An Indoor Navigation System for Reduced Mobility Users

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Abstract: Indoor navigation systems help pedestrians to find the best paths inside buildings. Existing systems only respond to the needs of reduced mobility users occasionally, by avoiding stairs. However, this is an obvious requirement, unlike others that are almost invisible to people without restrictions. This paper presents the results of the development steps of an indoor navigation system for reduced mobility users. In addition, we systematize the relevant information about the indoor environment that must be gathered to instantiate the requirements to a specific case. Finally, the paper overviews the developed prototype and describes its evaluation.

1 INTRODUCTION

Reduced mobility users demand additional requirements to indoor navigation systems, such as excluding stairs from calculated path (de Oliveira et al., 17). However, problems reduced mobility users face go beyond stairs and several barriers are almost invisible to people without restrictions (Dzafic et al., 14).

In the last years, indoor navigation systems contributions focus on solving two main problems: user positioning and handling three dimensional (3D) environments. Global Positioning System (GPS) cannot be used straightforward in indoor environments, where its signal is generally not available (Gerstweiler et al., 15). Due to this restriction, for indoor user positioning, there are many proposals in the literature that resort to smartphone functionalities, such as kinematic techniques that use accelerometers and gyroscopes sensors (Pombinho et al., 11; Moder et al., 15), visual techniques that use cameras (Koch et al., 14; Carboni et al., 15; Deretey et al., 15; Gao et al., 16), and wireless techniques (Fallah et al., 13; Jain et al., 13; Koide and Kato, 05; Ozdenizci et al., 15; Matos et al., 14; Faragher and Rice, 15).

Indoor navigation systems represent 3D environments, i.e., buildings with many floors with two dimensional or as 3D representations (Koide and Kato, 05; Thill et al., 11). Despite 3D representations can provide more information, they need more storage and processing.

In addition, performance problems are raised when algorithms used to calculate best paths are applied in 3D environments. Bian et al. (2014) present an approach that overcomes these performance issues in 3D environments. These algorithms have also been subject to adaptations to meet specific needs or preferences of users (Fallah et al., 13; Koide and Kato, 05; Akasaka and Onisawa, 08). In (Koide and Kato, 05) and (Akasaka and Onisawa, 08), the authors already address some specific needs of wheelchair users, calculating paths that do not include stairs. However, as stated before, avoiding stairs from calculated path is just one (and an obvious one) requirement for reduced mobility users. As far as we know, Dzafic et al. (2014) present the widest work about wheelchair user requirements for this kind of systems.

With the final goal of developing an indoor navigation system for reduced mobility users, in this paper, we start by focusing on the requirement analysis phase of our work. Based mainly on the work of Dazfic et al. and on the experience of one of the members of our team who is a wheelchair user, we start by eliciting customer oriented requirements (C-requirements) and then we detail developer requirements (D-

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requirements) associating them with each component of the system: user positioning, path planning, representation, and interaction. In addition, we systematize the information about the indoor environment that needs to be collected before developing its navigation system. Finally, we also present the w4all, an indoor navigation system for reduced mobility users, and its evaluation phase that involved users with normal and reduced mobility. A preliminary version of this work can be found in (Cardoso et al., 16).

Next section presents related work, while Section 3 details the requirement analysis of indoor navigation systems for reduced mobility users. Section 4 describes the w4all prototype and Section 5 presents its evaluation. Finally, last section ends with future research directions and conclusions.

2 RELATED WORK

According to Fallah et al. (2013), an indoor navigation system can be organized in four components: user localization (also named user positioning), path planning, representation, and interaction. This section presents the main challenges of each one of these components and the corresponding contributions of the state of the art.

2.1 User Positioning

The user positioning component is responsible for determining user's position. GPS, widely used to determine outdoor positions, is not adequate for indoor environments because its signal is generally not available here (Gerstweiler et al., 15). Still being an open research area, we can find many proposals in the literature for indoor positioning that take advantage of smartphone functionalities, such as sensors (accelerometers and gyroscopes), cameras, and wireless technologies (Koch et al., 14; Carboni et al., 15; Fallah et al., 13; Jain et al., 13; Ozdenizci et al., 15). The proposed positioning techniques can be grouped into three different classes (Jain et al., 13): kinematic, visual, and wireless; which can be combined to enhance position accuracy (Molina et al., 18; Torres-Sospedra et al., 18).

Kinematic techniques estimate user positions based on previously estimated or known positions by using accelerometers and gyroscopes smartphone sensors and dead reckoning algorithms (Pombinho et al., 11; Moder et al., 15).

On the other hand, visual techniques determine user position by comparing environment images captured with the smartphone camera with reference images stored in a database (Koch et al., 14; Deretey et al., 15; Gao et al., 16). These reference images can be encoded using, for instance, Barcodes or QR-Codes (Carboni et al., 15).

Finally, wireless techniques calculate user position resorting to light waves or radio waves. They can be sub-grouped in direct sensing, triangulation, and fingerprint techniques. The first ones (direct sensing) use identifiers or tags previously installed in the environment, supported by technologies such as RFID, Infrared, Barcodes, or NFC (Fallah et al., 13; Jain et al., 13; Koide and Kato, 05; Ozdenizci et al., 15). Indoor triangulation techniques use Wi-Fi technology and determine user position by triangulating the position of access points (APs) through their signal strength, as GPS does for outdoor positioning. Lastly, fingerprinting techniques calculates user position by comparing the signal strength that the user device receives from APs with a pre-built fingerprint database (Matos et al., 14; Faragher and Rice, 15).

