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A universal design approach to wayfinding and navigation

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Abstract

This paper investigates the problem of urban accessibility and proposes a system for the generation of accessible paths in an urban university campus. Universal Design has been adopted to explore the different perspectives of the involved stakeholders; an interdisciplinary team has iteractively developed a web application targeted at public administrators and two versions of a mobile app (one for Android and one for iOS) to be used by citizens. The mobile app is able to propose and guide users on paths that best fit their characteristics and preferences; for example, if a user declares some motor and/or visual impairement, the app proposes paths that avoid the architectural barriers related to such impairments. Not only pedestrian paths are considered in the system, but also routes for private cars or public transportation, and thus information about reserved parking lots and limited traffic zones are also managed. The app has been currently tailored to the campus of the University of Brescia, which is distributed in different districts of Brescia, a town in northern Italy; however, it can be easily scaled to other organizations or whole towns, since Google Maps and its APIs have been used as mapping service. Twenty five participants, including blind people and persons with motor disabilities, have been involved in the evaluation of the usability and accessibility of the two versions of the mobile app.

Keywords Universal design · Urban accessibility · Architectural barrier · Mobile navigator · Software accessibility · User evaluation

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1 Introduction

Urban accessibility represents a challenge for several towns all over the world and this has been underlined by important international documents such us, among the others, the UN Agenda 2030 for Sustainable Development, in particular Goal 11 [36], and the New Urban Agenda Habitat III [37]. The possibility to reach different places in a city following the most suitable and preferred routes (on foot, by private car or by public transportation) is a need experienced by anyone and in particular by people with disability. This requires knowing the spatial, distributive and organizational-managerial characteristics of the places and services of the city [38].

The Italian Laws 41/1986 and 104/1992 require local administrators to catalog all architectural barriers in their municipality and deal with their removal appropriately. In particular, a plan for architectural barrier removal (Piano per l'Eliminazione delle Barriere Architettoniche - PEBA) in public buildings must be created by every municipality in the country in a paper-based format, or by using a digital tool, such as a spreadsheet or a geographic information system (GIS) [22]. Besides the accessibility of the buildings, most of the Italian Regions have also considered to promote an urban accessibility plan (Piano per l'Accessibilità Urbana - PAU), in order to obtain an overall and actual accessibility of the cities.

Obviously, urban accessibility does not only deal with the removal of the architectural barriers, but it also involves providing information about public transportation, parking lots for disabled people, and limited traffic zones (Zona a Traffico Limitato - ZTL, in Italian), namely areas (usually downtown) where private cars cannot circulate, at least in some time slots, and where disabled people can be authorized to transit. In this perspective, information is as important as the removal of an architectural barrier, since knowing the position of an obstacle allows to choose a different path in order to avoid it.

We started exploring the problem of urban accessibility from our university, in order to conceive a solution that could be useful to its students, teachers and visitors. The University of Brescia can be regarded as an urban campus because its buildings are located in different areas of Brescia, a 200.000-inhabitants town in Northern Italy: some buildings, the most historical ones hosting the Faculties of Economy and Law and those hosting the administration offices, are located in the city center; other modern buildings, hosting the Engineering Faculty and the Medicine Faculty, are located in the northern district of Brescia. When one needs to reach a specific office or room within the University of Brescia, proper instructions must be obtained; particularly, people with mobility or visual impairments should be guided on pedestrian paths that avoid architectural barriers, or obtain information about public transportation, or, when a private car is used, about reaching parking lots and passing through limited traffic zones.

Taking the Universal Design (UD) perspective [35], our interdisciplinary team has explored the problem of PAU development, combined with the need of supporting people interested in reaching the buildings of the University of Brescia. UD is "the design of products and environments to be usable to the greatest extent possible by people of all ages and abilities" [35]. It provides seven principles: according to the first principle, *equitable use*, all users should be provided with the same means, without segregating or stigmatizing any users; whilst the second principle, *flexibility in use*, requires that design accomodates a wide range of users' preferences and abilities. In our project, called UniBS4All, we aimed at following these two principles by developing a mobile app able to suggest personalized navigation paths towards and among the buildings of the University of Brescia. The app simply provides accessible paths, according to the user's needs and preferences, by choosing them among those without architectural barriers. The development of the mobile app was performed taking into account usability engineering methods [26, 33], thus the other UD principles were naturally considered: indeed, the third principle, *simple and intuitive use*, recalls usability definitions; the fourth principle, *perceptible information*, suggests that users must be able to perceive the necessary information regardless of the context or their own sensory abilities, as also prescribed in the Web Content Accessibilty Guidelines [40]; the fifth principle is concerned with *tolerance for error*, and usability engineering usually denotes this aspect as system robustness [26]. Finally, the sixth and seventh principles are *low physical effort* and *appropriate size and space for use* respectively, which concern reducing fatigue and taking care of the usage context; however, since we just developed a software application rather than a physical object/environment, we considered these principles less critical in our case.

In summary, we contributed to the research on urban accessibility and Universal Design by iteratively developing and testing the UniBS4All system that consists of a web portal for managing a subset of PAU information related to architectural barriers and two versions of a mobile application (one for Android and one for Apple iOS) for accessibile wayfinding and navigation. The mobile application is based on Google Maps API to compute the paths tailored to the users' characteristics and preferences.

A preliminary version of this work was presented in [1]. This paper significantly expands over the presentation of the UD methodology adopted for system design, the overall system architecture, the details of the involved applications, the experimental activity and the comparison with related research.

The paper is structured as follows: Section 2 discusses related work in the field of accessible wayfinding and navigation; Section 3 presents the iterative UD approach that led to the development of UniBS4All; Section 4 describes the system architecture, as well as the web portal and the mobile app functionality; Section 5 illustrates the evaluation with users, consisting of three experiments carried out with a total of 25 participants; Section 6 provides a discussion about the main contributions and limitations of the paper and delineates future work.

2 Related works

In the last years, the theme of urban accessibility is gaining momentum; several research groups all over the world are addressing this problem by carrying out citizens' surveys and proposing different kinds of software applications. Comai and colleagues [11] carried out a literature review on urban accessibility, by identifying several mobile apps targeted at users with mobility impairments that provide information about the accessibility of sidewalks and points of interests (restaurants, parking lots, etc.). The review hightlights that most of these apps are focused on technical aspects related to the construction of accessibile paths, such as the collection of GPS data measurements to build the trajectory followed by the user (e.g.: [7, 21, 27, 34]). For instance, Path 2.0 [27] is one of the first geo-crowdsensing proposals that allow users to passively contribute routes during their everyday movements, by assuming that these routes can be useful to other users with similar needs. PAM (Personalized Accessibility Map) [21] is able to combine the general needs of wheelchair users with individual specific preferences to obtain personalized paths. IBM Sidewalks [34] is a geo-crowdsourcing mobile application that allows users to capture pictures and upload data about relevant aspects of sidewalks, such as steps, holes, etc.

