of reports. The final user interacts with the system to obtain personalized data and routing services.

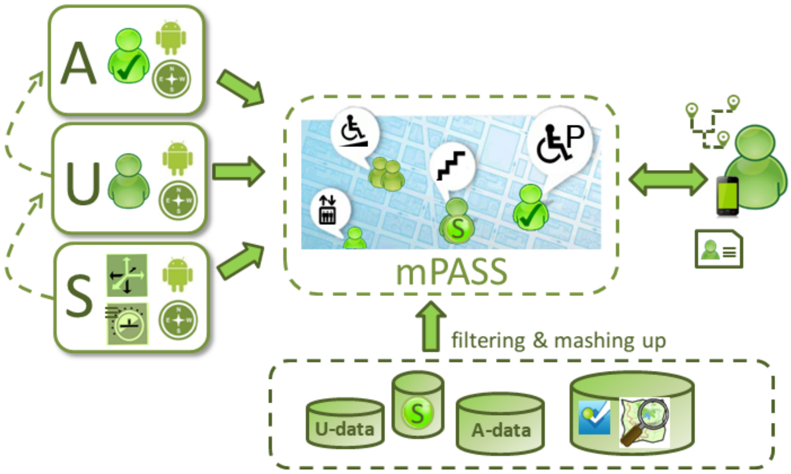


FIGURE 2.1: Data Gathering and user interaction in mPASS

2.4 User Profile

To support personalized services, we developed a user profile on the basis of the above described categories of aPOIs. Users are identified with access credential and classified as simple user or authorities, according to the model used to gather data. Users running the mPASS app can activate/deactivate the sensing module.

The profile describes the user's preferences related to each accessibility barrier or facility classified by mPASS (i.e., each aPOI). In order to represent such preferences, the profile associates a value to each type of aPOIs. Possible values for each user preference are:

- NEUTRAL: this value indicates that the user has neither difficulties nor preferences related to the aPOI type and it is totally irrelevant to him/her to meet such a kind of aPOI on his/her way. For example, in the profile of a young walking pedestrian, the value for the "stairs" aPOI type could be NEUTRAL.
- LIKE: this value means that the user prefers this type of aPOI, when available. This value is usually related to accessibility facilities and not to barriers. For example, in the profile of a user who wants to follow a safe path,

the value for the “zebra crossing” and “traffic light” aPOI types could be LIKE.

- DISLIKE: this value is used when a user can face an aPOI type, but with some efforts. In this case an alternative path is preferred, but it is not necessary. An example of possible use of the DISLIKE value is in relation with the “stairs” aPOI type in the profile of an elderly user.
- AVOID: this value means that the aPOI type represents an insurmountable barrier to the user. As an example, in the profile of a wheelchair user the value associated to the “stairs” aPOI type should be AVOID.

This set of values is used by the mPASS routing algorithm to compute a path that meets the LIKEd aPOIs when possible, gets round the DISLIKEd ones if feasible and totally avoids the ones labelled as AVOID. Currently the profile is pre-compiled on the basis of self-declarations done by users.

2.5 System architecture

The system architecture is shown in Figure 2.2. mPASS users can access to services both by using mobile devices and through the Web. Mobile services are provided by an Android app that includes the sensing activity. As shown in the following Figure 2.2, it is based on three main modules; each one is responsible for a main function of the system.

The *Sensor Analysis Module* performs a part of the data fusion and analysis, in order to add S-reports to the mPASS DB. This task is performed by using data coming from a Sensing App, running on Android on users' smartphones. Currently sensed barriers are simple steps and stairs with multiple steps.

The *Data Filtering Module* adds data provided by other systems and services to the mPASS DB. It permits the integration with external dataset (e.g. Foursquare, OSM, municipality open data). In particular, the integration with Foursquare,

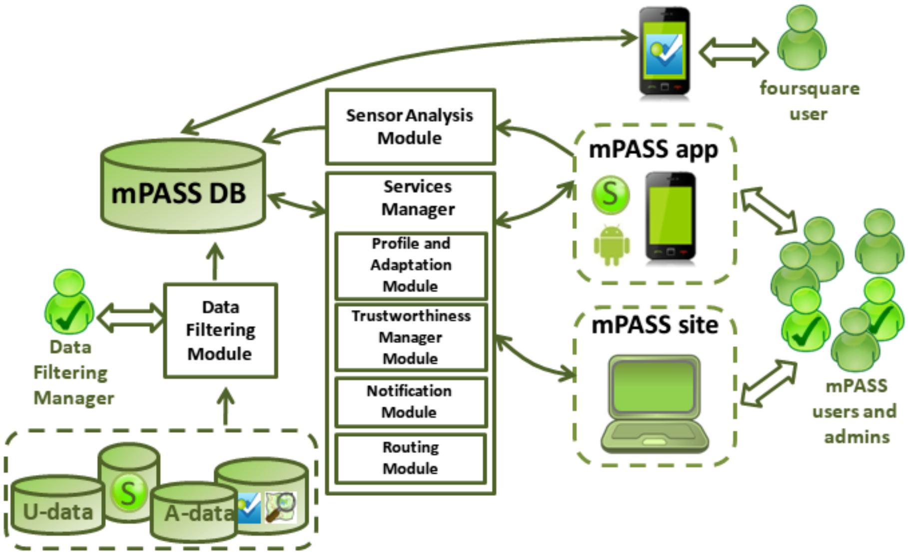


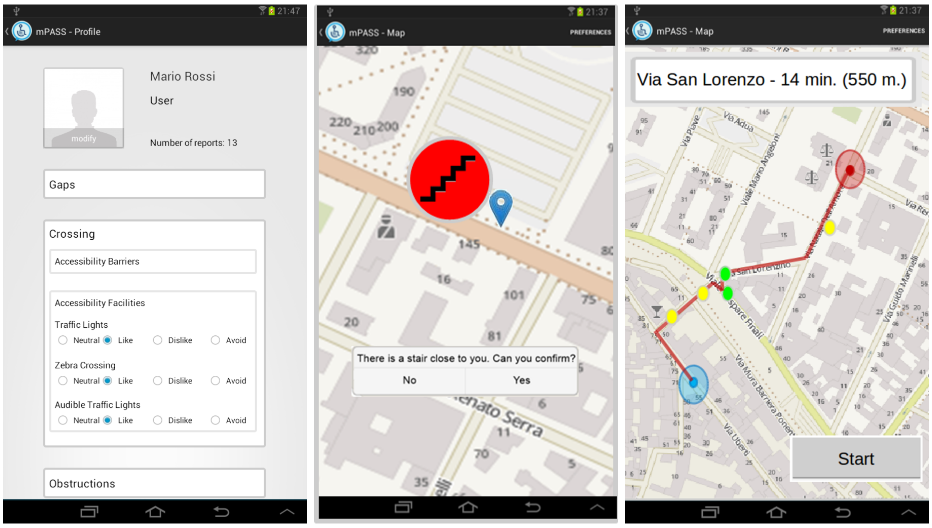
FIGURE 2.2: Figure 3. mPASS architecture

due to it wide diffusion, allows to extends the range of platforms that can be used to interact with the mPASS system.

The *Services Manager Module*, which is composed by three sub-modules:

- the *Profile and Adaptation Module*, that stores information about users' preferences (see Figure 2.3(a)) and provides users' profiles to the *Routing Module* each time a map or a route is computed;
- the *Trustworthiness Manager Module*, that manages APOIs and reports trustworthiness, users' credibility and sensors accuracy;
- the *Notification Module*, that is responsible for sending requests to the mPASS app on the user's mobile device and for adding the obtained U-report to the mPASS DB (see Figure 2.3(b));
- the *Routing Module*, that is in charge of computing the best route for a user, according to his/her profile (see Figure 2.3(c)).

Data provided by other systems and services are added to mPASS by using the Data Filtering Module. This activity needs to be managed, in order to fit data collected by others inside the mPASS DB. Finally, to provide a better integration with Foursquare, reports can be added and retrieved from the mPASS DB



(a) Setting the user profile (b) Notifying the presence of a stair nearby the user (c) Getting a personalized path for a wheelchair user

FIGURE 2.3: mPASS app screenshots

by using a Foursquare application. Due to Foursquare wide diffusion, this application extends the range of platforms that can be used to interact with the mPASS system.

We have developed a prototype of the mPASS system that provides the main functions described above. In particular, we have created the mobile apps needed to access the system: the mPASS app and the Foursquare application for mPASS. The mPASS app runs on Android version 3.0 Honey and greater and it exploits OpenStreetMap. It allows users to:

(i) configure their profile;

(ii) spontaneously insert a report;

(iii) receive notifications to validate the presence/absence of accessibility barriers/facilities;

(iv) view the past report logs;

(v) display the report localized in OpenStreetMap (*Open Street Map* 2015);

(vi) search the best route.

Tasks (v) and (vi) are performed on the basis of the user profile. A simple sensing system to detect steps has been developed, together with the corresponding part of the Sensing Analysis Module. The Foursquare application for mPASS allows the user to join the app and to answer to a survey during the check-in phase. We took care to provide users with a simple and short survey. Reports are stored in the mPASS DB, developed on PostgreSQL (*PostgreSQL* 2015) with PostGis extension (*PostGis* 2015). We have developed the Data Filtering Module and we have filtered and integrated data provided by several existing systems. We re used both geo-referenced data (filtered to fit the mPASS DB) and not geo-referenced data. The latter one has been automatically geo-referenced by means of their address and name. Moreover, data provided by other services are reclassified as S, A or U-reports, depending from the source type. For example data gathered by the Foursquare community are considered U-reports, while data provided by Ingresso Libero (*ingresso libero* 2015) and the other official reviews providers, are classified as A-reports.

2.6 Test with users

In order to evaluate our prototype, we planned a three-phase assessment:

1. A preliminary questionnaire with mockups showing the mPASS interface.
2. A prototype evaluation conducted by some users with disabilities, testing some specific mPASS characteristics, through paths with barriers and facilities which have been mapped in advanced.

The following subsections present the obtained results.

2.6.1 Preliminary questionnaire

In this design phase we have involved 60 European users (including blind and people with low vision, wheelchair users and users with physical impairments, deaf and hard of hearing users and elderly people), thanks to the engagement in our project of organizations supporting people with disabilities we aim of obtaining a first evaluation of mPASS. We have invited these users in answering an online questionnaire, asking them some general questions about their potential interest in using our application, according to its aims and some specific characteristics; moreover we have shown them some mockups and asked them to provide their feedbacks. The group of users involved in such a first phase were composed by 60 people (26 female, 34 male), with ages ranged from 19 to 68 (with an average value of 44).

Some general questions, reveal that 66% of the users exploits some assistive technologies on their smartphone (including font magnifications, speech-to-text applications, and so on). 63% of them usually exploits GPS navigation systems so as to get information about urban pedestrian paths in their activities (i.e. Google Maps, Ariadne GPS, etc.) and 70% of the users declare they trust systems which provide geo-referenced information on the basis of crowdsourced data (including Foursquare, TripAdvisor, and so on).

All the users declare their willing in exploiting a system on their mobile phone which provides personalized pedestrian paths, on the basis of their specific needs and preferences. 80% claim they would afford a path longer of 30% to reach their destination if the path is tailored on to their preferences and needs, while 20% of the users would afford a personalized path longer more than 30%. Being aware of the possible presence of uncertain data (that can be produced by information coming from sensing and crowdsourcing activities), 73% users would prefer affording a longer path in order to avoid a detected barrier which is not actually present on the path, instead of meeting an undetected barrier in their path or instead of having a path with a detected facility which is not actually present. The most of the users (81%) expressed their willing in sharing their personal data and information about their preferences, including details about the routes they usually perform in their daily life (77%); only 4% of the involved users declare they would not share any data about the paths they use to go along. Almost all the users (98%) declare they would be very interested in exploiting information about public means of transport routes which can be involved in their habitual paths. Then, we have asked the users to express their interests in having some specific personalized pedestrian paths, which are depicted in Table 2.2. The users chose among different choices, expressing multiple preferences.

TABLE 2.2: Preferences about personalized paths

Path type	**Preferences (%)**
Accessible paths	44%
Safe pedestrian paths	73%
Safe paths (avoiding unsafe areas)	37%
Lit paths	15%
Most crowded paths	27%
Less crowded paths	14%
Less polluted paths	12%
Less noisy paths	29%

Details about the resulting preferences are reported in Table 2.2 and show a strong interest in having above all personalization on the basis of pedestrian safety issues (i.e. zebra crossing, traffic lights, etc.) and then in having personalization on the basis of element of urban accessibility (avoiding barriers and meeting facilities). The users declared their preferences in terms of categories of urban elements they are interested in having details along their personalized paths. The users can set multiple choice, and they showed interested above all in having details about public means of transports stations (including bus stops) and vehicles. They expressed preferences also for detailed data about sidewalks, stairs (including steps, curbs and ramps), obstructions (including trees, garbage bins and traffic signs) and crossing elements (including zebra crossing, traffic lights and audible traffic lights). While surfaces (including road pavement) and parking spaces obtained less interest. Details about these results are depicted in Table 2.3.

We have concluded this first phase, asking the users to evaluate some HTML mockups, showing information about a complete urban pedestrian path and details about a specific part of a path, warning about the presence of a barrier.

TABLE 2.3: Preferences about personalized paths

Details on urban elements	**Preferences (%)**
Stairs, steps, curbs and ramps	31%
Obstructions	31%
Zebra crossing and traffic lights	29%
Parks	14%
Surfaces and road pavement	19%
Sidewalks	32%
Buses and trains	34%
Public means of transport stations	37

Obviously we have prepared two different sets of mockups: one set provides graphical representation of the maps, while the other one provides textual representations. The users generally appreciated the proposed interface and interaction (72% of positive feedbacks), considering them clear and easy to understand and to interact with.

Some users provided suggestions to improve mPASS, commenting the presence of data considered needless or considered not so clearly understandable (10% of feedbacks in this sense) or the lack of information they would like to exploit at a certain step of the interaction with the app (16% of comments in this sense). We have exploited such detailed comments in order to build the second phase of the assessment, as described in the following subsection.

2.6.2 Prototype Evaluation

In this second phase of tests with users, we have emulated the mPASS operation in the city of Cesena (Italy), for a set of users with different disabilities. In particular, we have involved 3 blind people, 3 wheelchair users and 4 elderly people, equipped with their mobile devices, mounting different versions of Android, the assistive technologies they usually exploit (whenever necessary) and our mPASS prototype. We have mapped in advance 3 different urban paths, with the same starting point (the building hosting the degree course in Computer Science and Engineering, University of Bologna) and the same destination (the railway station). We have collected detailed information about barriers and facilities along such paths, so as to adequately populate the mPASS DB, and we have prepared suitable profiles together with the users, according to their preferences and needs. Then the users have exploited the mPASS prototype to reach the railway station from the University, going along the proposed personalized path, applying the Thinking Aloud method. We have followed them during the trials and we have collected their comments and suggestions. Moreover, they have filled a post-test questionnaire.

The users involved in this second phase appreciated the mPASS prototype, all of them declare that the interface and the interaction mechanisms are clear and easy to be used. 90% of the users found that all the provided information (shown in Figure 5 and 6) are clear to be understand and all the functions are easy to interact with. 100% of the users declare that all the information are useful, while 50% of the users declare that they would appreciate additional data about public means of transport and bus stops and stations eventually involved in the proposed path. Moreover, 60% of the users are interested in some more details about the path, in particular more significant comments and suggestions are related to add:

- More information about pavements and surfaces. In particular, such details should include the position and the dimension of the uneven road pavements aPOI (shown in Figure 6), information about the feasibility of that aPOI, clarifying if it is necessary to bypass it or quantifying the effort in crossing it. Features that allow users to upload and share pictures of aPOIs would be really appreciated and would let the users to really be aware of the aPOI.
- Information about the presence of one-ways streets involved in the path and the directions of the vehicles in such streets.
- Information about the presence in the paths of landmarks that can help users in orienting (i.e. schools, stores, café and so on) and of squares, open spaces and roundabouts.

- Features that let users provide comments and that let users exploit comments coming from users with a similar profile who have already gone along the same path, meeting the same aPOIs. Such comments could be related to the whole path and/or to the single aPOIs.
- Information about the presence of works in progress and road works.
- Details about the availability of rest areas (such as benches) along the paths and in their nearby.
- Information about wi-fi areas available along the paths.

All these comments convinced us about the need of enlarging our data model and confirm the need of a strong personalization mechanism based on a dense and granular database of information related to the urban environments.

2.7 The integration of public transport open data

With the aim of equipping citizens with a complete and multimodal urban mobility service, we have designed a platform that integrates different systems: (i) OpenStreetMap (Haklay and Weber, 2008; Mashhadi, Quattrone, and Capra, 2013); (ii) WhenMyBu app that provides customized information based on real time data obtained by bus operating companies; (iii) mPASS system that collects data produced by sensors and data gathered via crowdsourcing by the users (mPASS system) to calculate pedestrian personalized paths. All these services are exploited to provide users with multimodal paths tailored to their specific needs and/or requirements.

Some online systems (e.g., Google Maps, Bing Maps) provide geospatial mapping services, suggesting routes from a starting point to a destination chosen by the user, including public means of transports, when available. Such proposed routes are computed for users with average mobility abilities. To provide a more effective service, some additional data on barrier, facilities, bus routing and equipment are needed. In particular:

- Data about urban accessibility, in terms of barriers and facilities, which could be obtained by crowdsourcing and sensing activities conducted by citizens equipped with mobile devices.
- Open data about real time availability of public transportation means, their equipment in terms of accessibility barriers and facilities, their time of arrival and route etc.

With the aim of equipping citizens with a complete and multimodal urban mobility service, we have designed a novel system based on OpenStreetMap, exploting Bologna public transport open data.

2.7.1 Multimodal accessible way-finding

Our case study exploits real time data provided by bus operating companies combined with data produced by sensors and data gathered via crowdsourcing by the users. All these data are exploited to provide users with paths tailored to their specific needs and/or requirements. Our system involves two mobile applications: mPASS and WhenMyBus. WhenMyBus is a mobile app, designed and developed by the University of Bologna, in collaboration with the Bologna municipality, with the aim of supporting citizens who travel by bus in the city , equipping them with a dedicated service. It directly interacts with official open data, providing real time information about public means of transport availability and equipment (in terms of accessibility facilities for citizens with disabilities).

These two applications, mPASS and WhenMyBus work on a user's profile, which describes the users' needs and abilities. On the basis of such a profile, the system filters geo-referenced data from OpenStreetMap (*Open Street Map* 2015) and specific databases in order to provide personalized paths and maps, by customizing them to meet users' needs. This way, the applications support citizens in moving in the Smart City dimension, by equipping them with personalized, accessible and multimodal paths.

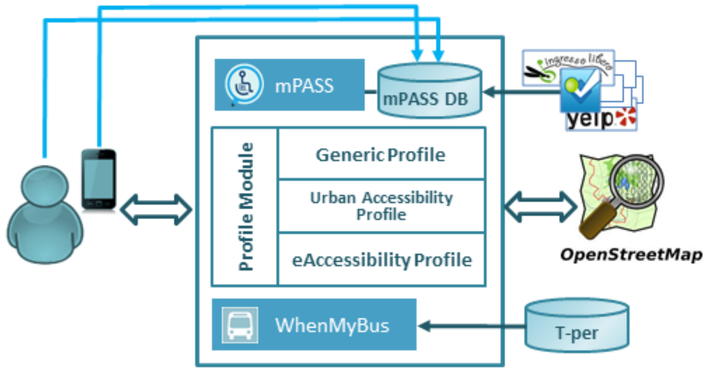


FIGURE 2.4: Multimodal accessible way-finding architecture

Personalization of the proposed routes (taking into account accessibility of the urban environment and of public means of transports) has been addressed by computing a personalized and accessible route (including accessible means of transport), according to a user's preferences and needs. These are describes in a profile, both in terms of urban accessibility and e-accessibility requirements, so as to make accessible even the application on the mobile device in use (as detailed in Chapter 3).

In our multimodal system, by means of the profile, the users can declare specific characteristics, such as average speed when moving in an urban environment. Moreover, device sensors can also track users' movement, compute their average speed and adequately adjust this data in the profile. This information can be very different, in particular for those users who are equipped with a wheelchair (that could be a manual wheelchair or an electric- powered wheelchair) and for the elderly citizens. Users' average speed can become a crucial data in computing a personalized path, in particular when the route includes a pedestrian path to reach a bus stop or a metro station to catch a public transport. Profiling of users put together with the real time data about buses availability makes our system able to meet effectively the specific need of citizens.

System architecture

Figure 2.4 shows the overall architecture of our system, which includes two main services, which work together: mPASS and WhenMyBus. It is worth noting that WhenMyBus is not just an external data source but it is a complete and independent system and it requires us to design a different system architecture, as detailed in the following paragraphs.