In their review, Comai et al. [11] observed that most works often disregard actual users' requirements. For this reason, they followed a user-centered design approach to develop MEP (Maps for Easy Paths), a project aimed at providing users with two mobile apps for automatically collecting users' pedestrian routes and visualizing relevant information on accessibility maps respectively [8–10]. They used focus groups to gather the requirements of users using manual and electric wheelchairs; then, they developed the MEP Traces app for recording routes where users are travelling and algorithms for the reconstruction of accessible paths [9]. Another app (MEP App) then exploits the information collected by MEP Traces to support users in finding accessible paths and possibly signal the presence of barriers or parking lots [10]. However, this requires a community of people willing to participate in data collection; in addition, even though the app was judged as easy to use, user tests have been carried out with middle and high school students without a real need for the app, and this reduced the perception of its utility [10].

The system mPASS [25, 31] is able to integrate data from three different sources: i) smartphone sensors, ii) users who voluntarily review urban accessibility information, and iii) official reviews provided by authorities and organizations. As to our knowledge, the system is however still under development: some experimental data are discussed in [25] by considering only the emulation of mPASS operation in the city of Cesena (Italy).

The proposal illustrated in [30] is to enrich applications for geo-crowdsourcing with gamification elements, in order to stimulate users (with or without impairments) to participate in signaling the presence of architectural barriers through an engaging and playful user experience.

Geo-crowdsourcing data should however be carefully analyzed by technicians, who are expert in accessibility, before entering them in the system, in order to guarantee a correct and uniform information. In fact, the concept and the perception of a barrier is very subjective, so it needs to be properly checked.

All the described apps consider the accessibility of sidewalks and thus usually propose accessible pedestrian pathways. Indeed, most of them follow a vertical approach to accessible mobility, by regarding users with special needs as separate from other users and thus providing them with a personlized service. Melis and colleagues [24] assume a different perspective: they propose an infrastructure, called Smart Mobility for All (SMAll), based on the concept of Mobility as a Service (MaaS), in order to offer a unique interface to users for accessing heterogeneous transport options offered by different mobility providers. SMAll is regarded as an enabling technology for publication, retrieval and orchestration of microservices related to mobility, such as crowdsensing, crowsourcing, acoustic recognition and route planning [24]. A possible use case (not yet implemented) fostered by this solution involves a blind user that sets up his/her profile and obtains a personalized path by the microservices working together in SMAll. This bottom-up idea (from microservices to user applications) is complementary to our top-down approach (from user requirements to software algorithms), but the idea is similar, that is, providing each user with the possibility of declaring his/her needs and preferences and thus obtaining the path that is most suitable to him/her.

The problem of finding accessibile paths in limited areas is being addressed by several universities and colleges all over the world. Most of them make accessibility maps available on official websites for downloading; however, these maps contain static information, thus they cannot be used for real-time navigation and usually comprise obsolete information. Among the projects addressing the development of suitable interactive tools for wayfinding and navigation there is Way-finder [23], a system targeted at students and visitors of the University College

Cork (Ireland), which supports blind and low-vision people in traditional orientation and mobility training. The already mentioned PAM application [20] has been developed on the basis of the requirements provided by 20 campuses in US and then tailored to support the students of the University of Pittsburgh in trip planning. These applications are however usually tailored to specific places, and thus also maps (such as the university pedestrian network with accessibility information) and navigation algorithms are often developed ad-hoc. In this way, their flexibility for easy adaptation to other contexts remain limited. Instead, we would like to develop a general application for urban accessibility, which is first targeted at the visitors, students, and personnel of the University of Brescia, but that could be easily applied to other universities, to public authorities distributed in different areas of a town, or to whole cities. Therefore, we decided to use Google Maps APIs, which already provide the fastest routes between two points in different modalities (walking, car, public transportation), and we paid attention also to the usability and accessibility of the user interface of the app itself. In addition, we have chosen to develop two native mobile applications, instead of a web application like for example PAM [21], in order to exploit device features and make interaction more efficient and coherent with the related operating system.

Finally, differently from all the other applications, UniBS4All is also ready for use inside the buildings: indeed, if building plants are uploaded in the indoor navigation service of Google Maps, the algorithms for accessible wayfinding of UniBS4All may keep on operating correctly inside buildings. A problem we are currently solving is indoor localization of the user in places where GPS signal is weak or absent. A possible solution we would like to explore is that proposed in [12], which is based on Bluetooth Low Energy (BLE or beacon) technology and is currently under development at the University of Bologna (Italy).

3 An iterative universal design approach

The research methodology adopted to design and develop UniBS4All is based on the Universal Design approach [35]. Hence, the idea underlying the project was developing a system that could be used by everyone to find the path that best fits his/her needs and preferences at that moment in a given context. In other words, we did not want to develop an application that could be used only by disabled people to find information about the type and location of architectural barriers, but an application where each user may fill in his/her profile and find the path that is most appropriate to such profile. This led us to create an interdisciplinarity team including human-computer interaction (HCI) experts, software developers, architects, civil engineers, and representatives of some users' communities (such as the national association of blind people), in order to gather different perspectives on the requirements that the project should satisfy.

Another pillar of the project was assigning a correct *semantics* to the data characterizing paths and places [28], thus the expertise of civil engineers in the field of accessibility and in the preparation of plans for architectural barrier removal was considered fundamental to assign such semantics and guarantee data validity. This led us to design a system architecture (see Section 4), where an important component is a web portal that allows experts to insert and categorize the architectural barriers.

The development process was carried out in an iterative way. The work started with two brainstorming sessions, followed by a visit to real routes from the Brescia train station to the Engineering Building of the University of Brescia; this visit was performed with the participation of one person on wheelchair and two blind people, and allowed the design team to examine the architectural barriers along the paths and better understand the mobility problems that different kinds of people may encounter everyday. After this phase, the HCI experts and software developers created some scenarios and mock-ups of the mobile app to be discussed with the rest of the design team and gather feedback for developing a first interactive prototype of the Android version of the app. Since the beginning, the idea was developing an app very similar to the well-known Google Maps app, in order to make its user experience easy to recognize and learn. For the same reason, but also for their powerfulness and reliability, the map services provided by Google were chosen as the basis of UniBS4All operation.

The first prototype was then iteratively evolved to integrate and implement the new requirements and suggestions obtained during additional meetings of the design team. Two important requirements emerged during such meetings: first, people with disabilities who travel by car are often interested in knowing where the reserved parking lots are located; second, when they go across ZTLs but are not resident in that municipality, they must inform the local traffic authority by providing their car plate and access permit. The satisfaction of these requirements led us to design features for parking lot retrieval and selection as destination, for signaling the presence of ZTLs in the generated paths to both disabled and not disabled people and for sending an automatic email to the traffic authority when a non-resident disabled person is traveling in a ZTL.