The user can interact with our system by means of an application running on his/her mobile devices. He/she can set up his/her preferences and needs in the profile (managed by the Profile Module), together with his/her traveling habits in the urban environment. The user profile is organized in Generic Profile, Urban Accessibility Profile and eAccessibility Profile. More details about the Profiling System can be found in Chapter 3. Both mPASS and WhenMyBus share the user Profile Module. mPASS computes the pedestrian parts of the path by exploiting the Bidirectional Dijkstra routing algorithm, considering the accessibility barriers as constrains. When a bus route is included in the path, WhenMyBus exploits the T-per open data to compute the bus route parts in the path.

By means of the mobile Android application, the user can ask for a personalized route, specifying a starting point and a destination. Our system computes a set of proposed paths, involving mPASS and WhenMyBus services (if they include public means of transport). WhenMyBus is directly connected with T-per open data, with the aim of providing real time information about buses availability. mPASS is directly connected to its database, which collects geo-referenced information gathered by means of crowdsourcing and sensing activities (involving the users and their mobile devices). Moreover, the mPASS database includes information coming from geo-referenced social networks, e.g. (*Foursquare* 2015), and from official reviews done by experts, with the aim to provide users with information about indoor accessibility of places which are nearby their destination. The information about the proposed paths and

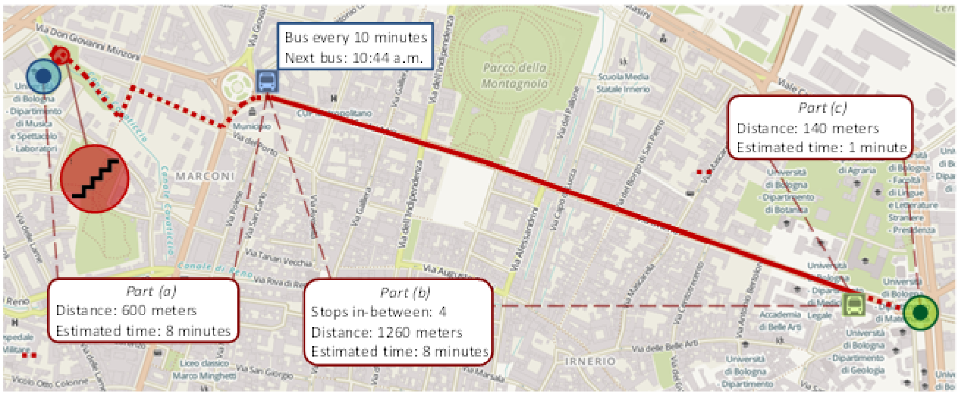


FIGURE 2.5: Path proposed by traditional geospatial mapping platforms

their accessibility (including the accessibility of the POIs and of the buses) are delivered to the users by means of OpenStreetMap (*Open Street Map* 2015).

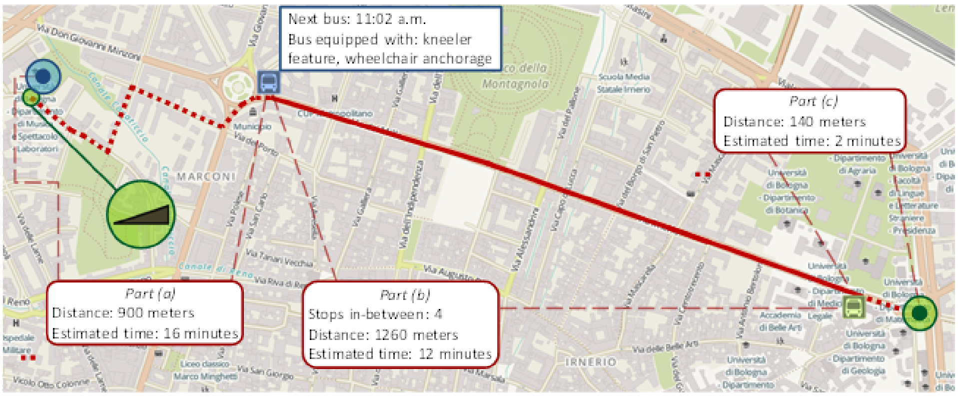


FIGURE 2.6: Path proposed by our multimodal accessiibily wayfinding system, tailored on user's needs and preferences and on public means of transport real time data

A case study

In order to prove the effectiveness of our approach, we tested our system with many different user profiles (such as users with reduced mobility, elderly people, blind users and users with low vision). In this section, we present a scenario which illustrates a user with special needs and preferences, who requests a personalized path, by using a smartphone. In particular, let us consider a male user equipped with a manual wheelchair who asks for a specific path (including accessible bus routes) in the city of Bologna (Italy).

The user has set up his UAProfile declaring that he LIKEs ramps and curb cuts (as gap facilities), parking slots reserved to people with disabilities (as parking facility), kneeler features and wheelchair anchorage (as bus facilities), zebra crossing and traffic lights (as crossing facilities). He initialized uneven road surface and tactile paving (in the surface category) as DISLIKE and gap and obstructions barriers as AVOID. Handrails, audible, braille and tactile information are NEUTRAL for him. Figure 2.5 depicts a fragment of such a user's profile.

Figure 2.6 shows a portion of the map of Bologna with the starting point (blue circle) and the destination (green circle) chosen by the user. The path shown in Figure 2.5 is the one suggested by the most commonly used geospatial mapping platforms (e.g. Google Maps, Bing Maps, etc.), taking 17 minutes as a whole and being is structure in three parts:

(a) a pedestrian part to reach the bus stop (represented with a blue bus icon in Figure 2.5); this part is supposed to take 8 minutes to the user;

(b) a part of a bus route (from the blue bus stop to the green bus stop); this part is supposed to take 8 minutes (with four in-between stops);

(c) another pedestrian part from the arrival bus stop (represented with a green bus icon in Figure 2.5) to the final destination; this part is supposed to take 1 minute.

This path presents some issues our user has to face:

1. there is a stair in the first pedestrian part of the path (highlighted in Figure 2.5 with a red icon) and there is no information about its presence; this means that our user cannot afford the suggested pathway, but he has to find another alternative and accessible route;

2. there is no information about accessibility of the public mean of transport and of the bus stops; in particular, not all the vehicles are provided with facilities to support our specific user, such as ramps, kneeler features and lifts;

3. estimated time to reach the departure bus stop from the starting point (8 minutes, for 600 meters) is computed taking into account abilities and speed of an average user, instead of considering the actual abilities average speed of our specific user;

4. information about bus arrival time is derived from a time table, instead of referring to the real bus position and availability.

Our system computes a different and personalized path, by taking into account real data about bus availability and the user's profile, in terms of barriers to avoid, LIKEd facilities to include as much as possible, user's personal average speed (set up as 0,98 m/s (Tolerico et al., 2007)). This path is structured in three parts (shown in Figure 2.6), where only the first part is different from the path shown in Figure 2.5. In particular:

1. our path suggests a different first pedestrian part of the path, taking into account the presence of that stair and finds an alternative accessible path, including a ramp (highlighted in Figure 2.6 with a green icon);

2. information about the accessibility of the public means of transport is provided; in particular, the path is computed taking into account a bus equipped with a kneeler and wheelchair anchorage features;

3. estimated time to reach the departure bus stop from the starting point is computed taking into account our specific user's abilities and average speed, as declared in his profile (16 minute, for 900 meters);

4. information about bus arrival time is provided taking into account T-per open data about the real bus position and eventual delays.

The time to complete the path is estimated to be 30 minutes and it is computed according to the user's average speed and real bus availability (by considering T-per real time data about eventual delays, traffic, and so on), as follows: 16 minutes for part (a), 12 minutes for part (b), and 2 minutes for part (c).

The whole path proposed by our system is the result of the mPASS routing module (based on the Bidirectional Dijkstra routing algorithm), which considers user's preferences about APOIs as constrains for the pedestrian parts, and of WhenByBus and T-per routing algorithm for the bus routes.

2.8 Conclusion

In this Chapter we introduced mPASS, a system that has been designed with the aim of providing personalized maps and routes to users with special or specific needs. The system is a prototype that performs a set of basic functions, including a simple sensing module to sense steps, a basic routing algorithm, the user profiling, an app to support users and authorities/experts in adding reports about accessibility barriers and facilities and, finally, a notification system to ask users and authorities to improve validity (trustworthiness) of data.

A challenging part of the work has been devoted to filter and mash up data provided by other services and datasets, including open data of the public transportation. As case study, we implements a multimodal accessible way-finding including in mPASS the functionality of a mobile app that exploits open data about the public transportation of Bologna. Traditional widely used geospatial mapping services provide users with suggestions tailored to average abilities. As discussed in the design issue section and shown by the case study, these suggestions can be almost useless for users with special needs, especially users with reduced mobility.

Chapter 3

User profiling and context-aware personalization

This Chapter is focused on the context-aware personalization approach we designed and developed in mPASS. In particular, the adaptations performed by mPASS works on three main dimensions: i) the user location; ii) the user profile; iii) data trustworthiness. The profile describes users' preferences and needs in terms of: *Urban accessibility*: the user can declare barriers that limit or inhibit his/her ability to move and facilities which can improve the mobility experience and the system performs adaptation individually tailored to the actual information needs; *E-accessibility*: the user can customize mPASS in terms of accessibility of information.

The reminder of this Chapter is organized as followed. Section 3.1 details the importance of context-aware and personalization services in mPASS in adapting maps and content on the basis of the user's preferences and needs. Section 3.2 compares related work with our approach. Section 3.3 illustrates how we profile the user. Section 3.4 describes the main adaptation techniques adopted by mPASS. Lastly, Section 3.5 concludes the Chapter, presenting some future works.

3.1 Background and motivation

Location-based systems and applications should provide information which is of interest to the user and it is personalized to his/her preferences and needs (Bereuter, Venkateswaran, and Weibel, 2009). This is especially true for those navigation systems which are devoted to guide pedestrian users in urban environments. In fact, such systems are more susceptible to errors and to specific details in computing paths than more common navigation systems tailored for vehicles (Retscher, 2004). Moreover, users are very different, from one another, in terms of capabilities and preferences.

In particular, in the urban environment there are several issues that can affect or improve the experience of pedestrians (e.g. obstacles and barriers, but also facilities); different paths, with the same starting point and destination, but with different characteristics and distances, can make a huge difference for pedestrians. This becomes a key issue for those target users with specific preferences and needs, for instance people with reduced mobility (i.e., people with physical disabilities, elderly people, etc.) or citizens with particular preferences in terms of safeness (i.e., kids coming back from school, women who require to avoid unsafe areas at night, and so on).

As described in Chapter 2, we have designed and developed a context-aware system, called mPASS (mobile Pervasive Accessibility Social Sensing) (Prandi, Salomoni, and Mirri, 2014), which aims to collect data about urban accessibility and to provide citizens with personalized and accessible pedestrian paths and maps. This context-aware system combines data produced by sensors and data gathered via crowdsourcing by users, together with information provided by experts. mPASS also re-uses information got by geo-referenced social systems by filtering or mashing up.

Such data are selected and transformed in order to provide personalized maps and routes and to meet specific users' needs. The adaptation performed by mPASS works on three main dimensions:

i) the user location;

ii) the user profile;

iii) data trustworthiness.

The profile describes users' preferences and needs in terms of:

- *Urban accessibility*: the user can declare barriers that limit or inhibit his/her ability to move and facilities which support it.
- *E-accessibility*: the user can customize mPASS in terms of accessibility of information.

The need of considering data trustworthiness in the adaptation process is due to the multiple sources nature of mPASS, which has to consider the quality of data gathered by users and sensors as a key element in computing personalized routes. To improve trustworthiness of collected information, mPASS runs a location-based notification system which involves volunteered and trustable users in verifying the actual position of barriers/facilities.

3.2 Related work

In analyzing related work we considered four main groups of research and applications: (i) research and techniques devoted to adapt and personalize maps representation and interface; (ii) studies about accessible maps; (iii) research and standards for profiling users' preferences and needs; (iv) location-based and/or context-aware services.

3.2.1 Personalized maps

The paper (Ginige et al., 2012) presents some general principles of interface design related to the representation of spatial data in mobile devices. The paper shows that one of the most challenge kind of applications involving spatial data are visual maps. The authors demonstrate that well-known interface design principles have to be adjusted to the limited characteristics of mobile devices, focusing on the context of use. In our work we have exploited these findings, applying them to our specific context. In (Setlur, Kuo, and Mikelsons, 2010a), the authors present the design and the development of map interfaces, so as to be exploited by means of mobile devices and tailored according to users' purposes. In particular, the authors discuss about what they experienced in terms of rendering, user interaction and adaptation techniques required for these mobile map interfaces, taking into account user experience and mobile device limitations (i.e. small screens, limited network connectivity, or reduced processing power) and not only users' interests. This work effectively describes map adaptation techniques and interaction mechanisms, giving us many interesting hints. However, it does not consider specific contexts, such as the need of accessible maps and personalized paths. The need of adapting maps so as to meet needs of users equipped with mobile devices is the main motivation of the work presented in (Van Tonder and Wesson, 2008). Mobile devices limitations are taken into account in this work, which proposes maps personalized according to individual characteristics of the user with the aim of improving mobile map-based visualization. The authors designed a model and developed a prototype of a mobile map-based visualization system, incorporating an adaptive user interface. Evaluation results show the effectiveness of personalized maps in supporting users' needs and requirements. Also this work provides interesting ideas and techniques, but it does not take into account specific and special needs of users. The author of (Weninger, 2012) proposes the idea of exploiting user-map interaction with the aim of personalizing maps to individual users. The author observed and evaluated users' interactions with maps. Some map interaction patterns have been identified and they are exploited so as to deduce parameters for maps personalization. In this work, interaction is considered as an exchange of data between the user and the map (e.g. when the user clicks on a button) and a reaction of the map on users' input (e.g. when the map shows a specific layer after the user clicked on a button). Some of the issues presented in this paper inspired our work in personalizing maps to meet users' needs. An interesting and useful map adaptation is the provision of textual and/or visual information in the map. The authors of (Church et al., 2010) investigated the differences between these two different kinds of maps interfaces. They developed two proactive mobile search interfaces and they involved 34 mobile users, studying the impact that the type of user interface has on the search and information discovery experience. The results of this work confirm that personal preferences, situational context and information needs play important roles in the choice of interface (sometimes in an unexpected way). Visual maps seemed to be an intuitive interface choice, but this study shows that text-based maps can be preferred by users who want and/or need precise location information or more location details. In our work we have taken into account these findings, together with the fact that text based maps can be exploited also by users with visual impairments.

3.2.2 Accessible maps

A lot of literature is devoted to describe problems faced by people with visual impairments when they use a visual map or geographical data or a location-based system and to present methods applied to improved maps accessibility. The authors of (Thomas et al., 2008) present a data-to-text natural language generation system which enables access to geo-referenced information, taking into account specific requirements so as to meet users with visual impairments needs. First of all, the authors focused on the need of generating textual summaries so as to provide adequate information (with enough details) to users and then they stated the need of equipping users with an interactive textual browsing system. The system has been designed to be exploited by specific users as a desktop application. Meeting the needs of blind users who interact with visual maps is the aim of (Buzzi et al., 2011). The paper discusses about accessibility issues of map-based applications and presents different possible interaction modalities and devices to use for achieving usage perspectives to meet blind people needs. The paper presents an interesting case-study, which describes the interaction of a blind user with a web-based map. Moreover, it investigates also new ways to interact with mobiles devices, by means of gestures and touch commands. Users with visual impairments are taken into account also by the authors of (Kaklanis, Votis, and Tzovaras, 2013), who present an interactive mobile maps application, investigating ways of presenting alternative formats that would replace visual information. Their application is called "Open Touch/Sound Maps", it is based on OpenStreetMap (*Open Street Map* 2015) and it has been developed as an Android mobile application, which enforces the accessibility of interactive maps for the visually impaired users. Multimodal interactions have been included in this application, such as sonification, Text-to-Speech and vibration feedback. All these previous work are based on the aim of improving the accessibility of outdoor maps. The authors of (Zeng and Weber, 2011) take into account also indoor maps. This paper discusses about accessibility issues of indoor and outdoor maps, desktop and mobile applications and pre-journey and mobile uses of those maps. Design issues are reviewed and missing features are presented. The same authors propose also the implementation of an audio-haptic map system (Zeng and Weber, 2010), based on novel touch-sensitive Braille displays. Such kind of devices lets the representation of geographic data in a tactile way and offers touch input features like panning, zooming and search at the same time. Interactive audio-tactile maps are at the basis of (Brock, 2013) and (Paladugu, Wang, and Li, 2010). The former paper presents the development of an accessible interactive map prototype based on the cycle of participatory design, where context and users' needs play a very important role. The prototype exploits a multi-touch screen, a tactile paper map overlay and audio output (Brock, 2013). The latter paper (Paladugu, Wang, and Li, 2010) uses an audio-tactile system and studies issues to better support blind users in getting directions on an interactive map. This work defines a set of design guidelines and patterns to develop technologies that really meet the needs of visually impaired users. The aim of the AccessibleMap (Wasserburger, Neuschmid, and Schrenk, 2011) is to equip blind users with an accessible map which shows the accessibility of the users' location and its nearby. This work develops methods to design web-based city maps to meet the needs of such kind of users. In this project, the map interface is adapted according to the users, as well as the information shown in the map. The author of (Miesenberger, 2012a) describes the main discussion topics, guidelines and standards related to accessible maps. This review describes not only techniques to make visual maps accessible to people with visual impairments, but also techniques to adapt visual maps so as to meet specific needs of users with cognitive disability, elderly people, deaf users and users with hard of hearing. Some works have been done so as to provide accessible maps to users with these latter disabilities. For instance, (Chang, Tsai, and Wang, 2008) presents a wayfinding system devoted to provide support to persons with cognitive disabilities. The approach of this work is based on the use of QR-code tags. Hard of hearing users' needs are taken into account by the authors of (Boulares and Jemni, 2012). This work exploits Google map and KML, which is a file format used by Google Map to display geographic data, with the aim of making KML information accessible to users with hearing disabilities equipped with Android mobile devices. The authors take into account users with hearing disabilities specific needs, which are related to the learning and understanding process of any written language. In particular, the authors define a system to automatically interpret textual information on the map according to the user's current position.

3.2.3 Profiling Users' Preferences

Another important area of interest is related to user profiling and modeling to support personalization so as to meet users' preferences and needs. User modeling has been used in a large group of research as an approach for generating and adapting user interfaces so as to address specific user needs and/or preferences. The authors of (Biswas and Langdon, 2012) and (Biswas, Robinson, and Langdon, 2012) have identified a set of human factors that can affect human computer interaction and they have formulated models to relate those factors to interface parameters. They have developed inclusive user models, taking into account needs of users with disabilities. Moreover, they have implemented a simulator and a set of Web services. Such a simulator aims to help designers in understanding, visualizing and measuring effects of impairments on interaction (by predicting a set of rules relating users' range of abilities with interface parameters), while such Web services adapt interfaces across different devices and kinds of users (dynamically changing characteristics such as font size, cursor size, color contrast, audio volume, spacing between interface elements, and so on). The authors of (Atkinson, Bell, and Machin, 2012) based their work on the idea that adaptation can work as a sort of micro-AT, providing personalization that increases the range of users who are able to access a content. As they act a crucial role in ensuring accessibility, adaptations and device-specific settings are increasingly being included in profiles, describing accessibility needs. In order to apply this issue, the authors of this paper use the semantic Web to model adaptations in terms of human capabilities. Their approach is based on the provision of a vocabulary that moves from device-specific to device-agnostic profiling through the logical structuring of profiles. Some XML and RDF-based standards provide ad-hoc vocabularies in the profiling users context, with the aims of describing their needs in specific conditions, for instance when they access content via some mobile devices, or if they present some disabilities. In these fields, the most common standards are: Composite Capabilities/Preference Profile (CC/PP) (Kiss, 2012) and User Agent Profile (UAProf) (Alliance, 2002) to profile device capabilities, ISO Personal Needs and Preferences (PNP) (*Access for all* 2008) and IMS Access for All (AfA) Personal Needs and Preferences (PNP) 3.0 (*IMS* 2012) to profile users' needs in terms of accessibility (in e-learning contexts). In particular, according to both these latter standards, users can explicitly declare in their profiles alternative access modes for original forms of didactical resources. For instance, a blind user could state he/she needs to access original visual resources as auditory or textual alternative content (Mirri et al., 2011). Such specifications do not deal with characteristics related to device capabilities (including those ones related to screen size, interaction methods, reduced processing power, networks and connectivity) and supported media features (such as supported formats, size or quality of video and audio resources), while these information are collected in the former device-related standards. A brief comparison among all these standards can be found in (Ferretti et al., 2009) and in (Mirri et al., 2011). CC/PP has been considered by the authors of (Ackermann, Velasco, and Power, 2012). This paper presents a modeling framework that supports dynamic adaptation of the user interface of web 2.0 applications. This work exploits the use of a semantic framework for Composite Capability/Preference Profiles (CC/PP), which lets the matching of device capabilities and user preferences arising because of functional restrictions. The combination of these models enables an adaptive transformation process that facilitates access to users with special needs. This approach is interesting, but it is essentially devoted to web applications and content. In our work, we have taken into account this idea. In particular, in our work we need to exploit information about users' needs and preferences not only in terms of e-Accessibility, but also in terms of urban accessibility. Hence, we have included a profiling system, which describes users' needs and preferences both in terms of maps rendering and interaction and in terms of urban barriers/facilities.

3.2.4 Location-based and context-aware services

In this context, we are going to introduce related work in the following areas of research and techniques devoted to provide location-based and/or context-aware services, on the basis of adaptive maps.

Several works have been done with the aim of offering applications and services based on maps and geo-referenced data, which are personalized on the basis of pedestrians' location (Retscher, 2004; Gartner, 2004; Raper et al., 2007; Panahi, Woods, and Thwaites, 2013). Many of them take into account not only the position, but they adapt the maps on the basis of the user's direction and device orientation (Yin and Carswell, 2011; Raubal and Panov, 2009).

To better adapt maps and the rendered information, several of these works are based on users' contexts, usually described by means of profiles, so as to include also his/her interests and/or behaviours (Fischer, 2012; Zipf and Jöst, 2006; Ricci, 2011). On the basis of these user's profiles, such systems can provide suggestions and recommendations about specific Points of Interest (POIs) in the map (Kurata, 2009). These profiles can be directly configured by the user (Kurata, 2009) or devised by means of recommendations systems and collaborative filtering techniques (Barranco et al., 2012) or extracted by social networking profiles (Bereuter, Venkateswaran, and Weibel, 2009).

Among these works, some of them present interesting studies and techniques related to mobile map adaptation. In (Setlur, Kuo, and Mikelsons, 2010b), the authors present the design and the development of map interfaces, so as to be exploited by means of mobile devices and tailored according to users' purposes. In particular, the authors discuss about what they experienced in terms of rendering, user interaction and adaptation techniques required for these mobile map interfaces, taking into account user experience and mobile device limitations (i.e., small screens, limited network connectivity, or reduced processing power) and not only users' interests. This work effectively describes map adaptation techniques and interaction mechanisms, giving us many interesting hints.

The need of adapting maps so as to meet needs of users equipped with mobile devices is the main motivation of the system named MediaMaps and presented in (Tonder and Wesson, 2008; Tonder and Wesson, 2009). Mobile devices limitations are taken into account in this work, which proposes maps personalized according to individual characteristics of the user, with the aim of improving mobile map-based visualization. The authors designed a model and developed a prototype of a mobile map-based visualization system, incorporating an adaptive user interface. Evaluation results show the effectiveness of personalized maps in supporting users' needs and requirements.

Both these previous systems just provide maps adaptation features, but they do not take into account the need of personalizing paths, tailored to the user profile and on the basis of user contexts. Adapted maps and personalized paths, related to touristic activities, are at the basis of the work presented in (Kurata, 2009). This system lets the user explicitly declare his/her preferences and computes a personalized path, guiding him/her in a planned tour. The user can rate the visited POIs, enriching his/her profile. According to it, the system can adapt the map, showing different kinds and number of POIs.

3.3 Profiling users

To provide personalized services, mPASS exploits a user XML-based profile, structured in three interconnected parts:

(i) the Urban Accessibility Profile (UAProfile), which describes user's preferences related to each urban accessibility barrier/facility;

(ii) the e-Accessibility Profile (eAProfile), which describes user's preferences related to the e-accessibility of the map;

(iii) the Basic User Profile which includes some more general data about the user, such as personal info, language, unit of measurement, device(s) in use, average speed and data about his/her credibility.

The UAProfile and eAProfile are not separated, but they are integrated in the same XML elements (as detailed in the next subsections). Moreover, the profile includes some more general and common data about the user, such as personal data, the language, unit of measurement (meters, miles, etc.), average speed and data about the his/her credibility. Obviously such latter data cannot be set up by the user, but they are computed and then stored into the profile by the mPASS Trustworthiness Manager Module, as described in Section 2.5.

TABLE 3.1: Barriers and facilites preferences

Preference	Description	Example
NEUTRAL	The user has neither difficulties nor preferences related to the aPOI type. The presence of this type of barrier/facility on a path is irrelevant to the user.	Stairs aPOI type is set as NEUTRAL in the profile of a young pedestrian or in the profile of a blind user.
LIKE	The user prefers aPOIs of this type, when they are available. The presence of this type of barrier/facility on a path is positive to the user.	Zebra crossings and traffic lights aPOIs are set as LIKE in the profile of a user who wants to follow a safe path or in the profile of a blind user.
DISLIKE	The user can face this aPOI type, but with some efforts. In this case, an alternative path is preferred (when available), but it is n ot necessary. The presence of this type of barrier/facility on a path is negative to the user.	Stairs aPOIs in the profile of an elderly user or uneven road surfaces in the profile of a wheelchair user are set as DISLIKE.
AVOID	The user cannot face this a POI type and an alternative path is necessary. The presence of this type of barrier/facility on a path prevents the user from following this path.	Stairs in the profile of a wheelchair user or obstructions in the profile of a blind user are set as AVOID

3.3.1 Urban Accessibility Profile

The Urban Accessibility Profile stores information about users' preferences related to each barrier/facility in the urban environment. In particular, users can define each aPOI as NEUTRAL, LIKE, DISLIKE and AVOID, as summarized in Table 3.1 and described in 2.4).

On the basis of these preferences, mPASS computes a route, which:

- comes across the LIKEd aPOIs when feasible;
- gets round the DISLIKEd aPOIs if possible;
- totally avoids the AVOIDed aPOIs every time.

The system provides users with different paths characterized by different lengths and different matches with the user's preferences. Then the user can choose the best path, in terms of barriers or facility, trustworthiness of aPOIs, number of collected reports and distance.

It is worth noting that users cannot set any facility as NEED, because some paths and urban areas can be fully accessible even without any support or accommodation. Selecting ways on the basis of hypothetical needed facilities would mean to exclude paths which do not need any of them to become accessible. When the path is not fully accessible without those facilities, the set of above mentioned values drives the algorithm to appropriate solutions. Let us consider, for example, the case of a wheelchair user who wants to reach a place located at the second floor. In this case, user's preferences related to stair are set to AVOID while user's preferences related to ramp and elevator are set to LIKE. The routing algorithm searches for a way to reach the second floor which avoids stairs. This path, if it exists, would include the liked facilities (ramps and/or elevators).

Moreover, positive preferences can be associated to barriers and negative preferences can be associated to facilities. As an example, a blind user can set as LIKE some specific barriers, such as stairs and steps, because they can represent a reference point.

Analogously, wheelchair users can set tactile paving as DISLIKE, because such surfaces can be uncomfortable for them. In the current version of our prototype, the profile is pre compiled on the basis of self-declarations done by users.

The screenshot shows the settings related to the GAP aPOI type done by a wheelchair user. More interesting is to investigate how to improve it by observing the user's behaviours. For instance, if the user likes to cross on zebras, the system could learn it and could assign the LIKE value to the "zebra crossing" aPOI type.

3.3.2 e-Accessibility Profile

The e-Accessibility Profile is devoted to store preferences and needs in terms of maps rendering.

The main selection is the one related to textual/graphical representation of the map and of the personalized path. On the basis of it, users can choose specific styles to represent aPOIs. For instance, the graphical representation can be personalized in terms of colors and size of the aPOIs icons in the map, addition of textual labels, visualization (show or hide) of aPOI categories or of aPOI types. In particular, the user can set up style rules for the whole mPASS application, for the categories (LIKE, DISLIKE, etc.) and for each aPOI. Such style rules work with a cascade mechanism, similarly to a style sheet. Hence, aPOI rules are stronger than categories rules, which are stronger than general application ones.

3.4 Map adaptation techniques

On the basis of the above described profile, mPASS customizes maps in order to meet the specific (and special) needs of users. Together with the user profile, adaptation is driven also by the trustworthiness of gathered data. Maps are adapted with the aim of providing users with (i) data related to barriers/facilities which impact on their paths; (ii) information about trustworthiness of such data; (iii) accessible information.

mPASS supports users equipped with mobile devices by providing them personalized accessibility maps, according to their preferences and needs, as set in their profiles. In order to reach this goal, some adaptation techniques are applied. Information about users' geographical coordinates and details about the chosen pedestrian path (i. the starting point, ii. the destination and iii. the aPOIs met during the path) are shown in the map. The visualization of the map is affected by the characteristics of mobile devices, in particular by the screens size (Setlur, Kuo, and Mikelsons, 2010b). In addition, the user can have some preferences and needs in terms of accessible visualization, that have to be addressed, so as to let him/her better exploit the map. In this context, effective rendering of information is very important. In order to personalize the rendering of urban accessibility maps, making them more accessible, we draw inspiration from a collection of perceptual cartographic techniques (Setlur, Kuo, and Mikelsons, 2010b) and we have taken into account some well known accessibility ones (Miesenberger, 2012b). The main adaptation techniques we have applied in mPASS are: Map-to-text, Exaggeration, Elimination, Typification, Color personalization and Textual detailing, as described in Table 3.2.

In particular, Elimination is automatically applied to aPOIs set as NEUTRAL: they are shown only if the user explicitly asks for them in the profile. In fact, some users can benefit from the rendering of neutral aPOIs, so as to better contextualize their position in the urban area (i.e., a blind user could ask for the textual rendering of stairs and steps, since they can be reference points). Moreover, Elimination is used to hide barriers and facilities which are classified as *absent* and facilities which are classified as *uncertain*, on the basis of the aPOI trustworthiness . mPASS applies Typification by showing the aPOIs as colored icons (letting users select and zoom them, so as to enjoy the related icon). Different shapes are exploited to give information about the trustworthiness of the aPOI : a dot means that the aPOI is classified as *present*, while triangles are used to show those barriers considered *uncertain*.

In order to prove the effectiveness of our approach, we tested our system with many different user profiles (such as users with reduced mobility, elderly people, blind users and users with low vision). In this section, we present a scenario which illustrates a user with special needs and preferences, who requests a personalized accessibility map, by using a smartphone. In particular, let us consider a male wheelchair user who asks for an accessibility map of a specific area in the city of Cesena (Italy). In Section 3.4.1 we detail his profile, while in Section 3.4.2 we describe his interaction with the mPASS app and how our

TABLE 3.2: Adaptation tecniques

Techniques	**Description**	**mPASS Application**
Map-to-text	A textual description of the personalized paths is provided to users	This technique is applied with the aim of meeting needs of visually impaired users and of users who contextually set such a preference.
Exaggeration	Size magnification and line exaggeration rules are used to increase special details and the visibility of the map objects.	This technique is applied to meet needs of users with low vision and of elderly people. It can also give emphasis to those elements that are interesting for the user in a specific moment/context.
Elimination	Map objects are selectively removed because they are useless or too small to be presented in the map.	Map objects are removed on the basis of their trustworthiness and/or users' preferences.
Typification	Feature density and level of detail are reduced while maintaining the representative distribution pattern of the original feature group.	Map objects are grouped and/or typified on the basis of their trustworthiness and/or users' preferences
Color personalization	Colors are set up by users. This technique consists of letting users set u p the colors background of the a POI icons.	It is applied with the aim of meeting needs of users with color blindness, users with low vision and elderly people.
Textual detailing	Labels and tables are shown to add readable details to map objects.	This technique adds details to mPASS map, such as sizes of the aPOI (ramp width or step height), aPOI credibility, notes, etc. It is applied with the aim of meeting needs of users with low vision, elderly people and users with cognitive disabilities.

system adapts and renders maps, showing paths personalized according to his needs.

3.4.1 User's Profile

The user has set up his UAProfile declaring that he LIKEs ramps and curb cuts (as gap facilities), parking slots reserved to people with disabilities (as parking facility), sidewalks with an adequate width (in the pathway category), zebra crossing and traffic lights (as crossing facilities). He initialized uneven road surface and tactile paving (in the surface category) as DISLIKE and Gap category APOIs and obstructions barriers as AVOID. Handrails and audible traffic lights are NEUTRAL for him, as well as street lighting.

In his eAProfile, he has set up NEUTRAL preferences as hidden and the other categories as shown and he has confirmed for default icons colors (green for the LIKEd APOIs, yellow for the DISLIKEd APOIs and red for the AVOID ones) and size. He also requested a specific set of style rules for sidewalks rendering, so as to hidden them in the map. Listing 3.1 depicts a fragment of such a user's profile. When this user asks for a path from the starting point A to the destination B, then mPASS computes personalized routes taking into account the user's profile (i.e. avoiding such barriers which affect him and including as much as possible the LIKEd facilities), the trustworthiness of the APOIs the user would meet along the paths, the distance and the estimated time.

3.4.2 Interaction and maps adaptation

Once the user asks for a personalized path, the starting point and the destination of the path has to be set up. Our user has already set up his profile and he has specified the starting point and the destination of his path. The mPASS system computes and proposes different personalized paths, with different characteristics (in terms of length and number of involved APOIs, grouped by categories). The user can set the number of personalized paths proposed by mPASS among which evaluates his favorite one and then he can start his path. In our case, the user has set the preference to choose among two different personalized paths. Figures 3.1 and 3.2 show the first and the second different maps (and paths) rendered on the mPASS system.

```
...
<neutral style="hidden"/>
<like style="ok"/>
<dislike style="warning"/>
<avoid style="alert"/>
...
<gap>
  <steps type="barrier" pref="avoid"/>
  <gaps type="barrier" pref="avoid"/>
  <stairs type="barrier" pref="avoid"/>
  <ramps type="facility" pref="like"/>
  <curbcuts type="facility" pref="like"/>
  < handrails type="facility" pref="neutral"/>
 ...
</gap>
  ...
<surface>
  <uneven_road type="barrier" pref="dislike"/>
  <tactile_paving type="facility" pref="dislike"/>
   ...
</surface>
...
```

LISTING 3.1: Wheelchair user's profile fragment

The user can take a look to each one of these three options. On the left it is rendered a map with the whole proposed path (in dark red), the starting point (marked with a blue circle) and the destination (marked with a dark red circle). Colored icons along the path are shown in the map, corresponding to collect

APOIs. Maps depicted in Figures 3.3 and 3.4 do not show NEUTRAL APOIs, as well as sidewalks, according to user's profile. In fact, the elimination technique has been applied to those kinds of APOI. Beside the maps, on the right, the user can move from one proposed path to another one. Details about the shown path are also available on the right, letting the user have more information about the proposal, so as to better choose the most adequate urban path. In particular, for each path is shown:

- The whole distance of the path (express in the unit of measurement as set up by the user). In our case, Path 1 is longer (650 meters) than Path 2 (600 meters).
- The estimated time to go through the path (express in terms of minutes), according to the average speed, as set up by the user. Such estimated values are 15 minutes in the first path and 14 minutes in the second one.
- A summary of the APOIs the user will meet in the path, grouped by their trustworthiness and according to user's preferences as he had expressed in the profile. Different colors (as chosen by the user) and shapes are used in order to mark such different groups. A number closed to the related icon shows the amount of that kind of APOI. In the first proposed path of our case study, the user would meet 14 APOIs with a hight trustworthiness (6 APOIs marked as LIKE, 6 marked as DISLIKE and 2 marked as AVOID) and 1 DISLIKE APOI with a low trustworthiness's value.
- The sum of the reports collected from all the different sources. In particular, there are 217 reports related to the APOIs of the first path, while there are 323 reports related to the APOIs of the second one.

The presence of AVOID and LIKE APOIs can greatly affect the choice of the user among the proposed path. Hence, in this phase, the user can select the APOI icon on the map, so as to better understand the characteristics of the proposed path. In particular, in the proposed paths of our case study, there are a LIKE and an AVOID APOIs closed to the destination. The user can select and enlarge the related icons, and then a symbol is shown, so as to let the user know the APOI type. In Figure 3.3, the enlarged red icon shows the presence of a stair, while Figure 3.4 depicts the map with an enlarged green icon, showing the presence of a ramp. Once the user has chosen the preferred path, he can click on the Start button, then the mPASS system renders the adapted map of the personalized path and it shows on the right the Zoom in and the Zoom out buttons and some textual additional information. Figure 8 depicts a screenshot of the chosen personalized path, showing a portion, while the user is going through it and he is asking for details about a DISLIKE APOI. On the right, beside the map, the user can exploit the APOI details, in particular:

- The APOI type (in this case: Uneven road, in the Surface category).
- The preference the user has set up in the profile for this kind of APOI (in this case: DISLIKE).
- The APOI trustworthiness expressed in terms of percentage (in this case: 51
- The number of collected reports related to this specific APOI (in this case: 15).

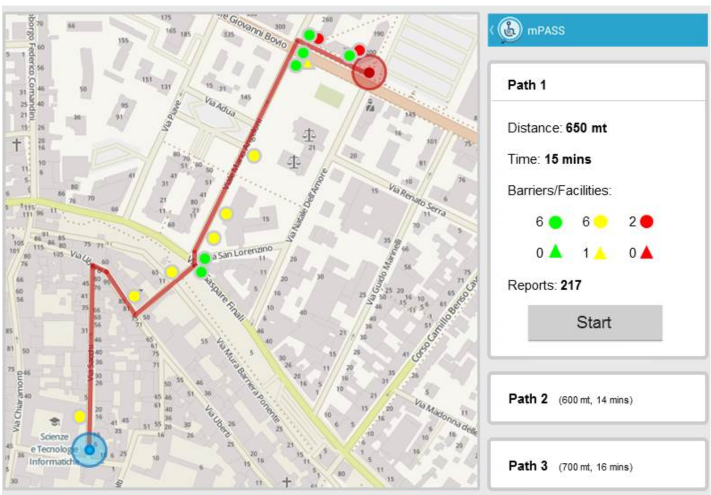


FIGURE 3.1: First proposed personalized path

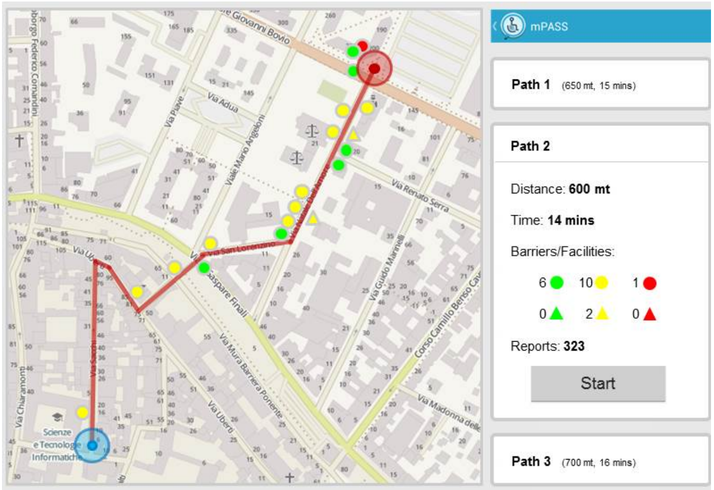


FIGURE 3.2: Second proposed personalized path

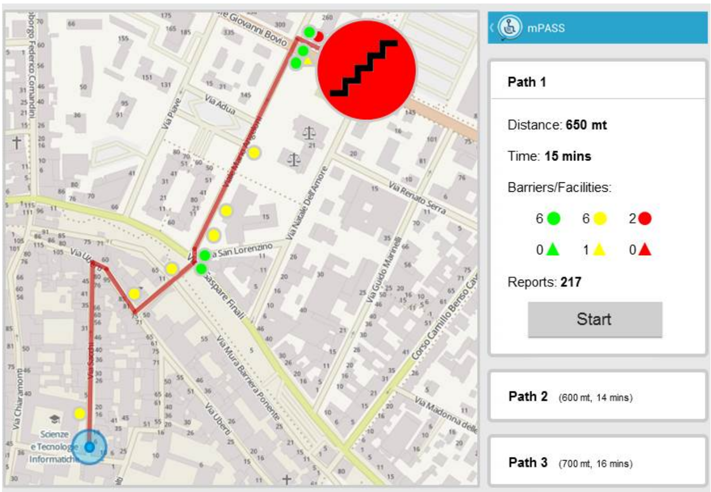


FIGURE 3.3: A path personalized for a wheelchair user with an enlarge aPOI icon

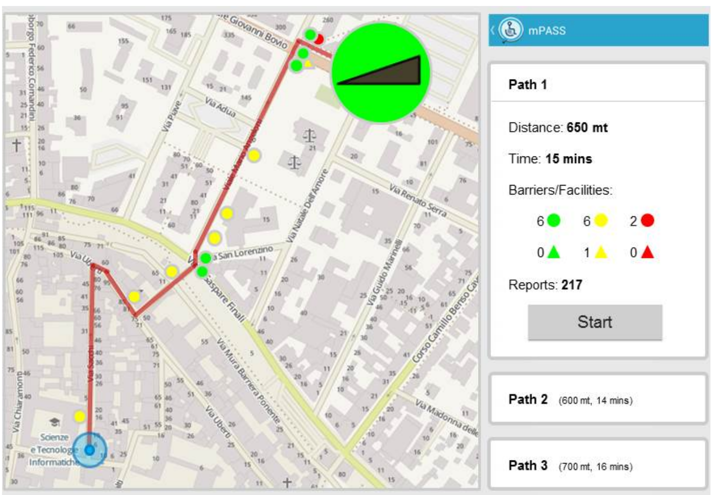


FIGURE 3.4: A detail of path shown in Figure 3.1

3.5 Conclusion

In this Chapter we introduced the profiling and customization strategies used in mPASS, so as to equip citizen with a mapping of urban accessibility and accessible way-finding. Maps and paths are customized to each user, on the basis of his/her location, his/her profile and the quality of data. A set of tailored map adaptation techniques has been used to provide users with an accessible map locating accessibility barriers and facilities. This Chapter describes a prototype we have developed and a case study, with the aim of showing the mPASS system at work. Some organizations supporting people disabilities have been involved in the mPASS design and development. Adaptation mechanisms can be applied to the user's profile, so as to dynamically modify it according to user's actual abilities, which can change during time. The idea is to exploit machine learning techniques and track users' behaviour while interacting with the map and with the urban environment. In particular, we are integrating a discrete-event multi-agent simulation library (MASON, Multi Agent Simulator Of Neighborhood) and a Q-Learning algorithm framework (PIQLE), with the aim of simulating users' behaviour and of evaluating how their profiles change.