The first complete version of the Android app was tested with users, who generally appreciated the app but identified some usability problems and provided interesting suggestions for improvement. After this experiment, the iOS version of the app was developed by replicating the functionality of the Android version, but by taking into account the results of the user evaluation, in order to solve the discovered usability problems. Further discussions within the design team did also take place to reflect on the experimental results and possibly identify new requirements. In particular, a fundamental weakness of the first version of the application clearly emerged, that is the lack of a functionality for easy access to the application by visually impaired people. This was solved in the iOS version by exploiting Apple support tools. Another functionality that became interesting to implement, also inspired by literature work (e.g.: [9, 25]), was the possibility for the user to signal the presence of architectural barriers. This crowdsourcing functionality was integrated in the iOS version as well, and a suitable mechanism for barrier validation was also hypothesized. Then, other aspects were improved, such as the navigator operation.

Two additional experiments with users were carried out for the iOS version, the former comparing it with the Android one on the same tasks, the latter investigating the usability of the new navigator and crowdsourcing features, by keeping on refining the app from one experiment to another.

4 The UniBS4All project

The overall system (see Fig. 1) includes a MySQL database storing all the data related to the architectural barriers, a web portal devoted to accessibility experts for populating the database, and the Android and iOS native mobile applications devoted to the end users. The following sub-sections describe the main features of the web portal and the mobile apps. For the sake of brevity, we only describe the visual interface of the iOS version, which includes the additional features mentioned before. Particularly, we illustrate the voice-over functionality of the app;

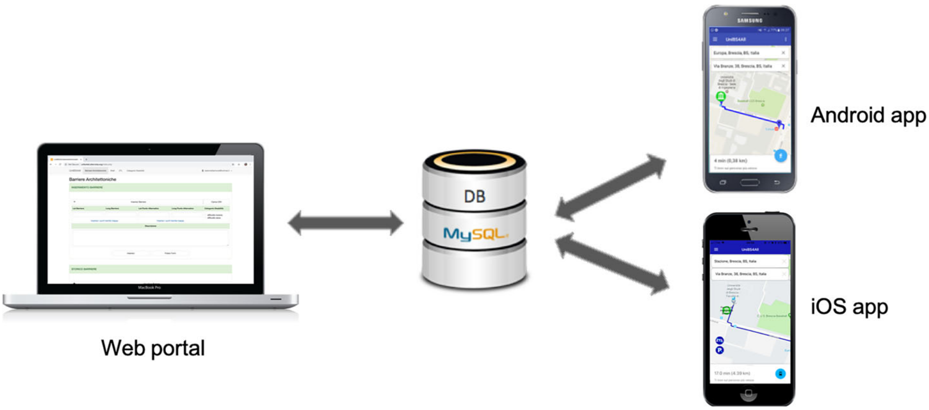


Fig. 1 System overview

please note that visually impaired people involved in the project told us that they usually prefer the iOS device. This preference of blind people is also confirmed by literature work (e.g.: [39]).

4.1 The web portal

Plans for architectural barrier removals and plans for urban accessibility are usually developed as paper-based documents or using spreadsheet tools. In some advanced public administrations, a GIS or a web GIS is adopted: these tools allow managing geographical information and support decision making on the basis of geographical data analysis and processing, but they must be used by personnel with high expertise in the field. A PEBA or PAU document includes information related to architectural barriers, for example their location in a building or town, and how to remove them (including the cost). The web portal developed for the UniBS4All project stems from the PEBA/PAU idea, and it was designed to be more intuitive than a GIS. More precisely, even though some extensions are still necessary to create PEBA and PAU documents to all effects, the web portal provides urban accessibility experts with easy-to-use functionality for creating and managing information related to architectural barriers and their alternative points. Indeed, the algorithm for the generation of accessible paths implemented in the mobile application is based on the concept of *alternative point*, that is, a point associated to an architectural barrier that must be included in a path instead of that one where the architectural barrier is located.

The web portal, currently developed in Italian, includes four sections: 1) architectural barriers; 2) parking lots; 3) ZTLs; 4) disability categories. The first section allows the user to insert the latitude and longitude of each architectural barrier and its corresponding alternative point, by indicating the disability categories, along with some textual description. An example is shown in Fig. 2, where the user has just inserted data related to an architectural barrier for people with mobility impairment ("difficoltà motoria" in the figure) with the comment "marciapiede all'ingresso della facoltà di economia" ("sidewalk in the entrance of the Economy Faculty" in English).

The insertion of points is made easier by the possibility of indicating points directly on the map through the link "Inserisci ipunti tramite mappa" (i.e., "Insert points through the map"), which allows opening the pop-up shown in Fig. 3.

Other two sections of the web portal allow inserting reserved parking lots and ZTLs respectively, by means of a similar interaction modality. In the case of a parking lot, only

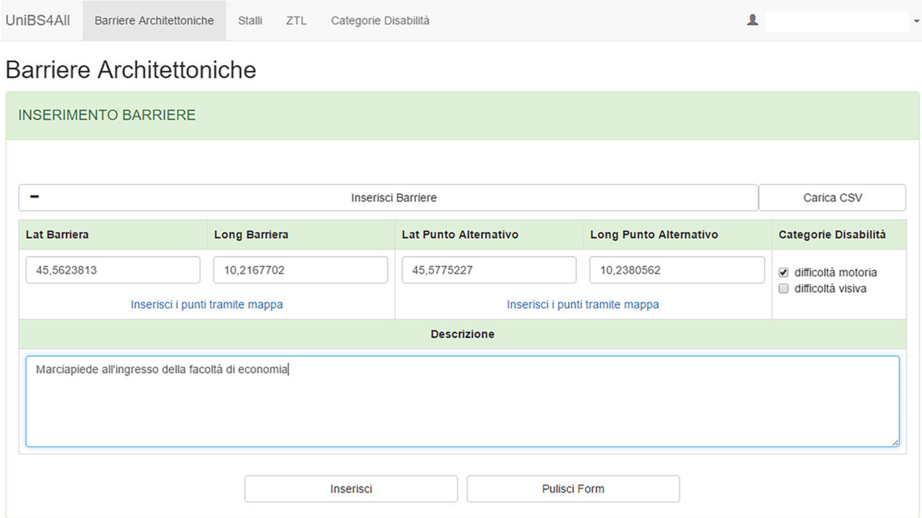


Fig. 2 Inserting data related to an architectural barrier and its alternative point

one geographical point will be inserted in the system; whilst, a limited traffic zone will be created by inserting at least three points, in order to obtain a polyline that defines a closed area. The last section allows the definition of different categories of disability to be associated to the architectural barriers and thus generate personalized paths on the basis of the user profile (for example paths suggested to people with mobility disabilities might be different from those suggested to blind people).

Finally, a function has been included to upload spreasheets with geographic data created with other systems.

In summary, in this project, we assumed that the burden of inserting the data about architectural barriers and related alternative points should be on accessibility experts, in order

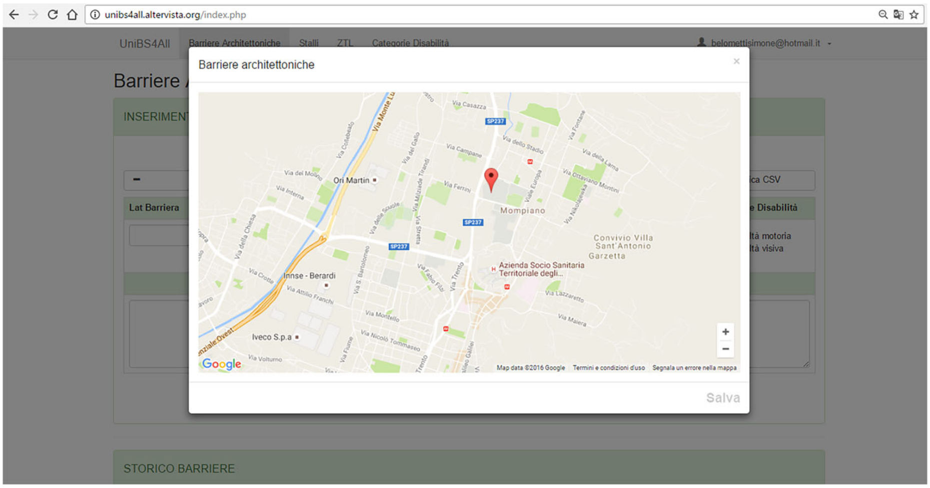


Fig. 3 Using the map to insert a point related to an architectural barrier or an alternative point

to guarantee the validity of data. Such experts could be the employees of a local administration, who are in charge of making barrier reliefs and preparing PEBA and PAU documents, which in this case assume a two-fold role: not only the answer to a legal obligation, but also the source of the data necessary for the generation of accessibile paths. Moreover, if an alternative point is detected during the mapping of an architectural barrier (the first step to prepare PEBA and PAU documents), then an immediate service towards accessibility is given, even if with some limitations (i.e. less options to calculate the paths). Once the architectural barriers will be removed, the alternative points will be removed as well, and there will be more options for path generation.

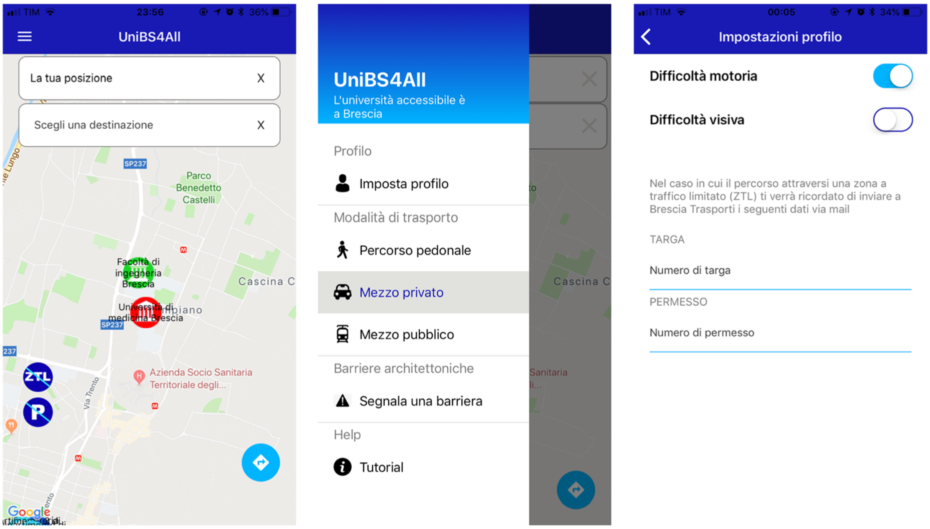
4.2 The mobile application

4.2.1 User profile and transportation settings

The main screen of the app UniBS4All presents a map centered in Brescia, with some of the main buildings of the University easily visibile, and the textboxs for selecting the starting and destination points, where the starting point is set to the user's current position by default (Fig. 4a).

The app provides the user with the most appropriate path according to his/her profile and the selected means of transportation (walking, private car, public transportation). Therefore, differently of most of other apps presented in literature, it does not provide pedestrian pathways only. This is possible thanks to the integration with Google Maps services.

To access the Profile section, the user must select the typical menu icon in the left-hand side of the toolbar: the navigation drawer is shown to allow the user selecting the traveling modality and setting his/her profile ("Imposta profilo", in Fig. 4b). As to the traveling modality, the user



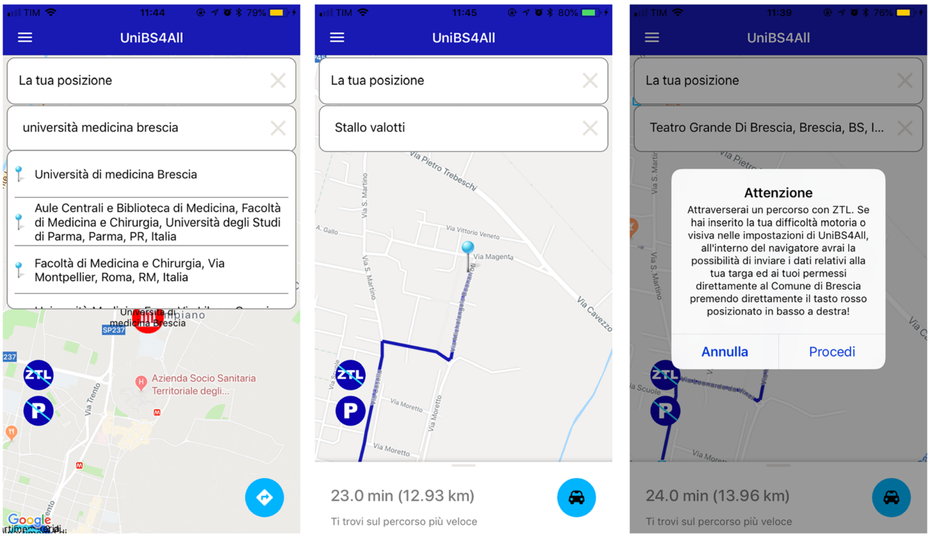
(a) (b) (c)

Fig. 4 Main screen of the app UniBS4All (a), Navigation drawer (b) and profile settings (c) may choose among pedestrian path ("Percorso pedonale", in Fig. 4b), private car ("Mezzo privato") and public transportation ("Mezzo pubblico"). When the user accesses his/her profile and sets mobility and/or visual impairments, he/she may also fill in the form to provide the car plate and ZTL access permit, which will be used in case of traveling through a limited traffic zone to send an email to the local authority (Fig. 4c).

4.2.2 Wayfinding

The map of UniBS4All shows icons that identify the University buildings and the parking lots reserved to disabled people (when the corresponding round button is activated). All these markers can be selected as destination points; otherwise the user may search for an address, and the Google Maps Places API is called to provide the user with proper suggestions. The user may also activate the visualization of limited traffic zones by selecting the ZTL button on the map. The light blue button with the arrow shown at the right bottom part of the screen can be used to start finding an accessible path (Fig. 5a); the computed path is thus visualized on the map as well as its length and duration, while, according to the selected transportation modality, a proper icon is shown to start the navigator (Fig. 5b). If the found path transits in a ZTL, the user is notified by a pop-up that advises of the possibility to send an email to the local authority or to look for another path if the user does not have the ZTL transit permit (Fig. 5c).