Chapter 4

Gamification to involve and engage citizens

In this Chapter we present the design process and some interesting field trial results of different game applications, designed and developed in order to extend and motivate the community of a crowdsourcing and crowdsensing system. As particular case study, we employed mPASS in our research study.

The peculiarly of this system is that it needs a huge number of reports to calculate accessible paths. This is especially hard in mPASS since the main target population (people with disabilities) represents a small group of citizens compared with other communities. In addition, in order to evaluate data trustworthiness our system requires multiple mapping of the same urban element.

To overcome this problem, we investigated gamification strategies in designing mobile applications targeting young adults walkers, aimed to enlarge the data contributors community to the ones that usually are not interested in contributing in this kind of service. The design process and field trial results of both games are presented, highlighting the design decisions resulted from feedback sessions, focus groups and experience prototyping.

The reminder of this Chapter is organized as follows. Section 4.1 presents background and related work, while Section 4.3 presents design of the two gamified apps, from ideation to the experience prototype. The development of both mobile apps are described in Section 4.4 while Section 4.5 details some interesting trial field results analysing data from different prospective: the quantitative one and the qualitative one. Finally, Section 4.6 concludes the Chapter, discussing possible future works.

4.1 Background and motivation

As already mentioned, our work was inspired by the potential of pervasive computing and crowdsourcing to develop a system that provides citizens with customised accessible pedestrian paths. In order to calculate these personalize paths mPASS needs a whole updated picture of the accessibility urban elements in the environment (Mirri et al., 2014a).

A key factor for the success of any crowdsourcing system is the recruitment of a sufficiently large group of users to reach critical mass engagement. This is especially hard in mPASS since the main target population (people with disabilities) represents a small group of citizens compared with other communities.

In fact, the peculiarly of this system is that it needs a huge number of reports to calculate accessible paths. The collected data needs to be redundant (in order to evaluate data trustworthiness), reliable and updated to allow to provide accessible and effective services. On the one hand mPASS needs to collect a sufficiently dense, detailed and trustworthy amount of data. On the other hand, the community interested in obtaining accessible paths is not big enough to reach the critical mass of information needed by the system in order to provide effective services. To overcome this problem, we investigated gamification strategies in designing mobile applications targeting young adults walkers, aimed to enlarge the data contributors community to the ones that usually are not interested in contributing in this kind of service.

These requirements motivated the research questions described in this Chapter: i) how can mPASS involve and motivate a wide variety of citizens in collecting data about urban accessibility during their daily routines?; ii) how can the system provide a constantly updated picture of the accessibility barriers and facilities in the urban environment?; iii) how can mPASS obtain multiple validation reports that ensure the trustworthiness of data?. All of these research questions suggested gamification as a potentially interesting strategy to adopt. In fact, gamification is the use of game elements and mechanics in order to increase motivation in performing certain tasks (Seaborn and Fels, 2015).

Our intent was to use gamification to enlarge the community of mPASS users by recruiting people that are not directly interested or benefiting from the services provided by our system. We archived this goal by exploiting either intrinsic motivation (entertainment and/or social belonging) or extrinsic motivation (rewards) to engage a different target of citizens to map their surrounding location and report accessibility points such as zebra crossings, stairs, traffic lights, steps, disabled access ramps, etc..

In particular we deployed two different strategies:

(i) Gamify the mPASS data gathering app, in order to engage people in mapping data exploiting extrinsic motivation, by means of explicit rewards.

(ii) Develop a georeferenced pervasive game, in order to involve people using intrinsic motivation associated with curiosity, exploration, spontaneity, interest and fun.

In order to conceive and design the games, we adopted an iterative design process. We started by sketching a number of possible game concepts that would involve citizens in reporting barriers and facilities. Then, we organized sessions of feedback with fellow researchers and students from our institution in order to validate refine and select the best game concepts. Out of several generated game concepts, we selected two to be developed further into experience prototyping sessions. The experience prototyping enabled the understanding of the flow of the game, and the engagement of users. The games experience allowed us to capture improvements and suggestions from the users and it also highlighted practical logistical problems. Moreover, an interesting and unexpected concept emerged from the sessions: users surprisingly noticed their lack of awareness about the surrounding urban environment. After the experience prototype sessions, we developed the resulted two games and we conducted a field trail with a target of young and avid walkers and players, showing interesting results that prove the feasibility of our approach in involving a different community in mapping urban accessibility.

4.2 Related work

Our research draws inspiration from a wide variety of projects focusing on gamification. These include alternate reality games, pervasive games, games with a purpose (GWAP), serious games, exergames and gameful design. In particular, we have investigated how gamification concepts can be exploited in crowdsourcing and crowdsensing systems. This section briefly describes the most significant research in these areas, which are related to:

(i) gamification in crowdsourcing systems that can benefit people with special needs;

(ii) crowdsourcing system to collect data in urban accessibility.

4.2.1 Gamification in crowdsourcing system

In recent years there was a proliferation of research projects and systems exploiting crowdsourcing as human-computation technique to perform distributed and collaborative tasks. Crowdsourcing is recognized to be very useful for solving tasks that are hard or impossible to be solved by a computer (Hosseini et al., 2014; Pan and Blevis, 2011). The pioneering example was the EPS game (Ahn and Dabbish, 2004) develop by von Ahn. Other interesting examples are often related to the annotation and tagging of images, videos or web content with the purpose of improving the accessibility of web pages. For example, in the

ESP game the labelling of random web images with keywords is the basis of a simple online two-player game (Ahn and Dabbish, 2004). ESP is one of the first examples of a game with a purpose (GWAP), a game in which people, as a side effect of playing, perform some useful tasks through crowdsourcing (Ahn, 2006; Ahn and Dabbish, 2008).

Another example is the Phetch game (Ahn et al., 2006) that collects explanatory sentences (instead of keywords) for randomly chosen images. Phetch is a multiplayer game in which a player sees the image and helps other players to guess it giving a textual description of such image. The use of game mechanisms is a very important incentive to engage and motivate the crowd in performing voluntarily tasks of information retrieval (Harris, 2012). In projects like ESP (Ahn and Dabbish, 2004) or Phetch (Ahn et al., 2006), the game is used to motivate and engage people in playing voluntarily, just for their entertainment. The real purpose of these games is hidden in the game mechanism and users do not need to know it for playing.

Some games with a purpose have deep social values. For example HearSay (Borodin et al., 2008) is a non-visual web browser, where users collaboratively and voluntarily assign a label to each web page element using keyboard shortcuts or voice commands. These labels are stored in both local and remote repositories and shared with other users. The Social Accessibility project (Takagi et al., 2008) also operates on a voluntary basis of users. It involves crowd workers to externally modify Web pages adding accessibility metadata in a collaborative environment. Similarly, reCAPTCHA (Ahn et al., 2008) takes advantage of the people efforts in solving CAPTCHAs (Completely Automated Public Turing test to tell Computers and Humans Apart) to help to digitize books and newspapers. The Dotsub platform (*Dotsub* 2015) offers the option to engage the crowd for captioning video. Instead, the DVX project (Miele, 2012) crowdsources the creation and distribution of amateur video description, allowing sighted video viewers to verbally describe DVD and Internet-based media.

4.2.2 Crowdsourcing systems to map urban accessibility

During the past few years, crowdsourcing has been exploited also in several projects related to real-word context (Alt et al., 2010). In particular, different projects exploit accessibility issues. One example is the VizWiz smartphone application (Miele, 2012) where visually impaired people can take a picture using their smartphone, ask a question by speaking to the device, and then wait for a real-time spoken answers provided by paid workers on Amazon Mechanical Turk (*Amazon Mechanical Turk* 2015). A similar approach is adopted in (Hara, Le, and Froehlich, 2013) where workers from Amazon Mechanical Turk have to find, label, and assess sidewalk accessibility problems or bus stop locations and surrounding landmarks in Google Street View imagery.

Several projects were developed with the aim of collaboratively collecting data about the indoor and/or outdoor urban accessibility environment, such as AccessToghether (*Access Together* 2015) and AXSmap (*AXSmap* 2015). These tools allow users to collect accessibility information about places and services and display them in a map of the neighbourhood, using a mobile phone or a computer. Another example is Human Access (Kouroupetroglou and Koumpis, 2014), a mobile application that allows users to select a place using Foursquare and then to rate some attributes related with its accessibility. In Wheelmap (*Wheelmap* 2015) users can search, find and mark wheelchair-accessible places by the mobile application or the online map. Wheelmap is based on OpenStreetMap (*Open Street Map* 2015), a collaborative and free editable map of the world created by users. In (Cardonha et al., 2013c) the authors describe a platform that exploits crowdsourcing and crowdsensing to map outdoor accessibility elements in the urban environment. Another interesting work allows users to link accessibility annotations to geospatial data in order to compute a personalized route, considering the user's preferences and needs (Holone and Misund, 2008).

4.3 From ideation to experience prototyping

Drawing on studies on urban mapping crowdsourcing systems and on the role of playful elements placed at the service of our society, we designed three main goals guided our game design concepts:

(i) social belonging focusing on disability;

(ii) location-based entertainment;

(iii) daily health and fitness activities in the urban environment.

We adopted an iterative design process in order to conceive, refine and prototype the games. In this section with describe the outcomes of each phases involved in the design and prototype process, from the ideation by sketching of some game concepts, to the refinement of the most suited games through a series of feedback and experience prototyping sessions, in order to capture users feedback and explore the game flow.

4.3.1 Ideation

The creative process of generating new game concepts was driven to the main idea to transform the process of collecting and sharing data about urban accessibility into an entertaining task for a wide variety of users, extending the mPASS direct beneficiaries.

We started the process by brainstorming a series of possible urban games to engage a wide variety of walkers in mapping urban elements. We then explored each game concept considering different strategies to validate the sensing activity and the collected urban data. The outcome of the ideation session was the design sketch of three games, designed on the three above mentioned strategies.

A Geo-minesweeper game (based on the traditional minesweeper game) was designed to appeal to people who love walking and with a strong social belonging. In fact, such game would push users to explore the city (the game grid

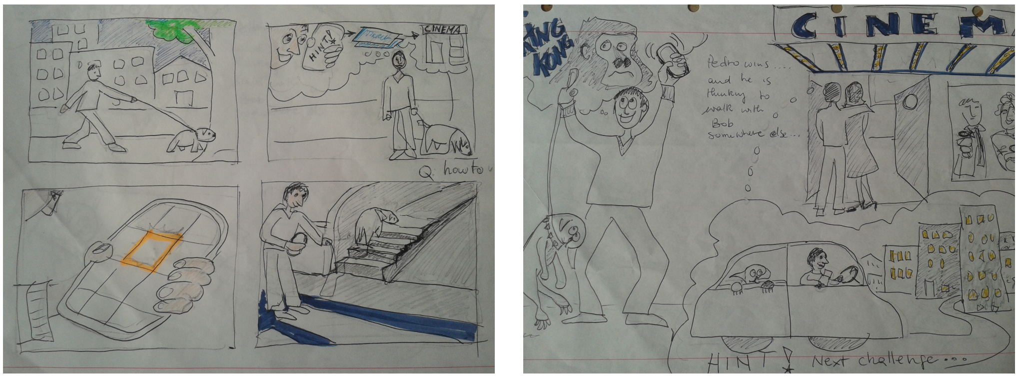


FIGURE 4.1: HINT! storyboards

is a area in the city map) and report accessibility barriers (that is the mines) in order to complete an urban path. If the player finds an aPOI and does not report it, he/she loses one game life and will have to start a new round of the game (like in the minesweeper traditional game). Our intent was to enhance feelings about social belonging, using the virtual mine as a metaphor: a mine, like an accessibility barrier for a person with disability, blocks the walker to reach his/her destination.

The second game concept was called HINT! (discovering your Hidden INTerest!). In this game the player has to guess the subject of the picture hidden under a specific area on the map. The more the player collects aPOIs via crowdsourcing and crowdsensing the more he/she obtains pieces of the puzzle in order to understand the subject of the pictures. The idea is to use different sets of pictures related to a specific topic (e.g. nature, animals, film, anime, culture, and so on) with the aim of enlarging the number of engaged player. When the user recognises the underlying picture, he/she obtains a voucher for the specific categories. We envisaged such game to appeal to the users who will strive to completed the puzzle and win the voucher, exploiting extrinsic motivation. In Figure 4.1 are shown two storyboard related to HINT! ideation.

A third game concept generated was called KidCom! (Short for Kids Competition). This game was designed to stimulate a treasure hunt competition among children. The game involves answering question regarding general knowledge of the city or specific topics set by the teacher. Answering questions unlocks hints for the participants, that will lead them to find a secret place. This game is beneficial for children because by playing, they can improve their feeling of awareness with the urban environment and understand which urban elements can influence (in a positive or negative way) the pedestrian urban mobility.

The fourth game sketched was Geo-Zombie. The goal of the game is to stay alive, avoiding to be eaten by zombies. While trying to do that the user is exploring the surroundings while providing location of aPOI for the mPASS application in order to get weapons and ammunitions to shoot the zombies. We envisaged that such strategy could engage people by exploiting the feeling of positive fear and challenges evoked by the zombies apocalypse.

After conceiving the rules and designing possible scenarios for such games and their users by means of personas and storyboards, we presented the concepts to an audience of researchers and HCI students. We collected their feedback in order to refine and improve the games, before proceeding to a structured focus group.

4.3.2 Focus group

After ideation we organized an expert focus group in order to: (i) assess the pros and cons of each game strategy in relation to our goals; and (ii) narrow the selection to one or two games, to bring forward to the deployment stage. The focus group was organized at the Madeira Interactive Technologies Institute and lasted around two hours and involved seven participants (all researchers with familiarity with gameplay, game design and interactive technologies). The focus group started with the introduction to the four game concepts through a series of slides. The discussion was open after each game concept presented, taking notes about comments and issues came to notice.

During the focus group the Geo-Zombie and HINT! games emerged out as the most engaging yet feasible ones. The Geo-minesweeper can have the side effects to correlate, in a wrong way, the positive behaviour of mapping accessibility elements with the negative one to mine the city. Moreover, it needs a very accurate GPS localization to avoid inconsistent gameplay. Instead, the game revolving around the children's competition (KidCom!) was discarded because kids required more motivation than just finding a secret location and it needs people involved in the game coordination and organization (like teachers and parents), making the game not suited to be played regularly. HINT! was criticized due the issues related to the copyright of the images but was appreciated the idea of using location-based voucher to motivate and engaged users.

We decided then to proceed with the experience prototyping of HINT! and Geo-Zombie, in order to assess if transferring the concept to a physical experience could reveal some unexpected findings.

4.3.3 Experience Prototyping

Experience prototyping is a technique borrowed from experience design and service design disciplines in order to test an experience or service in physical space and over time (Kean and Nisi, 2014). Such prototyping technique helps to refine the concept and the overall design of the experience before any investment is made in implementation details. Experience prototyping can be used in three critical design activities: understanding existing experience, exploring ideas, and communicating design concepts. We made use of the experience prototype to advance the design and understanding if the simulated game flow can motivate the walker in playing (and so, mapping aPOIs). By employing this method we were able to better understand the flow of the experience, the issues encountered by the participants as well as their feedback and desires regarding the game design.

In order to carry out an experience prototyping Geo-Zombie and HINT! we recruited four users who in turns tried both the games. For the Geo-Zombie, we prepared paper wireframes of the phone interface and physical zombies

(a) The killing of a zombie

(b) The puzzle voucher in HINT!

(c) The reporting of a zebra crossing

FIGURE 4.2: Pictures related to the experience prototyping

paper puppets to chase the users. To shoot the zombies we used a plastic gun recharge with water (ammunitions), see Figure 4.2(a). For the Hint! game we prepared the paper wireframes of the screens and a puzzle final voucher for the players (Figure 4.2(b)).

Subsequently we defined a series of tasks for the users to execute, and we tagged along them, taking notes and videos while they were playing the games. At the end of the experience a short interview was conducted with each participant. Our participants were all employees (faculty and staff) of the Madeira Interactive Technologies Institute, two female and two male, ranging from 25 to 45 years old, with some experiences in technology and gameplay. In particular, U1 a 45 years old Professor, U2 a 25 year old Master student, U3 a 30 year old PhD student and U4 a 33 year old accounting clerk and administrative manager.

We asked participants to carry out a ordinary task, something they could do in their daily live, where the gameplay would be an extra entertainment. In fact, we asked the users to compare the price of the coffee in the students canteen with the closest bar near the university. As suggested during the focus group, we asked users to report only one type of aPOI in each experience prototyping round, preventing users from being confused by paying attention to many different possible types of urban elements. In particular, during the Geo-Zombie experience prototyping, we asked users to report steps and stairs, while during the HINT! game experience prototyping, we asked for zebra crossings (see Figure 4.2(c)).

4.3.4 Geo-Zombie experience

From our observations and interviews we can confidently affirm that during the experience prototyping of Geo-Zombie all the four users had a lot of fun. Two of them enjoyed the game so much that they continued to play after the task was completed reporting more aPOIs in order to acquire more points and ammunitions. Two of the users surprised us by entering in a building as an escape technique to hide from the zombies. That technique was successful for survival and for reaching faster some aPOIs, located close to the building. Another unexpected behaviour of one user was to switch strategy after some gameplay: instead of running away from zombies he preferred to chase them. At the end this user, U1, said:

> *"I found the game become too easy, it needs more zombies."*

Such comment made us focus our attention on the number of zombies and on the level of difficulties that different players would enjoy. The same user also reported:

> *"After obtaining the gun, I changed my strategy: I really wanted to kill the zombie but I was still interested in finding zebra crossings because I was not aware that there are so many of them around this place."*

Such comment made us realise that being engrossed in the game, may also distract players from reporting aPOIs.

Another consideration of the player U1 regarded the travelling speed of the Zombies.

> *"Maybe different speeds zombies can make the game more exciting"*

.

All of the Geo-Zombie players were so immerse in the game to incremented their walking speed to escape from the zombie. In some case they even started to run. A player explained:

> *"There was immediately a zombie there, and I had to kill him or I would die. The game made me feel different... excited!"*

4.3.5 HINT! experience

The second experience prototyping involved the same four players that had been involved with Geo-Zombie. The players seemed less excited to play HINT! than playing Geo-Zombie. This was somehow expected, since the HINT! game was designed to appeal to a different audience, motivated by the extrinsic motivation (the voucher) instead than by the game itself. The voucher was provided in pieces, making each single piece available to users for each aPOI reported. Getting the pieces of voucher seemed to be a strong motivator for three players out of four (U2, U3 and U4). Nevertheless, U2 was not interested in the voucher and U1 was disappointed by the type of voucher gift he received at the end. He clarified in the interview that it is important for the voucher to be personalized and connected with the user interests. On the other hand, two other players were excited to get some free voucher of any sort. U2 found particularly motivating the idea of using a voucher and confirmed:

> *"I prefer playing HINT!. It was kind of easy to do, without someone that was trying to catch me... and I like the voucher thing. Geo-Zombie was too much "of a game" to have in my daily routine."*

Important to mention was a comment of player U1 that said:

> *"I felt very motivated about reporting aPOIs just for the interest I had in exploring the area and discovering them. It is the space that I had around for ten years and I was surprised about how many zebra crossings there are besides zebra crossings are so big so I cannot imagine to look for another things!"*

U4 highlighted a similar thought:

> *"Mapping in itself it is a strong motivation, more than the gameplay, because people become more aware about the space they are surrounded by and it is very important."*

A final important finding was the importance of revealing the real purpose behind the game, to increment the intrinsic motivation in mapping.