The algorithm for path generation exploits the Google Maps Directions API, which returns the available paths between the starting and destination points. The first three returned paths are selected and saved for further processing. It the user did not declared a visual or mobility impairment or uses the private car, the fastest path is proposed (that is, the first path returned by the Directions service). Otherwise, if the user declared some impairment and selected the walking modality, the algorithm processes the three saved



(a) (b) (c)

Fig. 5 Search for a path (a), path visualization (b), and pop-up about the presence of ZTL (c) paths, one after the other, until a path that avoids all architectural barriers and transits through alternative points is generated.

The algorithm checks the first path returned by the Directions service, and in case a barrier is present, the coordinates of the alternative point are passed as parameter to the same service to obtain another path that transits through such point. The parameter is the *wayPoints* array, which may contain till 8 points. The new path returned by the service is checked again and, if it does not contain architectural barriers, it is proposed to the user, otherwise the previous procedure is iteratively repeated for all the barriers until the maximum number of way points is reached. If none of the three saved path provides a positive result, the app notifies the user that no accessibile path to reach the required destination exists. Algorithm 1 reports the pseudo-code of the function WalkingPath implementing this algorithm. As one can notice, the function repeatedly calls Google Directions API (called GoogleDirections in the pseudo-code), passing it the *wayPoints* array as parameter; then uses the function HasBarrier to check if there is at least a barrier in a route, and calls the function UpdateWayPoints to add a new point to the *wayPoints* array, which corresponds to the alternative point related to the first barrier encountered in the route.

Algorithm 1

```
Function WalkingPath(startLocation,endLocation,modality,barriers)
   wayPoints ← []
   routes ← GoogleDirections(startLocation,endLocation,modality,
                              wayPoints)
   numberOfRoute ← NumberOfRoutes(routes)
   if Count(routes) = 0 then
      ShowMessage('NoRoutes')
   else
      currentIndex ← 0
      hasBarriers ← true
      while (currentIndex < numberOfRoute AND hasBarriers) do
         hasBarriers ← HasBarrier(routes[currentIndex],barriers)
         if hasBarriers then
            if Count(wayPoints) < 8 then
               wayPoints ← UpdateWayPoints(routes[currentIndex],barriers)
               routes[currentIndex] ← GoogleDirections(startLocation,
                                      endLocation,modality,wayPoints)
            else currentIndex ← currentIndex + 1
         else ShowRoute(routes[currentIndex])
      end while
      if currentIndex = numberOfRoute then
         ShowMessage('NoRoutes')
end function
```

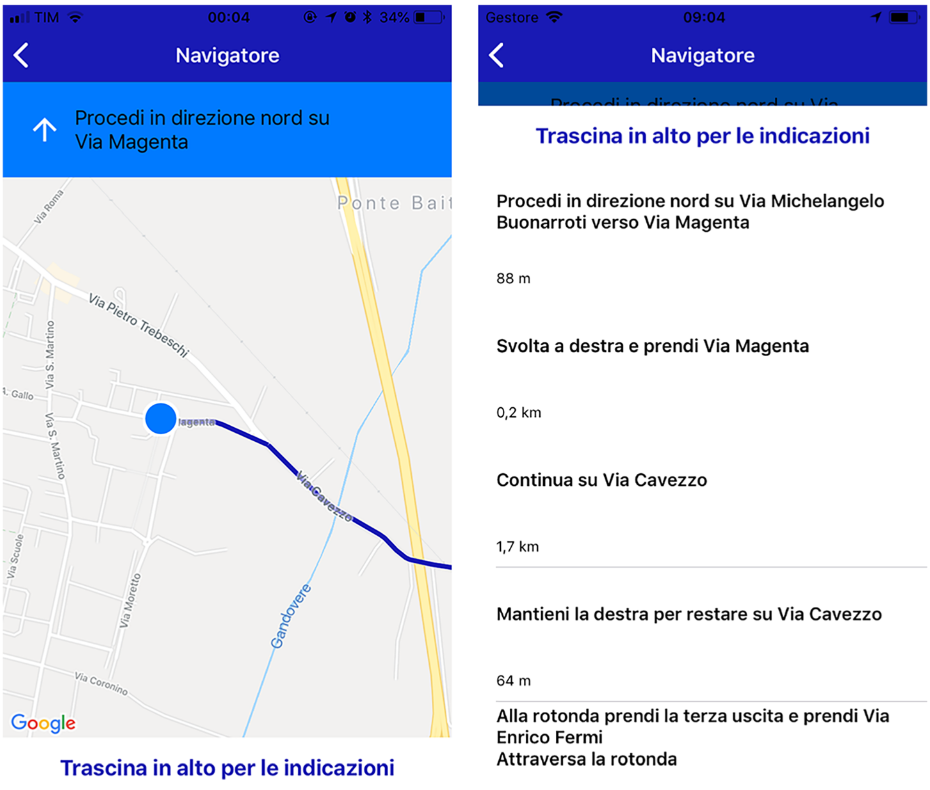
In the case of public transportation modality, since the path is usually a combination of public transportation and walking segments (as currently occurs also in Google Maps), the algorithm properly creates the entire path by exploiting the algorithm previously described for generating accessible walking segments.

4.2.3 Navigation

The path generated by the algorithm discussed in the previous section is stored in a JSON file. This file includes all route directions, times and segment lengths and, if the starting point is set to "La mia posizione" ("My position"), it can be used by the navigator and by the text-to-speech feature. In particular, a new navigator, as much similar as possible to the Google Maps navigator, has been developed for the sake of this project: the map with the path occupies the main part of the screen, and a textual indication about the next step is shown in the top of the screen (Fig. 6a); in addition, a collapsing toolbar includes the list of route directions (Fig. 6b). A voice guides the user throughout the path towards the destination.

Two operation modalities have been implemented, the former for pedestrian paths, the latter for paths with car/public transportation. These modalities differentiate with respect to the frequency used to update the user position and to the tolerance used to provide the user with new indications. For example, when the user is at a given distance from a turning point, he/she is notified by the navigator. The distance depends on the chosen tolerance in the two modalities, which has been determined after a number of tests.

Differently from Google Maps, if the user takes a wrong direction, UniBS4All does not recalculate the path automatically, but it alerts the user and brings him/her to the main screen.



(a) (b)

Fig. 6 The navigator with graphic instructions (a) and textual indications (b)

The need to keep efficiency at an acceptable level, given the operations necessary to recalculate a new accessible path, led the developers to adopt this choice.

4.2.4 Crowdsourcing

A functionality available in the Navigation drawer allows the user to signal the presence of an architectural barrier (Fig. 7). Here, the user may insert a description of the barrier and indicate the category of disability associated to it. This information, coupled with the GPS coordinates of the user, is sent to the web portal, where subsequently an expert can perform a validation activity, add the alternative point and save all data in the database.