4.4 Prototype development

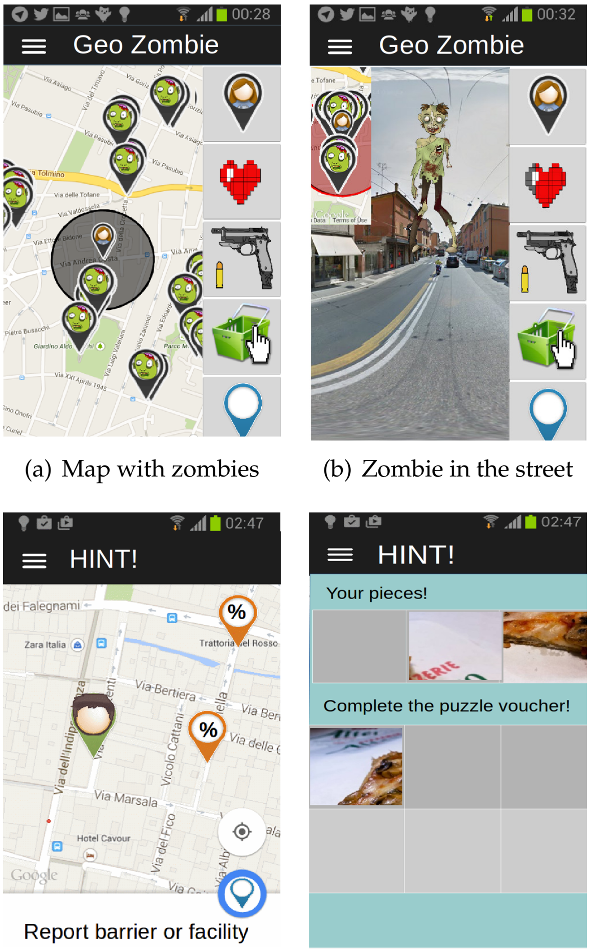
After integrating the feedback collected through the experience prototyping, we implemented both HINT! and Geo-Zombie. We tested the two multimedia apps on different smart devices running Android 4 or higher and iOS 7 and higher. Those smart devices feature a touch screen, a build-in GPS receiver, a camera, a accelerometer, a gyroscopic, and a Wi-Fi or cellular data connection capabilities. We wrote the software using web technologies (HTML, CSS and JavaScript) and the Cordova plugin APIs (*Apache cordova* 2015). We used Google Maps JavaScript API v3 (*Google Maps* 2015) to manage the position of the user (and zombies). The back-end part has been implemented as a RESTFull Web Services using Java 7 and the Spring framework. Data are stored in a PostgresSQL DB (*PostgreSQL* 2015), integrated with PostGIS (*PostGis* 2015) to enable support for geographic objects. The multimedia applications consist of three parts: (1)MAP, (2)WALK, and (3)PLAY.

Using the MAP function, people can document the urban accessibility environment, collecting data about barriers/facilities. To map an element, walkers need to choose the right category of the urban elements from a defined list and send this information together with its GPS position. Moreover, they can insert additional information (like description, notes and photos) and obtain more points. The MAP functionality is implemented in the same way in the two apps but it resulted in different rewards. It can be a voluntary action (the play decides to document the urban element) or it can the result of a system notification to confirm the presence/absence of the close barrier/facility. This feature has the aim of validating collected data and it can be used together with the sensing activity and the tracking of the user's paths to reinforce the quality of data and punished cheater players. Another mechanism implemented to limit selfish mapping is related to the points assignment: the more different walkers document the same barrier/facility, the more points they gain. The WALK function allows people to start the round, taking the GSP location and visualizing the current map (see Figure 4.3(a) and 4.3(c)). It is in this moment that the system starts to track the user's trace. The more players walk, the more they gain points as reward of the movement activity (physical and social).

Using the PLAY function, people can enjoy the apps. These two functionalities are implemented in different way in the apps on the basis of the various aesthetic components empathize in each one.

4.4.1 HINT! implementation

The multimedia game is focused on the reward (the voucher) so it has to reflect the user's interests and habits. In this first prototype, the system requires to complete a simple and not-detailed profile, due to the limited number of vouchers available. This profile becomes more customized on a specific user thanks



(a) Map with zombies (b) Zombie in the street

(c) Map with vouchers (d) The puzzle voucher

FIGURE 4.3: Screenshot of the developed prototype of Geo-Zombie and HINT!

the track of the user habits. In future, we intend to exploit recommended system based on users' on-line navigation to limited the filling manually and obtain a very detailed profile. The PLAY activity consists in collecting pieces of the voucher puzzle and then reorder them, composing the complete images. New shops (and so vouchers) are discovered based on the user's walked paths. It means that the more players walk - and wander -, the more vouchers they can obtain. Another benefit related to the Walk activity is to gain points to redeem with voucher pieces (see Figure 4.3(d)). Using the MAP activity people can document barriers/facilities and obtain points to spend buying pieces of puzzle voucher.

4.4.2 Geo-Zombie implementation

Using the WALK function, people start to play. To begin the round the system has to follows 3 steps: (1) obtain the GPS position of the player; (2) randomly create and locate zombies around the walker (with a maxim distance of one kilometre), and (3) orchestrate zombies using GIS-based routes, setting as their walk destination the player's GPS location. We used the Google Maps GIS routing algorithms.

Through the MAP function, people gain points to spend for ammunitions, weapons, and energy. During the mapping activity, zombies are stopped to facilitate - and not penalize - the walker. Thanks of the PLAY functionality, people see in the map their current position and the zombies one. Zombies walk at different speeds with the aim of catching the player, following the shortest path. When a zombie is close to the user (in an around of ten meters), the app visualization switches from maps to reality (camera view) and the user has to flush out zombie and shoots it, otherwise the zombie attacks, trying to bite (see Figure 4.3(b)).

4.5 Field trial results

After developing Geo-Zombie and HINT!, we ask to a class of fifty students enrolled on the Multimedia System Technologies course of the master degree in Computer Science and Engineering (University of Bologna, Italy), to experience them. We decided to recruit students in field trials who denote a target of avid player and walkers. The students attend courses in Cesena but they live in different cities, including Bologna, Cesena, Faenza, Rimini, and Ravenna. These cities have different densities and layouts, relevant factors in examining the variety of city urban environment. Students were free to decide if participate or not to one or more test fields. In fact, during the course, we asked the students to complete at least 6 class assignments on the 12 presented (as part of the final evaluation). We made the apps available to the students of the course and we monitored use by logging data in the PostgresSQL DB.

We studied approximately fifty students' use of the mPASS basic app, HINT!, and Geo-Zombie over three weeks (a week per app). The first week they could mapping barriers using the Basic app, a very simple multimedia app created to collect data about facilities/barriers in the urban environment. Using such an app, the user can easily map urban elements, sending information about the GSP location and the typology. To obtain the class assignment done, students just needed to download the multimedia app and map at least an urban element. The second week, they would be able to obtain a voucher with HINT!, that is, a valid class assignment, mapping at least 5 barriers/facilities. The last week they managed to fight with zombies using Geo-Zombie. As in HINT!, to obtain the valid class assignment, we asked for at least one urban element mapping.

After each field trial week, we involved students in filling a survey related to the trial app. The survey was composed of 16 items: 5 items related to the goals of the system, 10 items connected to the specific tried app, and one open question for comments and hints. The questions was inspired by the comments and issues emerged in the design process. We use the Likert scale (Likert, 1932) approach in ranking the firsts 15 questions based on a symmetric agree-disagree scale and we give the possibility to insert personal comments. We analysed resulted data from (i) a quantitative viewpoint and from (ii) a qualitative perspective, obtaining interesting results.

Quantitative results

On a quantitative view, a first element of interest is the fact that almost all the students of the class accepted our proposal and took the decision to participate (95%, approximately). While, this was reduced with the HINT! (47), a so large amount of students accepting to try to use both mPASS (48) and Geo-Zombie

TABLE 4.1: Quantitative results

Apps	N. of users	N. of report	N. of report per user (Average)	N. of report per user (Standard deviation)
mPASS	48/50	95	1.98	1.28
HINT!	47/50	311	6.62	3.56
Geo-Zombie	48/50	286	5.96	16.60

(48) version of our mobile application was not expected. Nonetheless, not surprising was the fact that the number of barriers/facilities documented using the mPASS basic app (95) resulted much lower than the amount of those reported through the use of either the HINT! (311) or Geo-Zombie (286) apps. This result can be easily explained with the consideration that both HINT! and Geo-Zombie apps supply concrete motivations to users to continue to play, while no external motivations exist that can encourage people towards a long term use of the mPASS basic app. All these numerical results are summarized in Table 4.1, along with the fact that the number of reports obtained with HINT! is comparable with those obtained with Geo-Zombie (311 vs. 286).

An additional interesting information portrayed in Table 4.1 is that almost all those users who played with HINT! made approximately the same number of reports (6 on average), while those who enjoyed Geo-Zombie provided mixed results. Precisely, 50% of them contributed with from 1 to 5 reports, while the other 50% contributed with more than 5 reports. These results are confirmed by: i) the high value of the standard deviation from the average number of reports per user measured for those who used Geo-Zombie app, and ii) the low value of the corresponding metrics for HINT!. This underlines a substantial difference between exploiting either fun/entertainment or a more concrete reward to motivate people to crowdsource accessibility data. In fact, while with HINT!, almost the totality of engaged students was driven to reach the threshold of five reports to have the assignment passed, with Geo-Zombie only those students intensely participated who felt emotively engaged by the multimedia gamified Zombie experience. Based on this preliminary result, one could guess that the amount of civic contributions that can be collected by offering a

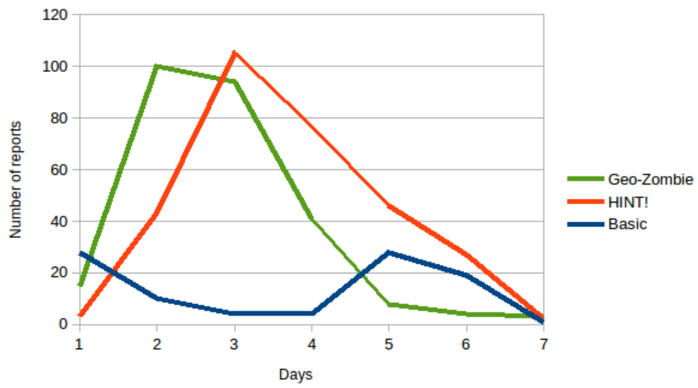


FIGURE 4.4: Number of report: evolution over time

concrete reward can be similarly obtained with a consistently lower amount of participants (approximately a half, in our case), provided that an emotionally captivating gamification strategy is adopted.

In summary, just using mPASS on its own we got to the lowest number or reports per person per week. While with HINT! we managed to significantly increase the number of reports: the voucher (extrinsic motivation) pushed a number of students to do at least 5 reports but, after obtaining the reward, they lost interest in mapping. We can assert this by observing the average number of reports for person that it is very close to the number of report required to obtain a class assignment as done (the voucher). With the Geo-Zombie game, we had an valuable increase in the number of reports and a high standard deviation value: this can be explained by the fact that some students just tried the game whereas others really felt engaged in experiencing the zombies game (intrinsic motivation).

To complete this discussion, Figure 4.4 shows the time dynamics through which the reports were obtained. Interesting here is only the fact that with both HINT! and Geo-Zombies a great part of the reports were collected within three/four days. This is easily explained based on the consideration that after a few days of urban exploration almost all the barriers/facilities, at a walking distance from the Computer Science Department, can be easily reached by quiet walkers.

Final and important considerations on a quantitative side can be derived also from an analysis of Figure 4.5. Each of these figures shows the geographical distribution of the barriers/facilities, present in one of the areas where our experiments took place, reported as either signaled (green dots) or not signaled (red dots) with respectively the Basic, HINT! and Geo-Zombie mobile app. To begin, we can observe the quite expected result that with the Basic app a lot of urban barriers/facilities remain undocumented (Figure 4.5(a)). Even more interesting is the result that the number of barriers/facilities detected with Geo-Zombie (Figure 4.5(c)) outperforms the amount of those intercepted using HINT! (Figure 4.5(b)). This fact has a very highlighting explanation that is as follows. If one considers the specific geographical area shown in our figures, she/he can discover that the Department of Computer Science is located in the northwestern sector of the map (top left, in the figures), while both the bus and the railway stations are placed in the southeastern section of the map (bottom right, in the figures). What happened with HINT! was that our students have privileged walking along their usual route from the stations to the Department (and back). This route amounts essentially to the line the transverses Figure 4.5(a) from its bottom right section to the top left one. With Geo-Zombie, instead, users favoured a form of non-destination-oriented walking over efficient, familiar routes. This is witnessed by the path connecting the northwestern sector of the map (top left) with the northeastern one (top right), whose barriers/facilities were signaled only by those walkers who used Geo-Zombie (Figure 4.5(c)). Finally, it is worth noticing that the two red islands approximately in the center of both Figure 4.5(b) and 4.5(c) are two internal courtyards, where the access to our students was prohibited.

4.5.1 Qualitative results

For the qualitative perspective, we analysed the students' answers in the surveys. Moreover, after the field trials, we also conducted short interviews with the participants in order to understand their feeling about the three apps. Some interesting - and sometimes contrasting - notion emerged related to different

(a) mPASS basic app

(b) HINT!

(c) Geo-Zombie

FIGURE 4.5: Existing barriers/facilities mapped (green) and not mapped (red) by the students

investigated design concepts. Not surprisingly, the first conception emerged from the interviews was the strong relation about the enjoyment of the multimedia app and the engagement in the mapping activity. Figure 4.6 shows the students' answers to the item "The mapping activity was boring", for each trial apps. As expected, comparing the results obtained from the three apps, we can reveal that almost all the interviewees found the Basic app too boring to be used frequently despite its social value, while different motivations were provided in support of the use of either HINT! or Geo-Zombies. Interesting results are related to HINT! if integrated with the quantitative data. The app is considered "neutral" (neither boring nor funny) by the 42% of the students, but this feeling didn't compromise their engagement in reaching voluntarily the voucher (a valid class assignment). This suggests that the most of the students were engaged by the curiosity in discovering the voucher. For example, a student

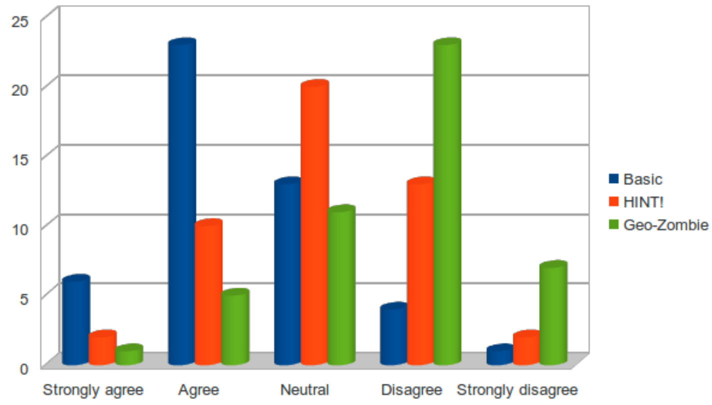


FIGURE 4.6: Students' answers to the survey item "The app was boring"

affirmed:

> *"I found HINT! more engaging that the Basic one, it was not funny, but I wanted the reward so I continued to report elements until I have achieved it!"*

Analysing the data in Figure 4.6, it is possible to notice that the 64% of the students found Geo-Zombie not boring. This result probably is related to the enjoyable sensation of positive fear perceived by students. In fact, a participant said:

> *"Playing with Geo-Zombie was really exciting! The idea of so many zombies ready to catch me was scary but at the same time, challenges! I liked that feeling!"*

According to this concept of positive fair, a student maintained:

> *"There was immediately a zombie there, and I had to kill him or I would die, the game made me feel differently... excited"*

Data in Figure 4.7 show an another interesting result strictly related with the concept of movement (physical and civic). In particular, with the mPASS basic app, students are not interested in changing their routine and their daily paths, and consequently, in expanding their mapping activity. Different results are obtained with HINT! and with Geo-Zombie. The use of gamification strategies

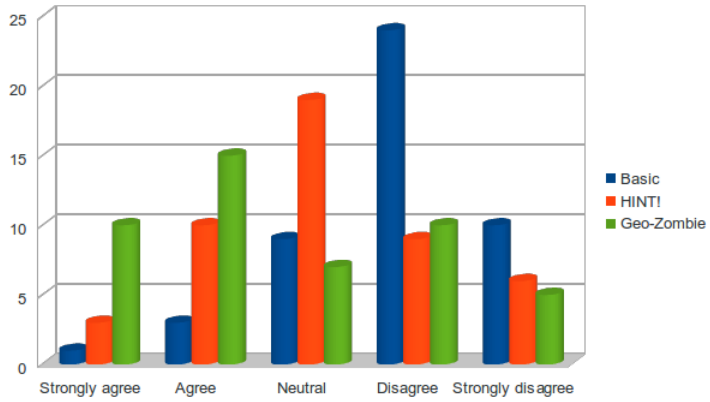


FIGURE 4.7: Students' answers to the survey item "I come out from my daily paths"

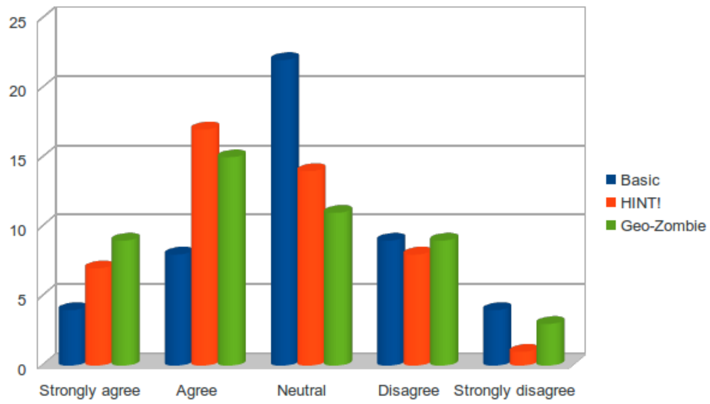


FIGURE 4.8: Students' answers to the survey item "I'm more aware with the presence of barriers/facilities"

seems to motivate participants to enjoy detours from their normal daily routines. In particular, it is very impressive that, by using Geo-Zombie, more than 50% of the students (22% strongly agree and 32% agree) explored new paths, broking their routine. This is probably a consequence of the game flow that allows players to forget about their daily habits in order to enjoy the game. A participant claimed:

> *"For the first time in three years I took a different route to reach the railway station as I had Zombies behind me, and I discovered a very interesting route, full of small food shops!!"*

In essence, with the use of Geo-Zombie, several participants broke the rigidity of their daily paths, urged by the need to escape from approaching zombies. Thus, in addition to exploring alternative walking paths, Geo-Zombie in some sense seems to have challenged the precise, algorithmic vision of those walkers who were used to follow always the same daily route. A complete contrasting aptitude was expressed by a student that was annoyed by the idea to be force in changing daily routines:

> *"I founded the zombies idea very cool but I do not want run away from zombies during my daily activities... I don't want run at all!"*

Another important aspect highlighted by the outcomes, is related to the awareness of the urban environment. As shown in Figure 4.8, Geo-Zombie and HINT! enforce the awareness of barriers/facilities in the urban environment, elements that are usually invisible in daily routine of avid walkers, and this is an important step in breaking boundaries of a (perceived) different community. Data show a correlation between the number of reports done and the awareness reached: (i) the Basic app obtained 1.97 average reports and an awareness (both Agree and Strongly agree answers) increased of 26%; HINT! got 6.60 average reports and an awareness increased of 51%, and, finally, (iii) Geo-Zombie obtained 5.95 average reports and an awareness increased of 51%. This emerged also from students' comments. For example, a participant emphasized:

> *"Using Geo-Zombie, I found a lot of unexpected urban elements that give problems to people with disabilities; just in the area which I supposed to know well!"*

It is worth noting that for the Geo-Zombie app, the Strongly agree answers are about 19% while they are about 15% in HINT!, witnessing an higher level of engagement in the Geo-Zombie game. In fact, some participants revealed that with Geo-Zombie they acquired an augmented amount of knowledge about the urban environment they used to live. According with the student's feeling:

> *"At a certain point, I was so worried about zombies that I started to walk quickly in the opposite direction to find news barriers! I really needed points to buy munitions... Zombies were so close to me!"*

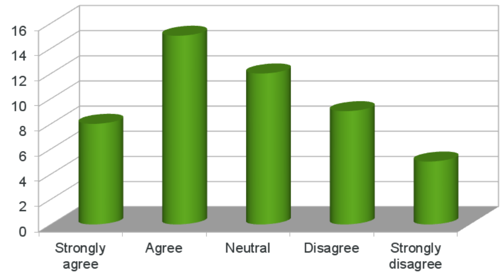


FIGURE 4.9: Answers to the survey item "I tried to kill the largest number of zombies"

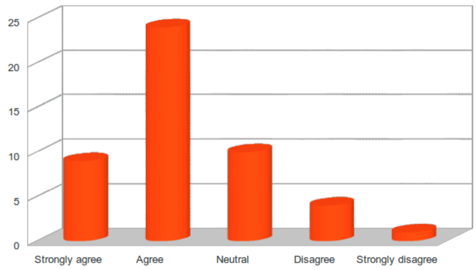


FIGURE 4.10: Answers to the survey item "I was just interested in obtaining the voucher"

This condition is the result of the game flow created by the pervasive game that allows to experience Geo-Zombie in a very immersive way, augmenting the focus on urban barriers/facilities. This outcome is also evident analysing data in Figure 4.9, related to the survey item *"I tried to kill the largest number of zombies"*. It reveals different reactions in students: some students loved the game flow and played a lot as effect of intrinsic motivation, and others did not (in agreement with the hight value of standard deviation obtained by quantitative data). The 47% of students have been pushed by the game flow in killing as many zombies as possible. Maximize the enjoyment for this kind of players is a key factor in incrementing the number of mapped accessibility urban elements.