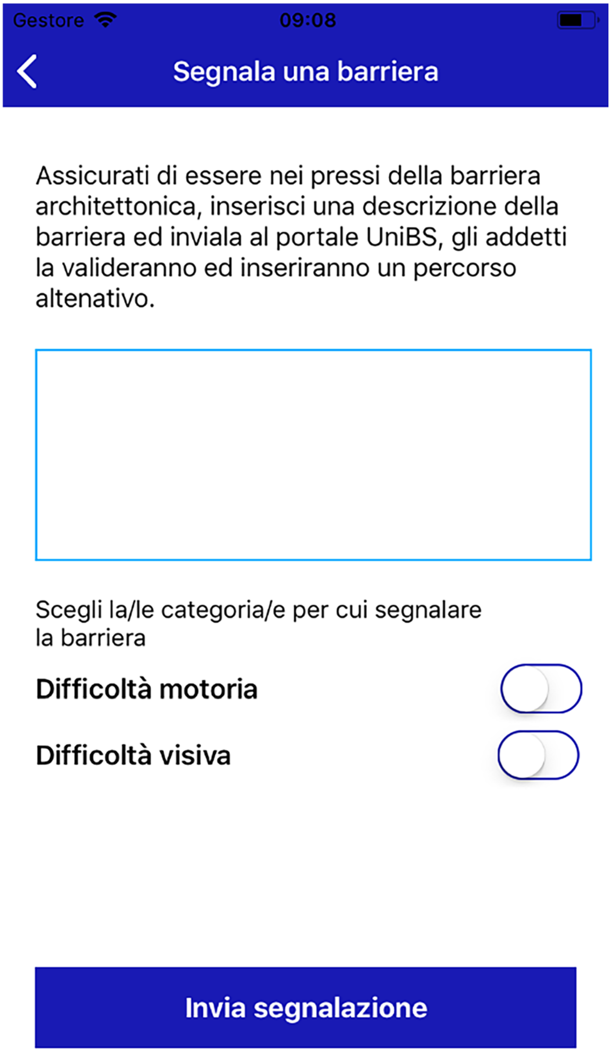


Fig. 7 Screen for signaling an architectural barrier

4.2.5 Accessibility for visually impaired people

To make the app accessible to visually impaired people, the iOS version of UniBS4All implements Apple Voice Over. Voice Over is a speech synthesizer that allows users to listen to object descriptions and interact with the app with suitable gestures (such as scrolling for listening or double-click for function activation), as well as to properly use the virtual keyboard. Each graphic element of UniBS4All has thus been associated with an accessibility label that can be read when the element is selected.

Then, the AVFoundation framework API has been used to integrate services for reading, interpreting and listening to textual information. In this way, the starting and destination points can be inserted through the Voice Over keyboard or through dictation. A tutorial has been implemented to explain the app functionality; it has been specifically studied to allow blind users understanding the general structure of the app without the assistance of other people. In addition, specific sounds are produced by UniBS4All to inform the user about changes in the user interface; for instance, whenever the list of possible destinations is updated, this is notified to the user by a given sound.

5 Evaluation with users

5.1 Experiment 1

A first usability experiment with 10 users was carried out on the Android version of UniBS4All. The goals of this experiment were identifying the main interface problems and collecting feedback by the users about the usability and usefulness of the app.

5.1.1 Method

A pre-questionnaire was submitted to the ten participants for collecting demographic information and other data related to education, profession and experience. Four females and six males participated in the experiment, their age ranged in 22–48 ($M = 29.4$, $SD = 10$). All participants had at least a secondary school education. As to profession, the sample included students, clerks, shop assistants, teachers, nurses, and housewives. Five participants declared mobility impairments, and one participant declared visual impairments. The users were asked to perform six tasks and one scenario, as follows:

Task 1: Set your profile indicating your impairments.

Task 2: Visualize the reserved parking lots near the Faculty of Engineering of the University of Brescia and set one of them as destination.

Task 3: Find the path with “Public transportation” modality from the “Brescia train station” to “Via Branze 38”.

Task 4: Find the pedestrian path from your current position to “Via Branze 38”. Visualize the indications and then run the navigator.

Task 5: Find the car route from your current position to “Teatro Grande Brescia”. Check if the route transits for a ZTL.

Task 6: Find the car route from your current position to the student administration offices of the University of Brescia.

Scenario: You are a student of the Law Faculty. You live in Bergamo [a town 50 km far from Brescia] and have a mobility impairment. You discovered that tomorrow morning a famous lawer will present his book at the "Teatro Grande" in Brescia. You have the transit permit no. 424242 related to the car plate ED042NN for traveling in ZTL. Use UniBS4All to find the fastest path with private car to reach the destination from home and send an email to the local traffic authority about your transit in the ZTL.

The smartphone of an experimenter was used in all the trials, but the users did not found any difficulty in using some other's device. No formal training was provided; only a brief explanation of the context and the goals of the project was given before starting the test. No reward was provided to the participants.

For each task and scenario, participants indicated its perceived difficulty on the qualitative scale {"very easy", "easy", "medium", "difficult", "very difficult"}. Furthermore, the completion rates were collected. Qualitative data from direct observation and comments of participants were annotated as well. In addition, at the end of the experiment, an interview was conducted with users to investigate the following questions:

Q1: Do you like the graphics of the app?
Q2: Do you think that the app is easy to use?
Q3: Do you think that the user interface is similar to that of Google Maps?
Q4: Do you think that the app might be useful for disabled people?
Q5: What do you like most of the app?
Q6: What don't you like of the app?
Q7: Do you have some suggestions to improve the app?

Finally, we submitted the System Usability Scale (SUS) questionnaire [5] and the Net Promoter Score (NPS) [32] to obtain a quantitative estimation of the app usability and user satisfaction respectively. SUS gives an overview of the user's subjective usability evaluation of a given system. It is a closed-ended questionnaire encompassing 10 statements on an ordinal 5-point Likert scale from "strongly disagree" to "strongly agree"; a single score ranging from 0 to 100 can be calculated on the basis of the responses to the questionnaire. NPS is a single closed-ended question asking a person to rate on the 0–10 point scale the likelihood of recommending a product or service to a friend or colleague and was originally proposed as a way for gauging the customer's overall satisfaction with a company's product or service and the customer's loyalty to the brand. NPS result may range from −100 to 100.

5.1.2 Results

Table 1 presents the results about the perceived difficulty and completion rate of each task and scenario. As to perceived difficulty, most of participants found the first three tasks "very easy" or "easy". Tasks 4 and 5, which were composed of different actions, were judged by most of the users as "easy" or "medium" to execute. Two participants assigned the "difficult" score to Tasks 6, because identifying the student administration building as destination, without knowing its approximate position in advance, was actually difficult for the majority of people (but this problem was solved in the iOS version as described in Section 4.2.2); only one participant assessed the scenario as "difficult", while most of the other users considered it as "easy", thus demonstrating that the application is easy to learn.

As to the completion rate, only Tasks 4 and 6 were not completed by all users. The problems encountered by the users were however useful to provide suggestions for

Table 1 Perceived difficulty of tasks and scenario and related completion rates (Android version)

	Very Difficult	*Difficult*	*Medium*	*Easy*	*Very Easy*	*Completion rate*
Task 1	–	–	–	*2*	*8*	*100%*
Task 2	–	–	*1*	*5*	*4*	*100%*
Task 3	–	–	–	*2*	*8*	*100%*
Task 4	–	–	*4*	*5*	*1*	*80%*
Task 5	–	–	*6*	*4*	–	*100%*
Task 6	–	*2*	*2*	*6*	–	*80%*
Scenario	–	*1*	*3*	*6*	–	*100%*

improvement. Interestingly enough, all participants completed the scenario, even though it was more articulated than the previous tasks.

From the observations and comments gathered during the experiment we found that some users did not initially understand that the icons of parking lots can be selected and used as destinations; also the use of the ZTL button for opening the precompiled email to be sent to the traffic authority was not so intuitive; furthermore, in the tasks requiring to find a path from the current position to a given destination, some inefficiencies emerged in case the GPS was not active. Finally, we derived several indications for improvement, which have been implemented in the iOS version described in Section 4.2: for instance, the users suggested to make icons more explicative; another suggestion is concerned with the visualization of route directions that, according to the users, should be provided just after the path computation, and not only in the navigator section; similarly, they proposed to visualize the position of ZTLs, if any, as soon as possible, thus anticipating the time of path acceptance or rejection before the navigator activation.

The interview provided encouraging results: all participants gave positive answers to questions Q1-Q4. As to Q5, the users appreciated the limited number of screens that help remembering the actions to perform, and they also declared their appreciation for the purposes of the application. The answers to question Q6 were focused on the ZTL management, because the meaning of the red button was not clear (this problem has been solved in the iOS version of the app). Among the answers to Q7, some participants suggested to provide a search chronology and to give the possibility of inserting permit information just before sending the email, thus avoiding to fill them in advance in the user profile; both suggestions have been implemented in the iOS version of the app.

Finally, the average value of the SUS score resulted to be 88.25, and the individual scores all greater that 68.5, the threshold usually adopted for declaring that a system is easy to use [4]. The NPS score was equal to 80, much higher than the level for declaring the success of a product (NPS > 50).

5.2 Experiment 2

A second experiment was carried out after the development of the first version of the iOS app, which integrated some of the improvements suggested by the experiment with the Android version.

5.2.1 Method

Other 10 participants (5 females) used the iOS version of UniBS4All: their age ranged in 17–52 (M = 34.5, SD = 12); 2 participants declared to have a primary school degree, 7 a high school degree, and 1 a university degree; the sample included clerks, workmen and students.

Three participants declared mobility impairments, one declared a deep deafness and two participants were blind.

The procedure for carrying out the experiment and the collected information were the same of the first experiment. The only difference was that, instead of providing a brief explanation of the project, the participants were encouraged to see the (new) app tutorial before executing the first task.

5.2.2 Results

Table 2 presents the results about the perceived difficulty and completion rate of each task and scenario executed with the iOS version of UniBS4All.

These results indicate that some features have been improved, since no participant considered a task/scenario “difficult” or “very difficult”. Particulary, all tasks, out of Task 2, have been considered “very easy” or “easy”. The two blind users found the difficulty of Task 2 as “medium”, since they had problems in selecting a parking lot directly on the map (they could search for it, but they did not know its name and this was not suggested in the task description). For this reason, they were not able to complete the task as requested in the experiment. All participants completed the scenario, and only one of them judged its difficulty as “medium”, whilst the others considered it as “very easy” or “easy”.

Also in this case, the answers provided in the interview were encouraging: all users highlighted how the interaction was intuitive and the functionality easy to learn. In particular, the two blind users appreciated the Voice Over features by judging it effective and coherent with the usual interaction with iOS devices.

As to Q7, the blind participants suggested to use a different sound for list updates (the chosen sound was the same of Siri functionalities), and to prepare a speech video instead of the tutorial that is currently read by Voice Over. The user with hearing impairment did not provide specific suggestions, since she did not encountered any problems in using the app.

The resulting SUS score was equal to 90 and the NPS resulted to be equal to 80, both much higher than the average thresholds.

5.3 Experiment 3

A third experiment was performed on the revised iOS app to better test the navigator and investigate the correctness, usability and accessibility of the new features and improvements integrated in the app. Since this experiment was carried out in a real context and not in the laboratory, this may be considered a pilot field study of the application.

Table 2 Perceived difficulty of tasks and scenario and related completion rates (iOS version)

	Very Difficult	*Difficult*	*Medium*	*Easy*	*Very Easy*	*Completion rate*
Task 1	–	–	–	*3*	*7*	*100%*
Task 2	–	–	*3*	*5*	*2*	*80%*
Task 3	–	–	–	*6*	*4*	*100%*
Task 4	–	–	*1*	*5*	*4*	*100%*
Task 5	–	–	–	*6*	*4*	*100%*
Task 6	–	–	–	*4*	*6*	*100%*
Scenario	–	–	*1*	*6*	*3*	*100%*

5.3.1 Method

Other five users (3 females, age M = 36.6, SD = 14) have been recruited for this experiment. None of these users had a university degree. Two participants declared to have mobility impairments and one user was blind. The procedure adopted for the execution of this experiment was the same of the other experiments, as well as the prepared documents and the type of data collected. However, participants were requested to carry out five new tasks, some of them requiring to follow the suggested pedestrian paths. To this end, task execution was performed starting from the courtyard of the Engineering Building of the University of Brescia. Here are the new tasks:

Task 1: Find the pedestrian path from your current position to "Via Branze Brescia", run the navigator and follow step-by-step the indications. Verify if the navigator brings you to the required destination.
Task 2: Pretend that in your current position there is an architectural barrier: send the notification of barrier presence, including a barrier description.
Task 3: Find the pedestrian path from your current position to "Via Branze 38". Take voluntarily a wrong direction and verify if within 200 m UniBS4All alerts you that you are in a wrong path.
Task 4: Find the path from your current position to "Via Branze Brescia" by dictating the destination to UniBS4All.
Task 5: Find the path from your current position to "Via Valotti Brescia". Verify if the navigator provides you the correct textual indications in the specific section.

5.3.2 Results

Table 3 summarizes the perceived difficulty and completion rate of each task executed in the third experiment.

As one may observe, all users completed the five tasks. Almost all the tasks were considered as "Very Easy" or "Easy". These results suggest that the revised version of the app operates correctly and the new features are coherent with the rest of the app, which, as a whole, can be considered easy to learn and to use also by people with disabilities.