A participant affirmed:

> *"I gained a lot of munitions in my neighbourhood just to walk versus the closer zombies and kill all of them! It was really funny!"*

In Figure 4.10, the question focused on the gamification element introduced in HINT!. As expected, it is possible to see that the most of students agreed to the

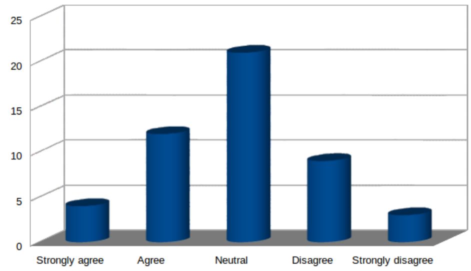


FIGURE 4.11: Answers to the survey item "The purpose of mPASS was really interested but I didn't feel involved in mapping urban accessibility"

question "I was just interested in obtaining the voucher". In fact, from the survey emerged a contrasting feeling about the real purpose of the app. Figure 4.11 shows the students' answers to the question "The purpose of mPASS was really interested but I didn't feel involved in mapping urban accessibility": students understood the importance of mapping urban accessibility but they didn't feel motivated in contributing.

4.6 Conclusion

In this Chapter we introduced our approach to the problem of engaging an important number of citizens in collecting urban data via crowdsouring and crowdsensing. Usually, in this kind of crowdsourcing system there are few users that collect most of the data. This is a problem for mPASS that needs a wide audience of users to validate the mapped elements and avoid errors, which cannot be limited to people who directly benefit from the mapping activity. To support the effectiveness and the trustworthiness of the data collection, it is necessary to attract different targets and enlarge the system community. With this in mind, we adopted gamification strategies in order to conceive and design few location based games that would engage a wide variety of users in mapping urban accessibility, exploiting intrinsic and extrinsic motivation. Through a design process of ideation, concept validation, focus group and experience prototyping, we evaluated the game concepts, captured players reactions, comments and preferences before starting with the coding process. The two best suited and well received games, HINT! and Geo-Zombie are being developed and tested. The results show the viability of our strategy in adopting gamification (and pervasive game) to enlarge the community of mPASS. Moreover, the outcome show that the game flow, together with intrinsic motivation, are two key factors to investigate to captivate users in crowdsourcing mapping activities.

Chapter 5

Data trustworthiness and user credibility

This Chapter presents the mPASS trustworthiness model, which is devoted to assess the actual presence/absence of facilities and barriers. Trustworthiness associated to each barrier/facility is computed on the basis of the credibility of each single user (and more generally each single data source). The system assesses trustworthiness of a specific barrier or facility by combining the credibility of all the sources reporting it. If trustworthiness of the barrier/facility is under a certain threshold, then it is considered as the product of some misinformation and it is ignored. The user's credibility is assessed based on his/her behaviour, by using a combination of majority voting and gold set techniques. The gold set is represented by authoritative data which are considered all time totally trustworthy and work as point of reference in order to evaluate users' credibility. Moreover, a majority voting mechanism comes into the picture when authoritative data are not available. The more the user correctly reports barriers recognized by the gold set or by a majority of the other users, the more his/her credibility grows. To assess our model, we conducted extensive agent-based simulation. We considered different scenarios, which demonstrate that the use of crowdsourcing and crowdsensing is efficient to identify barriers and facilities.

The remainder of this Chapter is organized as follows. Section 5.2 presents the background and related work, while Section 5.3 presents the assessment of the trustworthiness model mPASS. Section 5.4 presents results of a simulation of the assessment system. Finally, Section 5.5 concludes the Chapter.

5.1 Background and motivation

Collecting georeferenced data by using crowdsensing and crowdsourcing has become the main stream to provide a smart way of finding personalized services (Dua et al., 2009a). As already mentioned, our aim is to exploit this methodology of gathering information, combined with the use of a profiling system, which tailors the computed paths to the user preferences and needs.

The use of multiple sources of information permits to map the urban environment with data which are dense enough to effectively provide a tailored and detailed route. Density of data is essential to ensure the effectiveness of the service and meet the actual user's requirements. The more the available information the more likely to identify accessible routes for the specific user. It should be clear that in this context, trustworthiness of such data is a key challenge (Mashhadi et al., 2012). Tailored paths computed on the basis of inaccurate crowdsourced or sensed data might be useless or, in some cases, dangerous for the users. In computing accessible routes, untrustworthy data can generate cases of undetected barriers as well as cases of detection of not existing ones, adding challenging situation to the user scenario (Mirri, Prandi, and Salomoni, 2014a).

It is also important to consider that differently from subjective information/review about specific services and places (e.g. restaurants, shopping malls or airports), data about urban accessibility are objectively measurable. Barriers to accessibility, as well as facilities for pedestrian safeness, are located in a place or not; if yes, they have specific measurable characteristics and proprieties (Carvalho, Heitor, and Cabrita Reis, 2012). When these barriers/facilities are evaluated by authoritative data sources (e.g. people working for authorities and organizations), they are measured as they are and they can be considered totally trustworthy. Unfortunately, such a kind of information is quite poor, because of the lack of a real census and monitoring, or because information updates are not rapidly collected. Therefore, these evaluations are too few to be significant in effectively computing a route. To overcome the lack of density in collecting data, many systems use crowdsourcing to gather information about barriers and facilities (Song and Sun, 2010). In these cases, density of data is better addressed by involving a large number of people, mainly volunteering in gathering data about accessibility due to their direct interest in such information. Some other communities are motivated in contributing to crowdsource data about urban pedestrian environment by their knowledge on local environment. Motivations and expertise are key factors in defining the source credibility of each one of the volunteers. Besides crowdsourced data, some VGI (Volunteered Geographic Information) and georeferenced applications use sensors embedded in consumer electronics devices (including tablet PCs, smartphones and smart watches) (Venanzi, Rogers, and Jennings, 2013). The large availability of such sensor-equipped devices and their accuracy make information gathered from sensing a good opportunity to improve density of data about urban accessibility.

mPASS aims providing users with personalized paths, computed on the basis of user profiles and the accessibility facilities/barriers present in the environment. To perform this task, mPASS needs a set of georeferenced data that is trustworthy enough to avoid false positives and negatives, e.g. to prevent users from encounter on their path an unknown barrier or a non-existing facility. With these needs for trustworthiness and density in view, mPASS combines data gathered by users and sensors, with information produced by disability organizations and local authorities. We propose a method to evaluate trustworthiness of data, combining accuracy of sensors, source credibility of the crowd and the authority of experts. To assess the effectiveness of our trustworthiness assessment, we conducted a set of simulations on trustworthiness of data and credibility of sources, obtaining interesting results.

5.2 Related work

In this section we introduce some related works concerned with veracity, trustworthiness and credibility, with a specific focus in VGI and georeferenced systems and in social media, by comparing them with our mPASS system.

5.2.1 Veracity, Trustworthiness and Credibility

Reporting quality of social media and crowdsourcing information (and of its sources) can be related to the more general quality problem of Web resources (Schlieder and Yanenko, 2010). Research made in the field of Library science has identified different criteria such as authority (Is the author qualified?) or currency (When were the facts last checked?) that can help users to decide whether or not to trust a resource (Beck, 1997). However, these criteria directly address a knowledgeable human reader and are not designed to automate the evaluation process. But in several contexts, such as social media and VGI scenarios, the criteria of evaluation need to be cast into a computational form (Schlieder and Yanenko, 2010). The terms veracity, trustworthiness and credibility are often used in such contexts, to describe and address the quality of information and its sources. In this subsection we aim to clarify the meaning of such terms, as they can be used in VGI and georeferenced systems and in social media. It is worth noting that they are strongly related each other and they can be used as synonymous in many contexts. Generally, veracity is defined as the conformity to truth, which involves the truthfulness and reliability of data and information (Yin, Han, and Yu, 2008). The author of (Gal, 2014; Artikis et al., 2012; Daly, Lecue, and Bicer, 2013) emphasized the importance of veracity in data integration, for instance whenever integration of news feeds from social media is needed, in particular in the field of big data: since social media is an important source of big data, then big data integration has to couple with the veracity of data. In (Yin, Han, and Yu, 2008), the authors proposed veracity as the study of how to find true facts from a large amount of conflicting information on different topics, which is provided by different online data sources (in particular Web ones). A data source is considered trustworthy if it provides many true information, and an information is likely to be true if it is provided by many trustworthy online data sources. Veracity can also be understood as a characteristics of users, when they act as a source of information (Okolloh, 2009; Schlieder and Yanenko, 2010). In this sense, some works (Okolloh, 2009; Keßler, Janowicz, and Bishr, 2009) permits the assignment of a veracity value to users who provide information, by expressing the degree of trust in the author or in the content of the authored information. Hence, the veracity of users reflects the quality of the information they authored and it is strongly related to the reputation of the user (Bishr and Mantelas, 2008). Reputation and trustworthiness of information are important issues in crowdsourced and social media (Gupta and Han, 2011; Bertino, Dai, and Kantarcioglu, 2009) and they are at the basis of several works and of online systems, such as e-commerce and marketplace sites (it is obvious that no user will spend money at an untrustworthy online store or will buy anything from another user with a low reputation score) (Lanford and Hübscher, 2004; Serva, Benamati, and Fuller, 2005), recommendation systems, reviews and rating systems and knowledge sharing ones (Al-Dabbous, Al-Yatama, and Saleh, 2011). Similarly to veracity, trustworthiness is often referred to measure and quantify the quality of information coming from online resources and systems (Pattanaphanchai, O'Hara, and Hall, 2013). Several studies have been conducted with the aim of supporting users in quickly judge the trustworthiness of the information, providing automatically computed values, which can be continuously updated (Pattanaphanchai, O'Hara, and Hall, 2013; Golbeck, Parsia, and Hendler, 2003; Zhang, Chen, and Wu, 2006). In (Flanagin and Metzger, 2008), credibility is defined as the believability of a source or of a message, which is composed of two primary dimensions: trustworthiness and expertise (Burgoon, 1976; McCroskey and Young, 1981; Mo, Zhong, and Yang, 2013), and it can be related to the reputation of the source or of the message author. It can be further broken down into many components such as source credibility, message credibility (independent of the source), and credibility of the media through which the message was sent (Metzger et al., 2003). We have based our data model on those previous definitions, taking into account on the one hand that users' credibility is usually conceived as possessing at least some degree of both trust and expertise in combination. On the other hand, we intend trustworthiness (and veracity) when we deal with information and data (e.g. reports) provided by users and by other kind of sources (e.g. sensors).

5.2.2 Trustworthiness and Credibility in VGI and georeferenced systems

In this subsection we introduce some related works concerned with trustworthiness and credibility in VGI and georeferenced systems. As concerns trustworthiness in spatial crowdsourcing and georeferenced systems, (Shahabi, 2013) emphasizes that trustworthy computing has been successful in developing techniques to avoid any malicious software to manipulate the sensed data before sending it to some servers. To tackle the issue of trusting the user who provides the data (as a data source), the author provides a framework called GeoCrowd (Shahabi, 2013), which is equipped with a reputation score per user. Similarly, in our approach we assign a credibility value to users. Such a value is continuously updated, according to the information the user provides to mPASS (by means of reports on points of interest and of answers to the mPASS notification system). An interesting technique has been proposed in (Mashhadi and Capra, 2011): in this work the quality of data provided by users is estimated on the basis of the user mobility. The same is for their trustworthiness score, which is obtained on the basis of past contributions by the user him/herself. Thus, the main idea is to evaluate and to assign a value that express how much the user is familiar with certain locations at a given time. Moreover, user's credibility is computed on the basis of his/her past interactions with the ubiquitous and geo-referenced crowdsourcing application, with the aim of reflecting the usefulness of his/her past contributions as seen by other users. Hence, in this work these two information are combined together so as to compute a credibility weight of each user. In addition, the authors of (Mashhadi and Capra, 2011) focus both on data integrity (for those data which came from automatic readings from devices, as in participatory sensing systems) and data correctness and quality (since data coming from VGI systems are more subjective and can include users' opinions) (Mashhadi et al., 2012). Taking into account all these values (in particular, regularity and reputation), (Mashhadi et al., 2012) compares the user's contributions with those ones provided by local experts (i.e. the highly regular users at a specific point of interest, with a specific geolocation), hence it is possible to exploit local experts' experiences in those situations where there does not exist a benchmark comparison. Users' regularity and familiarity with a specific location are also at the basis of the model proposed in (Bishr and Kuhn, 2007; Bishr and Mantelas, 2008). Similarly, in mPASS, we exploit the idea of regularity in terms of affectability of users in participating and cooperating through mPASS, by means of a notification system, so as to solve those situations where uncertain data are present. Other differences between these works (Mashhadi and Capra, 2011; Mashhadi et al., 2012; Bishr and Kuhn, 2007; Bishr and Mantelas, 2008) and our system are that we do not need to evaluate users' familiarity with locations, and moreover, in our data model we have some authoritative information provided by experts (i.e. local administrations, municipalities, etc.). In mPASS, such authoritative information is considered as a gold set. The idea is to compare information provided by users with (already known) correct and trustworthy data, so as to compute and assign users a more effective credibility value, similarly to other works, e.g. (Vuurens, Vries, and Eickhoff, 2011). Some studies in participatory sensing have tried to solve the trust issue by incorporating a trusted software/hardware module in the users' mobile devices (Dua et al., 2009b; Gilbert et al., 2010). While this can protect the sensed data from malicious software manipulation on the client-side, it does not protect the data from users who either intentionally (i.e., malicious users) or unintentionally (e.g., making mistakes) provide wrong information about points of interest in a specific location. Moreover, these approaches work only for sensed data and cannot be generalized to any type of data (e.g., VGI and crowdsourced ones). Thus, while of main interest, this approach cannot be adopted in the scenario of mPASS, where crowdsensed data are combined with crowdsourced and with authoritative ones. The authors of (Venanzi, Rogers, and Jennings, 2013) defines a model to address the problem of fusing untrustworthy reports provided from a crowd, while simultaneously learning the credibility of each single user. In this paper, the authors focus on the unreliability of crowdsourced data which presents challenges when multiple reports of the same issue have to be fused together, showing how the wide diffusion of georeferenced mobile applications has provided a new prospective on this problem. In fact, people using their smartphones are equipped with a number of different sensors that can be exploited to collect data, as well as the users themselves, who can voluntarily provide georeferenced information. In particular, (Venanzi, Rogers, and Jennings, 2013) models user's credibility as an uncertainty scaling parameter of the user's estimates; such a value represents the trust degree of the beliefs from data and it is learnt and continuously updated. Similarly to this work, our system assigns an initial credibility value to each user, which is re-computed according to data coming from user's behaviour. Hence, our system learns the credibility degrees of users. Moreover, we take also into account and combine together the accuracy of sensors and the credential authority of experts.

5.2.3 Veracity and Trustworthiness in crowdsourced and in social media

In this subsection we introduce some related works concerned with trustworthiness and veracity in crowdsourced and in social media. The proliferation of crowdsourcing systems and social media posed the problem of identifying false claims and manipulations in user-generated content and of modelling information source trustworthiness. Several interesting works exploit methods based on transfer learning and supervised learning methods (Mo, Zhong, and Yang, 2013; Zhao et al., 2013; Raykar et al., 2010; Ipeirotis, Provost, and Wang, 2010), taking into account gold set or majority voting techniques or combinations of them (Chamberlain, 2014), with the aim of annotating the content, so as to identify trustworthy information and to avoid the noisy ones. In this sense the problem can be strongly related to the need of annotate all the social media content, in an automatic way. This challenge can be addressed by using machine learning techniques to train a classifier on a small subset of already annotated information, and then use it to annotate the other information (Pang, Lee, and Vaithyanathan, 2002). In more recent research and projects, acquiring annotations via crowdsourcing has become a common issue (from a group of volunteers or through micro-task markets, such as Amazon's Mechanical Turk) (Ipeirotis, Provost, and Wang, 2010). In this context, (Raykar et al., 2010) addressed the problem of training a supervised learning system in the absence of ground truth data, when all that is available is noisy label information from non-expert annotators. They estimate the sensitivity and specificity of each of the annotators, and also annotate unlabeled examples. All the work requires prior information such as prior knowledge about each labeler or the difficulty of each example. In real-world applications, this can be a non-feasible problem when tasks start up on the Internet (Zhao et al., 2013). Some of these works assign a score to the classifiers (Raykar et al., 2010; Ipeirotis, Provost, and Wang, 2010; Mo, Zhong, and Yang, 2013), with the aim of evaluate their credibility. In particular, the authors of (Ipeirotis, Provost, and Wang, 2010)propose an algorithm to separate bias and error, so as to generate a scalar score representing the inherent quality of each user. Users can provide the system with different kinds of answers and information, corresponding to different levels of correctness and precision. The assigned score to each user has to reflect these values. Similarly, in mPASS users have to deal with Boolean values (representing the presence or the absence of a barrier/facilities); hence, our trustworthiness model reflects this situation.

5.3 Trustworthiness Assessment

mPASS DB collects reports on aPOIs, obtained from authoritative sources, users and sensors. As already mentioned, not all the gathered data are totally trustworthy, e.g. the assessment of each report can vary, depending on the type of source and its characteristics.

5.3.1 Unreliable data

Each aPOI is evaluated based on reports obtained from one or more sources that might have different levels of trustworthiness. In particular, starting from the whole set of reports related to a specific aPOI, mPASS has to determine if a reported barrier or facility exists or not. This information is needed both to compute personalized routes and to show accessibility map of a specific area.

Since untrustworthy reports are used, mPASS can generate two different types of error (as summarized in Table 5.1), with different consequences, based on the aPOI characteristics (i.e. barrier or a facility):

1. *False negative – undetected existing barrier*: in this case the system might produce paths or maps without considering the presence of an existing barrier.

2. *False negative – undetected exiting facility*: in this case mPASS can suggest paths without taking into account the facility. A less accessible route can be suggested to the user, instead of the best possible one.

3. *False positive – non-existing barrier detected*: in this case mPASS might avoid an accessible path due to the incorrect detection of the non-existing barrier. Thus, it could suggests longer route or a route that is actually less accessible than the discarded one.

TABLE 5.1: Errors due to unreliable reports

<table>
<tr><th></th><th>False Negative</th><th>False positive</th></tr>
<tr><td>Barriers</td><td rowspan="2">Undetected existing aPOI</td><td rowspan="2">Non-existing aPOI</td></tr>
<tr><td>Facilities</td></tr>
</table>

4. *False positive – non-existing facility detected*: in this case the system might suggest a route considering it as adequate, because of the wrong detection of the non-existing facility. If the facility is needed by the user, this can prevent him reaching his destination.

It is worth noting that all the four types of error can cause difficulties to users, but cases 1 and 4 are more critical, because they can prevent the user from reaching his goal or destination.

5.3.2 Report trustworthiness

In mPASS, the presence/absence of an aPOI is computed on the basis of the whole set of obtained reports. Each report r sent from a user has associated a real value that represents its trustworthiness, $T(r) \in [0, 1]$ where 0 means that the source is totally unreliable, while 1 is used when the source is totally trustworthy. The trustworthiness of a report depends on the type of source. Basically, mPASS considers 3 types of reports: authoritative reports r_a, users reports r_u and sensors reports r_s and their trustworthiness is assessed in three different ways, as follows.

r_a trustworthiness. Authoritative sources are totally trustworthy by definition, they have the knowledge, the expertise and the tools needed to do a proper evaluation of each type of barriers and facilities (Flanagin and Metzger, 2013). As a consequence, the trustworthiness of each authoritative report is set as 1: $T(r_a) = 1$. The presence of an authoritative report overcomes all other reports and automatically states the aPOI real condition, at a given time. aPOIs reported by an authority are marked as KNOWN and are used to evaluate trustworthiness of other data sources.

r_u trustworthiness. Trustworthiness of a user report, $T(r_u)$, is defined on the basis of his/her credibility (Flanagin and Metzger, 2013). Users can provide very accurate reliable evaluations, but they can also provide (intentionally or not) wrong evaluations. For example, we can generally consider users with disability as very credible ones: they are interested to get correct data from the system and they are able both to add accurate reports and to identify relatively easily missing or incorrect information (Metzger and Flanagin, 2013). At the same time, we have to consider users that have too few expertize or motivations to do accurate evaluations and users who add wrong reports with the aim of damaging the service (Venanzi, Rogers, and Jennings, 2013).

The credibility of a user $C(u)$ is represented as a real number ranging from 0 to 1 (0 means "totally untrustworthy", 1 means "totally trustworthy"). When the user joins the mPASS system, $C(u)$, is set to UNKNOWN; to state it to a continuous value, we use the following procedure. $C(u)$ is derived by checking, for each report done by the user u, if the declared information (i.e. the aPOI presence/absence) matches with the r_a report value, or, if not-available, with the majority value of r_u reports. This step is iterated for every aPOI the user has reported. Then, $C(u)$, is computed considering the number of reports done by the specific user u assumed "right", compared to the total number of reports (done by u) hitherto. This process is periodically iterated in order to better assess the user's credibility and follow his/her evolution, according to his/her report history. Every time a user sends a report, the report trustworthiness, $T(r_u)$, is set according to the credibility of that user, $C(u)$, at the time the report is done:

$T(r_u) = C(u)$ (at this time).

r_s trustworthiness. Trustworthiness of a sensor report, $T(r_s)$, is computed on the basis of its accuracy $A(s)$. We have to consider that, in this context, sensors do not have to measure a value in a continuous range, but they have to state the presence/absence of a condition. Different research works state the feasibility in using sensors to detect elements in the urban environment (Chugh, Bansal, and Sofat, 2014; Bujari, Licar, and Palazzi, 2012b). For example, let us consider the sensing app developed in the mPASS prototype: it senses stairs and steps by comparing data resulting from the smartphone accelerometer with known patterns. The actual detection of a barrier/facility depends from many factors, first of all barriers/facilities to sense: for instance, sensing single steps is more difficult than sensing a stair. Other aspects that strongly influence the sensor accuracy are the user him/herself and the way he/she walks or runs, his/her speed, or where he/she has the device (e.g. in the hand, in the pocket, in the bag) and the device in use. All these variables let us to assess the sensor accuracy value, $A(s)$, as a real number ranging from 0 to 1, using the same procedure described for the user's credibility to improve it when the sensor joins the mPASS system. Every time a sensor adds a report (r_s), to the mPASS DB, the report trustworthiness, $T(r_s)$, s set to the accuracy of the sensor: $T(r_s) = A(s)$.

5.3.3 aPOI trustworthiness

We define the trustworthiness of an aPOI, $T(aPOI)$, as a boolean value that states the presence or absence of the specified $aPOI$. To asses this value ($true$ or $false$) we need to compute $T(aPOI)$ as a real number obtained considering each $T(aPOI)$ value related to the specific aPOI; the result is a continuous value ranging from -1 to 1, computed as follows:

- If a r_a report is present, stating the presence of the barrier/facility: $T(aPOI) = 1$.
- If a r_a stating the absence of the barrier/facility: $T(aPOI) = -1$.
- In all the other cases, trustworthiness of the aPOI is the average value of all the reports trustworthiness, considering them as positive if they state the presence of the barrier/facility ($T(r_s+)$) or as negative if they state the absence of the barrier/facility ($T(r_s-)$).

$$\frac{T(aPOI)=(\sum T(r_s+)+\sum T(r_u+))-(\sum T(r_s-)+\sum T(r_u-))}{\#r}$$

TABLE 5.2: aPOI trustworthiness values

Boolean Value	**Continuous value**	**Description**
TRUE	T(aPOI) = 1	The barrier/facility related to that aPOI is present
	0 < T(aPOI) < 1	All the positive values represent different grades of trustworthiness about the presence of the barrier/facility
FALSE	-1 < T(aPOI) < 0	All the negative values represent different level of trustworthiness about the absence of the barrier/facility
	T(aPOI) = -1	The barrier/facility related to that aPOI is absent

where $\#r$ is the total number of reports available for the specified aPOI.

It is worth noting that the positive component of the expression $(\sum T(r_s+) + \sum T(r_u+))$ sums all the trustworthiness related to users and sensors reports that evaluate the barrier/facility as present. In the same way, the negative component of the expression $(\sum T(r_s-) + \sum T(r_u-))$ sums all the trustworthiness related to users and sensors reports that evaluate the barrier/facility as absent. As a consequence of this definition, the aPOI trustworthiness ranges from -1 to 1. This obtained value is mapped to the boolean value as described is Table 5.2 a positive trustworthiness value indicates the existence of an aPOI, and vice versa a negative value indicates its absence.

To avoid false positives and false negatives, mPASS needs to remove uncertainty about a barrier/facility as fast as it possible, e.g. obtaining more reports for those aPOIs which trustworthy value is near to 0. To this aim, when an aPOI trustworthiness ranges in the interval [-0.5, +0.5], mPASS activates the notification mechanism and sends report requests to users, with a high credibility (currently the prototype asks users with a credibility higher than 0.7), who are in proximity of the aPOI.

5.4 Simulation assessment

From the previous discussion, it should be evident that the most critical issue is the correct measurement of the trustworthiness of aPOIs and the credibility of users that contribute to measure it. For this reason, during the evaluation of mPASS, we put the focus on trustworthiness assessment, by resorting to agent-based simulation. In particular, our aim was to assess two main aspects. First, we were interested to understanding if mPASS is able to correctly identify existing aPOIs (true positives) and to determine if some aPOI was erroneously declared (true negatives). The goal here is evident, i.e. having a correct vision of aPOIs in a given geographical area is the main requirement to offer effective path planning services to all users. A second aspect was to assess if mPASS is able to understand the users' credibility. This is an important factor, since it is clear the more credible a user is, the more probable that his reports are correct.

In this section, we present the evaluation of our Trustworthiness Model. Due to the need to test the feasibility and the effectiveness of our approach in a large scale scenario, the use of our current prototype in a real scenario was not a viable solution.

5.4.1 Simulation details and experimental setting

We employed MASON (Multi-Agent Simulator Of Neighborhood), a discrete-vent multi-agent simulation library developed in Java (Luke et al., 2005). In particular, during the implementation of the simulation model we have exploited a MASON extension (called GeoMason), which provides support for vector and raster geospatial data. During our simulation sessions, we varied the amount of users/agents, simulation length, simulated urban maps and level of trustworthiness of users.

In order to reproduce a real urban environment topology, in our simulations we have imported data from OpenStreetMap (OSM) (Haklay and Weber, 2008),

(a) Bologna layout in openstreetmap (b) Bologna layout in the simulation

FIGURE 5.1: Bologna layout

representing the Bologna city center. This choice was motivated by the availability of real georeferenced data about urban accessibility elements, already provided by authoritative data sources and volunteers (involved in local disability organizations). In particular, at the time we exported the OSM map, there were reported 21 steps, 45 barriers (gates, lift gates, bollards, cycle barriers), 221 crossing, 63 pedestrian traffic signals. We have transformed the OSM data in a shapefile, maintaining information about lines (streets) and points (generic POIs). Figure 5.1 shows a graphical representation of such a map: Figure 5.1(a) shows the original OSM data and layer of Bologna, while Figure 5.1(b) depicts the graphical result of the transformation, with data imported in GeoMason. To assess the ability of mPASS to detect real and fake aPOIs, during the initialization step, the simulator added some randomly introduced non-existing aPOIs (i.e., false positives mimicking some previous erroneous notification by some users, see red dots in Figure 5.1(b)), together with the actual existing ones (green dots in Figure 5.1(b)).

Our simulation environment is composed by points (nodes, representing places, which can be points of interest or not) and by lines (representing streets). Paths are composed by lines and points, linking a starting point and a destination one. In our simulations, agents (acting like pedestrian users) move in a pseudo-random way with a random speed. At each simulation step, agents changed their position along a path, with the aim of reaching their destination point (the blue dots in Figure 5.1(b)). Whenever agents meet an aPOI, they report it. The correctness of such reports is based according to their credibility. It is worth noting that from a simulation point of view, a report can be:

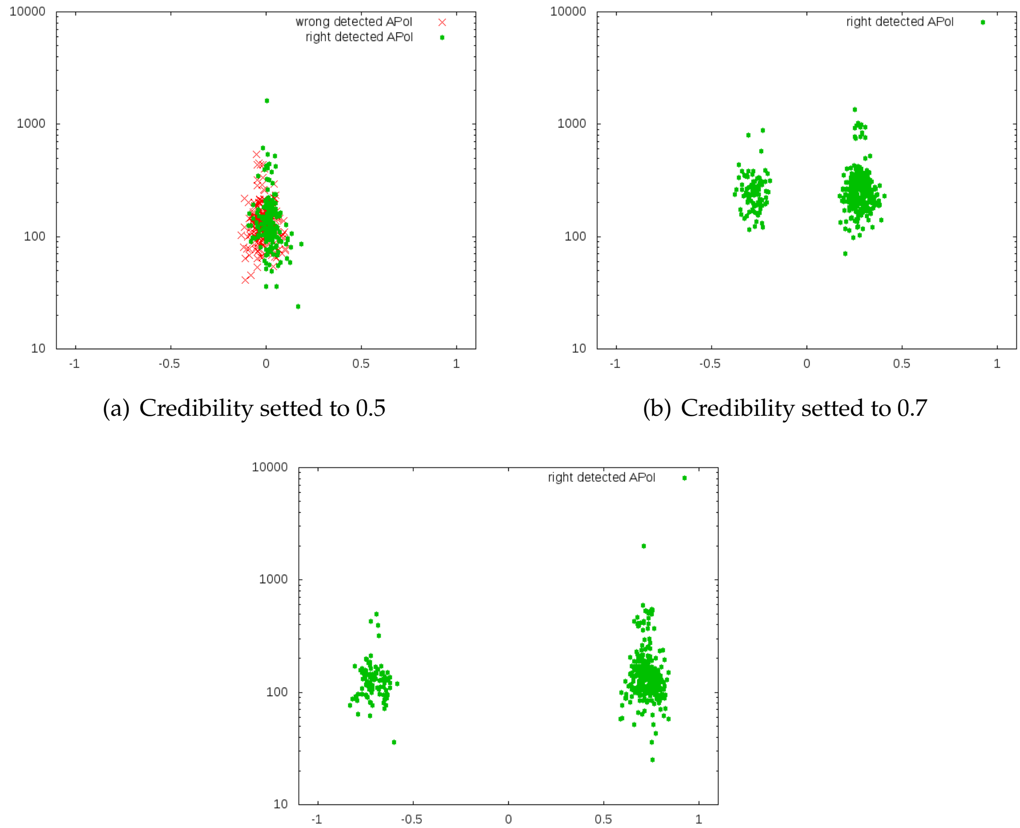
- "*right*": it means that the report states the presence of an existing barrier/facility (true,true) or the absence of a non-existing barrier/facility wrongly mapped (false,false);
- "*wrong*": it means that the report states the presence of a non-existing barriers/facilities (true,false) or the absence of an existing barrier/facility (false,true).

Hence, the obtained information is completely independent from the source (user or sensor). For this reason, in the rest of the Chapter, we will refer to users' credibility meaning even sensor's accuracy.

5.4.2 aPOI Thrustworthiness Identification

The aim of these simulations was to investigate the number of reports necessary to state the presence or the absence of a specific accessibility element in an environment with a pre-defined value of credibility/accuracy. In these simulations users were set to have the same credibility, as well as their devices have the same accuracy value. We varied these parameters in different simulations (in the charts these values are referred as the credibility of the whole users set). In particular, we varied credibility from 0.5 (out of 10 reports the user/sensor generated 5 wrongly reported aPOIs) and 0.9 (out of 10 reports the user/sensor generated 1 wrongly reported aPOI).

Figure 5.2 shows the trustworthiness of the aPOIs obtained with different system configurations. In particular, the goal was to assess if the system is able to correctly identify the real presence of an existing aPOI and the absence of a non-existing aPOI. Each chart in the figure refers to a specific credibility value. Dots in the chart correspond to aPOIs: green circles correspond to correct detections (i.e., true positives and true negatives); red crosses are wrong results



(a) Credibility setted to 0.5

(b) Credibility setted to 0.7

(c) Credibility setted to 0.9

FIGURE 5.2: Trustworthinss of aPOIs with defined credibility values

(i.e., false positives or false negatives). In the charts, the x axis shows the trustworthiness of the aPOI, as measured by mPASS, while the y axis reports (in log scale) the number of reports obtained for an aPOI. It is possible to observe that when the credibility of the users is set to 0.5 (i.e., they randomly decide to give a correct or an erroneous report with the same probability, Figure 5.2(a)), the trustworthiness of aPOIs remains near the 0 value; thus it is difficult for mPASS to identify if a given aPOI is present or not. Needless to say, this configuration is a high unlikely scenario, since we expect that users do not have such a random behavior. When we increase the value of the credibility (Figure 5.2(b) where credibility is setted to 0.7 and 5.2(c) where credibility is setted to 0.9), the system correctly detects the presence or non-presence of aPOIs. Indeed, the higher is the credibility value, the higher is the trustworthiness of present aPOIs.

Figure 5.3 shows the percentage of correctly identified aPOIs that have received a given amount of reports. In other words, given a set of aPOIs that received an amount of reports during the simulation (x axis), we measured the percentage of correct detections (y axis). The goal was to understand how many reports are in general necessary to identify the presence/non-presence of an aPOI. Again, when the credibility is set to 0.5, it is quite difficult to have correct identifications regardless of the amount of received reports. Conversely, when the credibility is set to a higher (more realistic) value, few reposts are needed to establish if an aPOI exists. It is worth mentioning that in these simulations we did not considered the presence of authoritative data sources. In fact, it is quite clear that the higher the amount of authoritative data sources (and the more active they are), the more reliable are the outcomes of our mPASS system. This was confirmed by specific simulations we made. In fact, from a simulation point of view, the presence of authoritative data sources imply simply that at a certain point the status of a given aPOI becomes perfectly set, and thus reports from other users become not useful. Put in other words, the presence of authoritative data sources reduces the uncertainty of the system; thus, while useful from an application point of view, their presence only limits the set of aPOIs to be considered in the evaluation. Conversely, we will consider the presence of authoritative data sources in the next subsection, to assess the credibility of users. In fact, in this case reports coming from authoritative data sources might improve the reliability on the measurement of the credibility of users.

5.4.3 Users' Credibility

In the previous subsection, we have shown how mPASS is able to correctly detect the real presence (absence) of an aPOI, assuming that the credibility of users was known, and that users have on average, a "good credibility". The aim of this section is to show that, indeed, a proper estimation of the credibility of users can be obtained, provided that a sufficient amount of reports is produced by the crowd. To this aim, we made several tests, starting with different configurations for the users' credibility. During our tests we assigned to users a

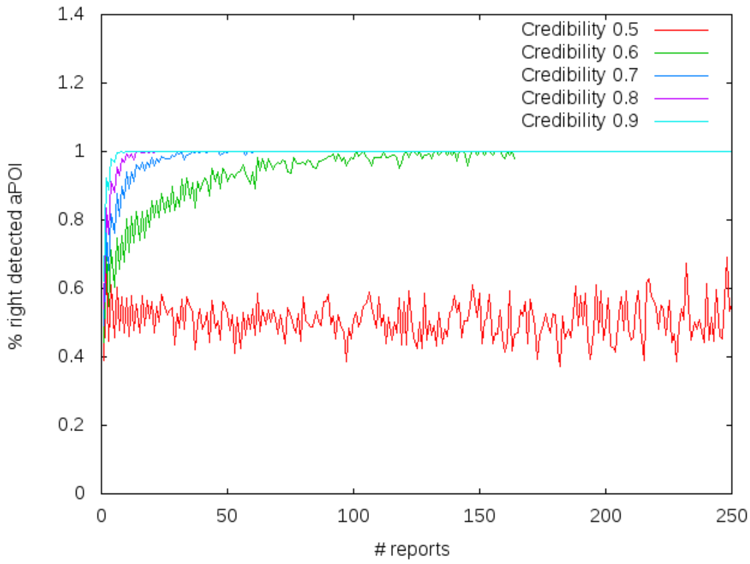


FIGURE 5.3: Percentage of correct identification of aPOIs w.r.t.credibility

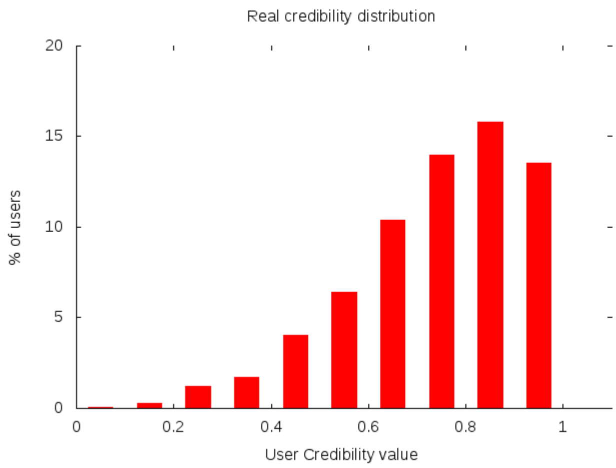


FIGURE 5.4: Percentage of users with a defined credibility value

credibility (that we called *real credibility* to distinguish it with the one assess by the system), whose distribution was a (truncated) uniform distribution, centred at 0.8 (as shown in Figure 5.4). The motivation behind the choice of this function is as follows. In the previous section, we have shown that the mPASS service would work when a majority of users has a good credibility value. Moreover, we claim that typically, since we are dealing with motivated and volunteered users, the majority of them should provide correct results. But of course, there are cases when users might introduce errors (voluntarily or involuntarily). We assume that, similarly, devices' sensors should provide correctly sensed data

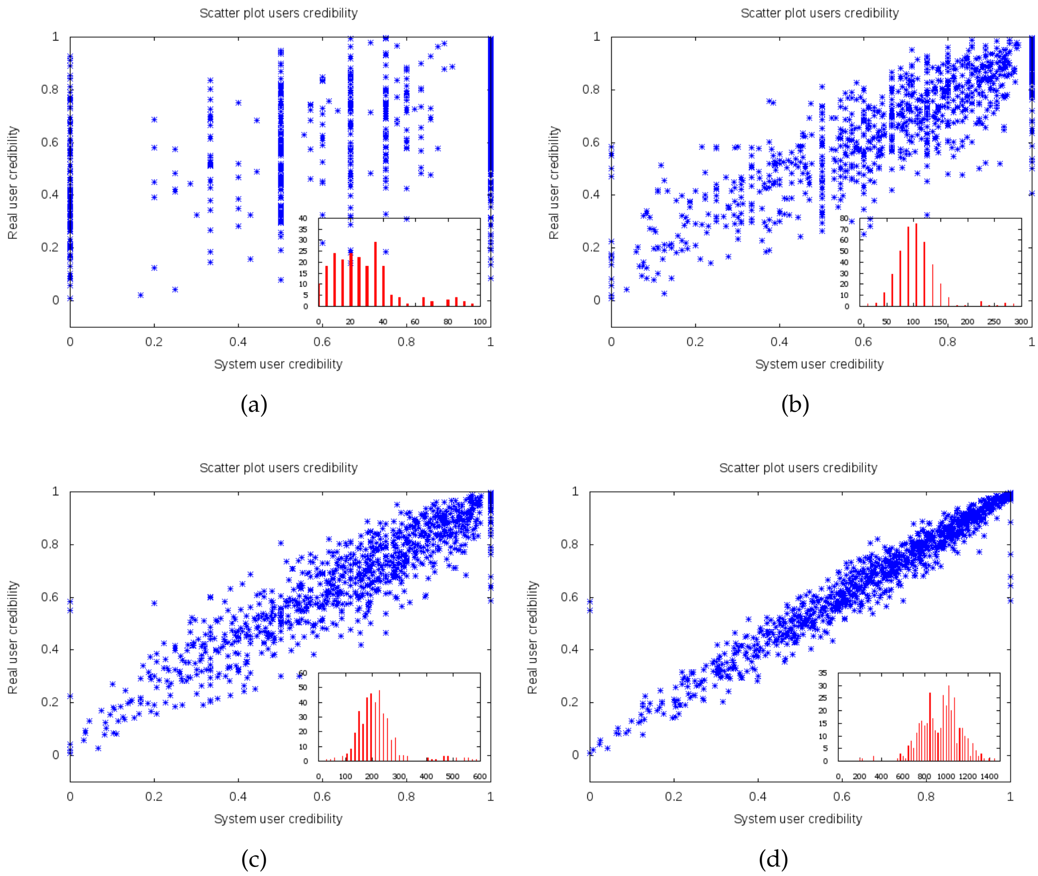


FIGURE 5.5: Users' credibility estimation at different simulation steps – majority approach.