These positive results were confirmed by the feedback gathered through the interview. For instance, all participants replied "Definitely yes" to Q4 ("Do you think that the app might be useful for disabled people?"). An observation that emerged during the interview is that most of the pedestrian paths are visualized on the roadways and not on the sidewalks, and thus the user position

Table 3 Perceived difficulty of tasks and scenario and related completion rates (revised iOS version)

	Very Difficult	*Difficult*	*Medium*	*Easy*	*Very Easy*	*Completion rate*
Task 1	–	–	–	*3*	*2*	*100%*
Task 2	–	–	–	*1*	*4*	*100%*
Task 3	–	–	–	*2*	*3*	*100%*
Task 4	–	–	*1*	*2*	*2*	*100%*
Task 5	–	–	–	*2*	*3*	*100%*

appears as not strictly following the suggested paths. However, this is a problem of the Google Maps API that returns the paths used in UniBS4All. Luckly, in the last months, Google is carrying out a mapping campaign of sidewalks, and thus the problem will be automatically solved.

Very high scores have been obtained also in this case for the SUS and NPS (equal to 93 and 80 respectively).

6 Discussion and conclusion

In this paper we have presented UniBS4All, a project encompassing a web portal and two versions of a mobile application for accessible path finding and navigation, currently applied and tested at the University of Brescia. In this section, we summarize the original contribution of the work with respect to the existing literature, and discuss some open issues for future research.

6.1 Original contribution

With respect to other literature approaches, we followed the Universal Design perspective, in that our mobile app is not focused on visualizing and notifying architectural barriers and accessible routes, but on supporting every user, with or without impairments, or possibly with a temporarily impairment (e.g., a person carrying a heavy object, a parent driving a stroller, etc.), to find the path that best fits his/her needs and preferences. The mobile app is based on Google Maps APIs and exploits its Directions service and available data. In particular, data about Points of Interests (POIs) and sidewalks are thus kept automatically up-to-date, and urban accessibility experts should provide only architectural barriers and alternative points.

The development of the mobile app was carried out to obtain not only a high usability, but also to satisfy accessibility requirements, especially for low vision and blind people. Indeed, these people may take advantage by an app that drives them along accessible paths, but this app should in turn be accessible itself. This aspect is usually disregarded in other approaches and solutions proposed in literature.

Literature works are mostly focused on accessible pedestrian paths and on people with mobility impairments such as those on wheelchair. The integration with Google Maps services allowed us not only to provide users with pedestrian paths, but to drive them along car routes (possibly travelling through ZTLs and/or reaching reserved parking lots) and to give information about paths exploiting public transportation.

Differently from existing literature in the field, the UniBS4All project arises from two main assumptions:

1) The PEBA and PAU documents that local administrations and public building managers must prepare to comply with Italian law should become "live" documents, that is, information that does not remain in an office drawer but that can be exploited immediately by all the citizens;
2) The project must be sustainable over time, also without the continuous intervention of software developers.

The above considerations led us to follow a *meta-design* approach [14, 15]; indeed, we did not only focus our attention to the development of a mobile app to avoid architectural barriers, but we conceived a more extended framework where a web portal for accessibility experts and local administration authorities could be used to evolve the project and apply it to a variety of contexts. The web portal is an easy-to-use web application for registering and characterizing geographical data, much more simpler than a GIS. Beyond allowing users to insert architectural barriers and their related alternative points, the portal includes a functionality for defining the categories of user impairment to be associated to architectural barriers, the possibility of drawing limited traffic zones on the map, and a functionality for indicating parking lots reserved to disabled people. All these features represent the first core of a tool devoted to experts in charge of preparing PEBA and PAU documents, which constitute the first step for barrier removal. This allows increasing urban accessibility by combining building interventions (material part) with information management (immaterial part).

Moreover, inspired by literature work [7, 10, 25], we integrated a crowdsourcing feature in the mobile app: users are thus able to signal the presence of barriers associated with their location (they can also be temporary works that cause architectural barriers); these notifications then appear in the web portal. In this way, the hard work that public administrators are called on to perform in order to satisfy current legislation [2, 19] may be facilitated by citizens' participation. However, it is important to underline that citizens' notifications about barriers usually represent partial and subjective perspectives. For this reason, the notifications arriving in the web portal must be validated by accessibility experts, who have the authority and competence to perform a site inspection and possibly identify alternative points to update the database used by UniBS4All. Alternatively, a trustworthiness model might be implemented to improve crowdsourced data following the proposal presented in [29].

Finally, in the project, the typical co-evolution of users and system phenomenon was observed [3, 6]: during the development of UniBS4All, thanks to the use of Googles Maps API, we realized that the original idea of developing an app just for the University of Brescia, could be extended by the creation of a more general app that, when its underlying database is properly populated, may help every citizen of Brescia or any other Italian town (or, in principle, any other town in the world) find an accessible path.

6.2 Limitations and future work

Notwithstanding the satisfying results obtained in the experiments with users, additional evaluation activities with much more users should be carried out, not only on the mobile app but also on the web portal. Such evalution should also include extented field studies.

The Android version of the app should be aligned with the iOS version, both in terms of functionality and accessibility features. In both versions, optimizations of the implemented algorithms could be studied, also to support efficient real-time path re-calculation when the user takes a wrong direction. Moreover, in the current version, the user profile is static and depends on user's explicit indications, whilst it might be useful to make the app adaptive by learning the user profile on the basis of the observed behavior, as proposed in PAM [21]. Furthermore, UniBS4All does not personalize paths for hearing impaired people; even though during the tests these people did not required specific features, this aspect should be explored in the future.

Literature work presents very interesting approaches to automatic collection of data about users' preferred paths and architectural barriers, by means of different kinds of sensors available in the mobile devices [10, 25]. Since the burden of inserting architectural barriers in UniBS4All is currently almost totally on the accessibility experts' shoulders, it would be interesting to study an approach that integrates these implicit and explicit modalities for data collection.

In addition, we are exploring the use of Google Maps APIs also for indoor navigation. To this aim, plants of buildings must be uploaded on the proper Google service, markers should be created to map all the relevant places inside buildings (e.g., rooms, stairs, elevators and so on), as well as architectural barriers and their alternative points must be added to our database. Since it is based on Google Maps Directions API, the algorithm used by UniBS4All to generate accessible paths can work also in the case of indoor navigation. However, suitable mechanisms for user localization inside buildings must be adopted in alternative to GPS; the idea of using Bluetooth Low Energy (BLE) sensors (beacons in brief), as proposed in the AlmaWhere project [12] and that we already tested in terms of accurancy and efficiency [13], appears as a promising solution to this problem. We are also planning to widen the project by integrating these navigation features into another system we developed in the cultural heritage domain, aimed at enhancing interaction with artworks in museums and cultural sites [18].

An important work we are planning to carry out soon is extending the web portal for barrier management to obtain a complete tool that supports local administrators in the preparation of PEBA/PAU documents while they populate the database of UniBS4All.

Finally, accessibility of the web portal should be supported as well, for example by taking into account the results obtained in [16], by implementing suitable design patterns [17].

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