(on average).

We refer to this users' credibility as "real credibility", since this is the value exploited by users to generate correct/wrong reports on given aPOIs. Users were asked to move randomly in the urban map, generating reports based on their real credibility. Conversely, the systems maintains an estimated credibility, stating the estimation of the credibility of a user, that the mPASS system has, based on the reports the users has generated so far.

Majority approach

A first set of tests was made in the absence of a gold set of authoritative data provided by authoritative data sources. Thus, the credibility of users was measured by considering a strict majority approach (half plus 1). In essence, for

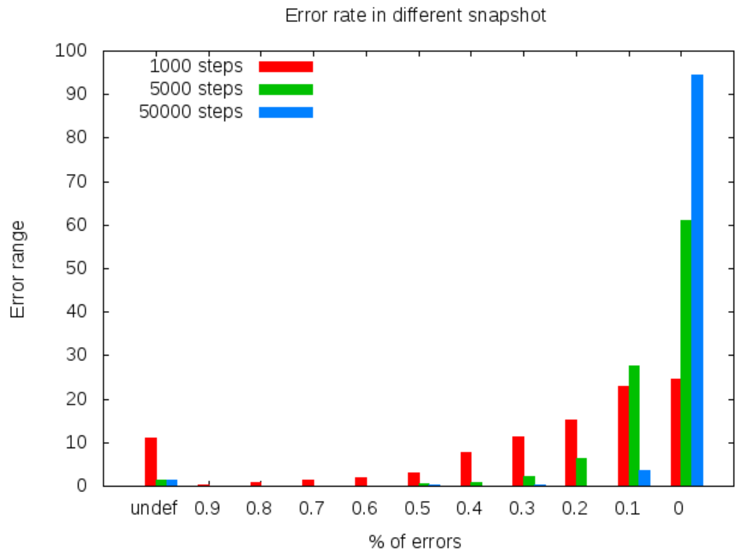


FIGURE 5.6: Error rate of estimated users' credibility – Majority approach

each aPOI, we consider its related report set.

For this set, the algorithm estimates that such aPOI is present/absent, taking the strict majority of obtained report values. Then, for each user we rank him by considering the amount of reports he generated that agree with the majority. Figure 5.5 shows that the system is able to correctly estimate the user set credibility as the amount of generated reports grows, with time. In particular, Figure 5.5 reported the assessed credibility for a typical simulation instance (we repeated the simulation multiple times, always obtaining qualitatively identical results). Each chart in Figure 5.5 shows a scatter plot that compares the real credibility (y axis) and estimated credibility (x axis). Hence, the more data are near the main diagonal, the better is. Each chart refers to a different simulation time step, as the simulation evolves. Each chart reports a small inner graph, which provides the report distribution for the set of aPOIs, i.e., how many aPOIs (y axis) received an amount of reports (x axis).It is possible to observe that while the system starts with very unreliable estimations of the users' credibility, in time such estimations become quite precise.

Figure 5.6 shows the average errors, in quantiles, of the estimations of users' credibility, taken at the simulation steps related to the charts in Figure 5.5. Each

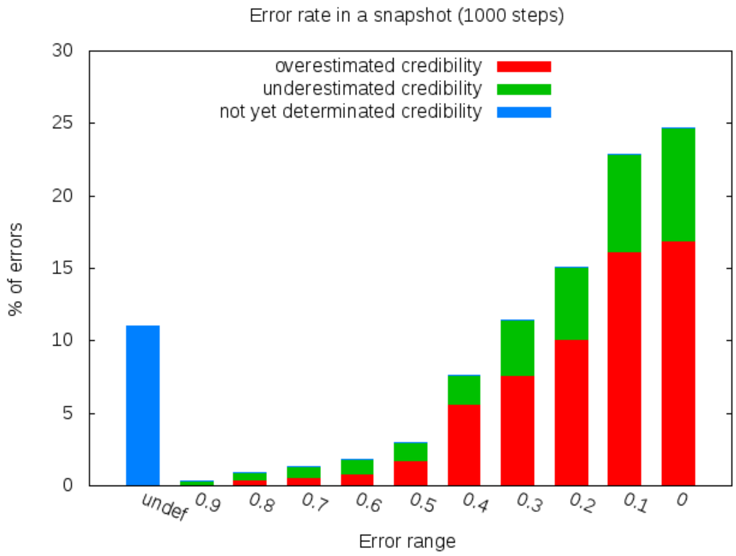


FIGURE 5.7: Error rate of estimated users' credibility (1000 steps) – Majority approach

histogram shows the percentages of underestimated credibility (i.e. estimated credibility lower than the real one) and overestimated credibility. The chart reports also the percentage of aPOIs that have not been determined thus far. It is worth noting that during the simulation, the amount of not yet determined aPOIs decreases while the system estimation of users' credibility improves significantly.

In Figure 5.7 is possible to see a zoom on the data obtained in step 1000. Each histogram shows the percentages of underestimated credibility (i.e. the estimated credibility was lower than the real one) and overestimated credibility (i.e. the estimated credibility was higher than the real one). The chart reports also the percentage of aPOIs that have not been determined thus far, i.e., at this point of the simulation the system cannot provide an estimation whether that aPOI is present of not. Of course, while the simulation goes on, the amount of not yet determined aPOIs decreases. It seems that the system tends to overestimate the users' credibility. Maybe it is due to the limited number of reports collected in this snapshot.

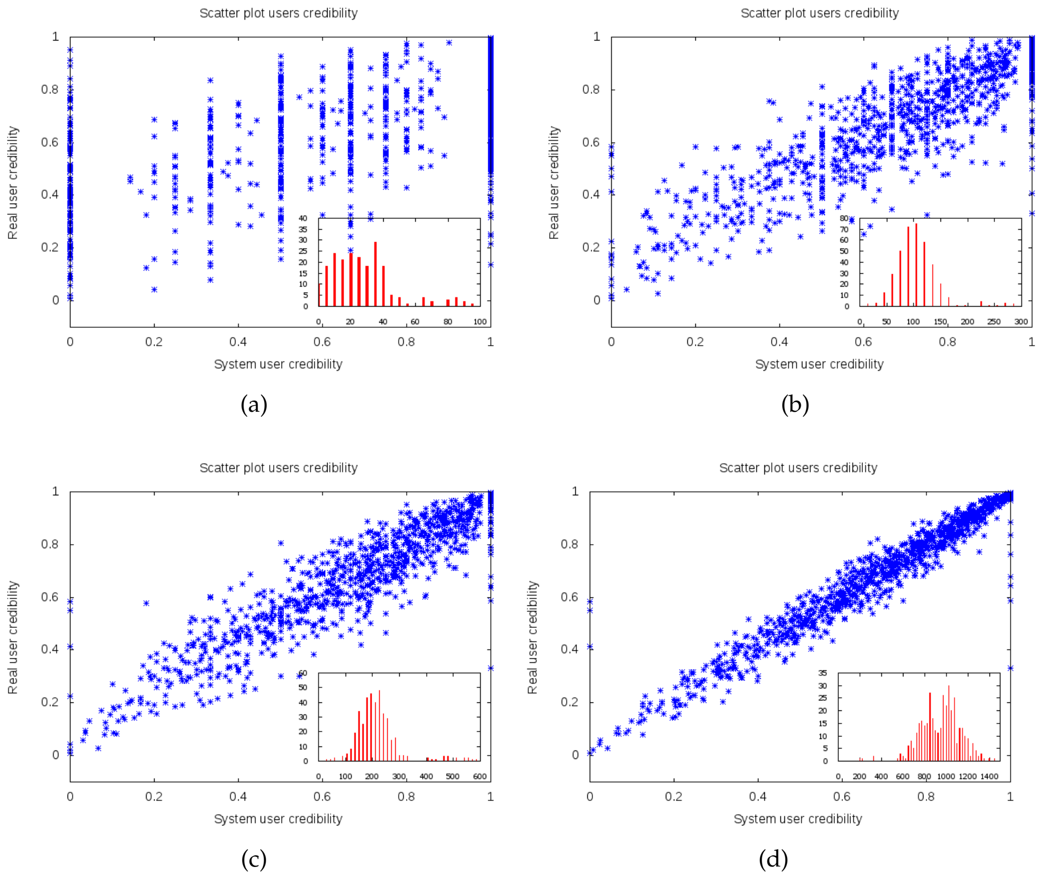


FIGURE 5.8: Users' credibility estimation at different simulation steps – gold set approach.

Gold set approach

Another set of tests was made, in presence of authoritative data sources. These data were considered as a gold set to exploit when estimating the users' credibility. In this case, each report generated by a user is compared to the authoritative reports associated to the considered aPOI. When an aPOI does not have an authoritative report associated to it, then the decision is taken using the strict majority approach. Thus, when a false aPOI has been declared erroneously, through direct requests to users mPASS can obtain a set of reports, which are employed to measure that aPOI's trustworthiness. Figure 5.8 shows the scatter plot for a given simulation scenario. Actually, results are quite similar to the previous approach.

Thus, when a high number of reports is available for aPOIs, the system is able

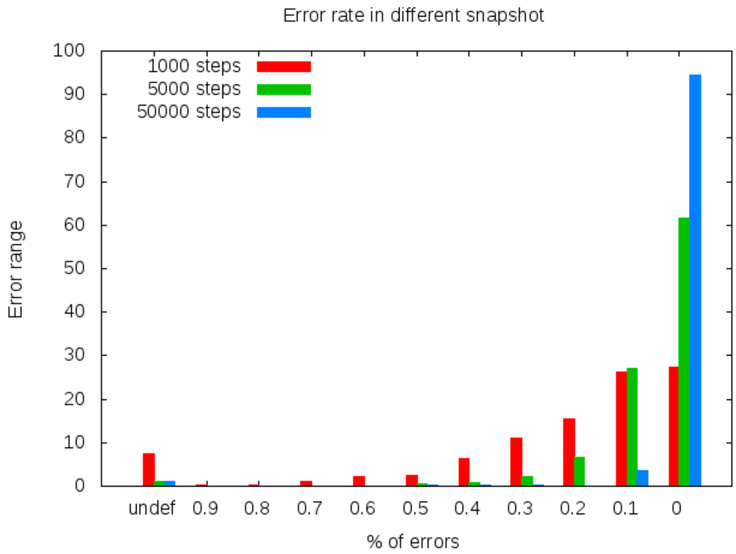


FIGURE 5.9: Error rate of estimated users' credibility – Gold set approach

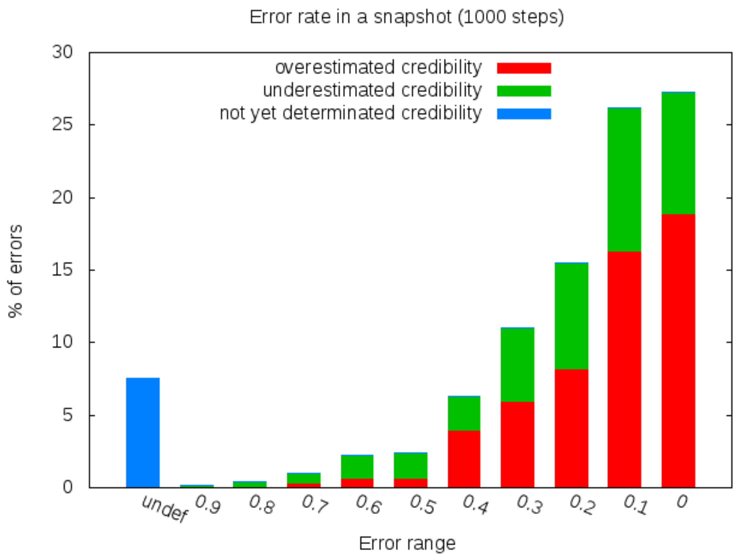


FIGURE 5.10: Error rate of estimated users' credibility (1000 steps) – Gold set approach

to effectively estimating the users' credibility. Figure 5.9 reports the average errors, in quantiles, of the estimations of users' credibility when the gold set provided by authoritative data source is employed. As for the previous approach, as the simulation goes on the amount of errors decreases.

In Figure 5.10 is possible to see a zoom on the data obtained in step 1000. The resulted trend is the same of the one shows in the previous approach.

5.5 Conclusion

In this Chapter, we have presented the trustworthiness model implemented in mPASS. The key features of the proposed approach are: (i) we use authoritative evaluations as representation of the real state of the urban accessibility, in order to assess the credibility of users; (ii) we use real data obtained by experimental results to state the accuracy of sensors in detecting each specific barrier/facility; (iii) we combine the sensors accuracy and the users' credibility to assess a global value of trustworthiness associated to all the reported barriers/facilities.

The results of an agent based simulation show that the trustworthiness of aPOIs can be efficiently measured through the use of authoritative, crowdsourced and crowdsensed data. Moreover, even in presence of misinformation, the system is able to detect the real barriers/facilities and to recognize the ones wrongly detected by users/sensors. This allows to conclude that the strength of mPASS lies on the user contribution and on use of crowd-sourced/sensed data.

There are interesting avenues for further investigations. First, we are now investigating how to exploit mPASS to responsively detect facilities failures and the introduction of changes in the urban scenario (as a facility built or a barrier removed). In fact, in these situations all data, including authoritative ones, could become wrong because they are too old to represent a new state of specific places. This is clearly a limitation that needs to be addressed. In fact, we are designing a trustworthiness model able to quickly detect a variation in the urban environment , considering the credibility value of the user who report the change and the timestamps of the actual report and of the previous ones. This model would make the mPASS system a useful tool to support the everyday life of all users (with or without disabilities) and to provide smart city technologies with users produced data.

In addition, we plan to exploit the system prototype to make some real tests in a non-controlled scenario.

Chapter 6

Conclusion

This thesis was inspired by the need to provide citizens with personalized services related to the urban environment, by exploit the power of the crowd in collecting data via crowdsourcing and participatory sensing. In particular, as case study, we analysed the issues related to the urban accessibility of the environment in smart city contexts. In fact, urban accessibility is a primary factor for social inclusion and the effective exercise of citizenship for everybody, including people with disabilities and elderly people.

These requirements motivated and framed the research issues described in this thesis.

6.1 Summary of Contributions

To deeply investigate the issues related to crowdsource and crowsence data for urban accessibility, we designed and prototyped a system, called mPASS (mobile Pervasive Accessibility Social Sensing). This system allows us to actual investigate the research questions related to the fruition and the collection of data via crowdsourcing and participative sensing of accessibility barriers and facilities to effectively compute personalized and accessible paths. Different research issues arose and our contribution was in investigating how to address the more innovative ones.

The first research contribution was related to the goal to improve the density and quantity of collected data. In fact, the availability of information about urban accessibility is very limited if compared with other geo-referenced data and a multiple-source gathering seemed to be the only effective mean to collect an adequate set of information. It is important to notice that the lack of information about the urban environment and its accessibility represents itself a barrier to those citizens, who are strongly discouraged from step out of well-known paths. Our approach to this issue was to integrate and merge different data source related to urban accessibility with the aim to create a large dataset of information. In particular, we considered (i) data gathered voluntarily via crowdwsoucing using mPASS; (ii) data collected automatically via crowdsensing using mPASS; (iii) data extracted from VGI (Volunteered geographic information) as OpenStreetMap; (iv) data obtained from open data repository and authoritative sources; (v) data merged with existing crowdsourcing systems focusing on accessibility. The outcome of this contribution is being published in (Prandi, Salomoni, and Mirri, 2014; Mirri et al., 2014b).

The second research issue came to light from the need to visualized all the retried data. The information globally gathered by mPASS is too complex, wide and heterogeneous to be entirely provided to users as it is, also considering that the main application target is suppose to be people with disabilities and special needs. Information needs to be adapted to become effective and to conform to users' needs. Our contribution was related in profiling and customization strategies so as to provide users with a complete but easily understandable mapping of urban and architectural accessibility. In mPASS, we addressed this issue selecting and transforming raw data so as to provide the user with a personalized service, customized on his/her special needs both in terms of mobility and in terms of e-accessibility of the application. The system performs the adaptation on the basis of a user profile and a set of visualization strategies that are dynamically applied to equip the user with an accessible map of urban accessibility. To show the results of such a customization in terms of usability of the application, we presented a complete case study of a user profile and adaptations applied to offer an effective mapping of accessibility barriers and facilities. The outcome of this contribution is being published in (Mirri, Prandi, and Salomoni, 2014b; Prandi, 2014).

Another one was related to study strategies to involve and engage citizens in voluntarily collecting data. In fact, a key factor for the success of any new crowdsourcing system is the recruitment of a sufficiently large group of users who can leverage the critical mass to start the crowd engaging. This is particularly relevant for mPASS since the main target population (people with disabilities) represents a limited group of urban citizens. In addition, in order to evaluate data trustworthiness, our system will require multiple validation reports. The integration of different data source increases the volume of information about the urban accessibility but it isn't enough to have an updated, completed and validated mapping of the urban environment. To recover from this situation, people without disabilities could be engaged in collecting data about urban accessibility. Our contribution in this issue was to investigate entertainment, from gamification strategies to pervasive game, in motivating and attracting urban walkers. In particular, to evaluate the feasibility of our approach, we designed and developed different mobile apps investigating intrinsic motivation, extrinsic motivation and the game flow and we conducted field trials, highlighting interesting results. The outcome of this contribution is being published in (Prandi et al., 2015b; Salomoni et al., 2015).

Our last contribute emerged from the needed to reliable and trustworthy data to avoid errors in computing the personalized and accessible path. mPASS can generate both false positives and false negatives errors due to: (i) non-existing barrier detected (false positive); (ii) non-existing facility detected (false positive); (iii) undetected existing barrier (false negative), and (iv) undetected existing facility (false negative). In order to avoid all these four mentioned situations, we studied a trustworthiness model that exploits majority voting or/and a gold set approach (when available) to rate the trustworthiness of data related to APOIs so as to decide if there is a specific type of barrier or facility and its characteristics. To do such an evaluation, the system needs to assess the user's credibility and sensor accuracy. In fact, quality issues mainly come from trustworthiness of sources: users involved in the crowd express their own opinion and they are not totally trustable and/or totally able to produce the information required. Analogously, sensors suffer from different accuracy issues which can compromise the quality of gathered data. We evaluated our trustworthiness model by means of simulation over a specific set of datasets retrieved from OSM, with different urban layout and typologies. The outcome shows that, the system is able to correctly detect if a barrier/facility is present or not in different system configurations and scenario. For example, we stressed the model varying the percentage of agents running in the simulated system that can spread misinformation (false or inaccurate information that is diffused unintentionally). The outcome of this contribution is being published in (Prandi, Mirri, and Salomoni, 2014; Prandi et al., 2015c; Prandi et al., 2015a).

6.2 Future works and research vision

Main future efforts will be devoted to exploit presented mechanisms to collect data via crowdsourcing and crowdsensing using new smart devices, like wearable devices. In fact, as adoption rises, smart watches and smart glasses can become interesting devices to investigate together with new smart sensors and argument reality. These innovative technologies can be profitably used to create pervasive games with the aim to involve users in mapping urban accessibility.

Moreover, machine learning algorithms can be exploit to automatically set the user profile and, consequently, the data, the map and paths adaptations and transformations. Machine learning can be also employed in gamification, to learn the user habits and to challenge the player, with the final aim to collecting more data. A machine learning approach can be also interested if applied to our trustworthiness model, in assessing user credibility on the basis of the user's daily routine.

We finally plan to evaluate the entire mPASS system on a dense and detailed set of data, with an important number of users.

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