Focusing on Wi-Fi based techniques, the ones we use in the w4all system, they are convenient only if there is a set of pre-installed dedicated APs, as they are error prone and costly to maintain (Carboni et al., 15). Comparing triangulation with fingerprint, the first one has better results in open spaces, while fingerprinting is better for environments with restricted pathways (Carboni et al., 15). In addition, we point out that the use of virtual APs, a technique where a single AP is used to realize multiple APs, significantly reduces position estimation errors, as stated in (Fallah et al., 13).

2.2 Path Planning

The path planning component calculates routes or paths. It determines the best path, normally the shortest one. The best path can also take into consideration user preferences or constraints, such as the requirements of users with reduced mobility (Fallah et al., 13; Koide and Kato, 05; Akasaka and Onisawa, 08).

Additional functionalities that this component can provide include calculating different paths to a destination, and dynamically re-calculating the path as user position changes or when the system detects that the user is not following the initial path.

Path planning components usually apply the Dijkstra or the A* algorithms to calculate the best path. These algorithms represent the environment by using graphs or grids (Fallah et al., 13). Graph based approaches divide the environment in a set of nodes connected with edges. Nodes represent doors, hall intersections, or elevators, for instance. Edge connects two nodes that are accessible from one another. Edges can have weights used to define preferences for the path planning algorithms (Bian et al., 14). In grid-based approaches the environment is divided into small parts named cells. As edges, cells can also have associated weights.

Comparing to outdoor systems, indoor systems present an additional challenge when the building has several floors. Bian et al. (2014) improve the A* algorithm to solve performance problems when it is applied to a building with many floors, considering, as well, user's preferences.

2.3 Representation

Indoor navigation systems represent the environment using maps, and, especially, floor plans, mostly (Russo, 13). In addition to 2D maps, some proposals use 3D maps (Koide and Kato, 05; Thill et al., 11).

Maps can also include information about the position and description of objects (such as room numbers), as well as points of interest (PoIs) that help to identify the space, such as statues, bars, the reception, or the information office.

2.4 Interaction

The interaction component includes user input and system feedback functionalities. User input for indoor navigation systems, mainly used in mobile devices, is similar to other mobile applications. However, system feedback presents more specificities related to this kind of applications. To provide directions to the user, audio, visual and haptic techniques are used. Some proposals apply a combination of these techniques to overcome particular limitations that each one presents individually (Fallah et al., 13).

2.5 Conclusions

Reduced mobility users have specific restrictions that current indoor navigation systems only meet occasionally, mainly providing paths without steps. Dzafic et al. (2014) identify the requirements of an indoor navigation system for reduced mobility users. Starting from this work, in this paper, we analyse requirements of indoor navigation systems for reduced mobility users. Besides that, as requirements depend on the characteristics of a specific building, we also systematize the information about this environment that must be collected before starting the system development.

3 REQUIREMENTS ANALYSIS

This section describes the requirements analysis of an indoor navigation system for reduced mobility users. We start by eliciting and analysing generic requirements for reduced mobility users and, after that, we systematize the information we need to gather from the environment to identify its barriers. We applied these results in the deployment of the w4all system, as detailed in the next section.

3.1 Elicitation and Analysis of Generic Requirements

To elicit requirements for indoor navigation systems, we surveyed related work and used the experience of one of the elements of the team, a wheelchair user. As far as we know, Dzafic et al. (2014) present the widest work about wheelchair user requirements for this kind of systems. These authors classify requirements as permanent vs. transient and absolute vs. mitigable. Permanent requirements are related to barriers that remain unchanged for a long time, while transient only last for a short time. Absolute requirements are applied to barriers that cannot be bypassed, unlike mitigable that can be overcome with the help of another person. In the following, we detail each requirement (C-Requirements), identifying the system components they influence.

Permanent and absolute requirements:

C1) *Handling of steps* includes two different requirements, one for the representation component (the "system should provide information about every stair, its height and the number of steps" (Dzafic et al., 14)) and one for the path planning component ("avoiding steps should be a primary goal for an indoor navigation system addressing handicapped" (Dzafic et al., 14)). Notice that a high number of huge steps is an insurmountable obstacle for a wheelchair user. But, for instance, one sole step with a small height can be a mitigable obstacle.

C2) *Avoidance of steep incline* also presents a requirement for the path planning component: "steep incline should be avoided according to the maximum doable incline settled by the user" (Dzafic et al., 14). The representation component should, as well, provide information about steep ramps.

C3) *Recording of door widths* implies that the path planning component should present paths free of too narrow doors, including elevator doors. This is also information that the representation component should provide.

Table 1: D-requirements for each component of an Indoor Navigation System.

	user localization	path planning	representation	interaction
Permanent and abso-lute requirements:				
C1) Handling steps		D1.1) Calculate paths without steps	D1.2) Show informa-tion about stairs	
C2) Avoidance of steep incline		D2.1) Calculate paths without steep incline	D2.2) Show informa-tion about ramps	
C3) Recording of door widths		D3.1) Calculate paths without narrow doors	D3.2) Show informa-tion about door widths	
Permanent and miti-ga-ble requirements:				
C4) Handling of automatic doors		D4.1) Calculate paths excluding automatic do-ors that have unreacha-ble buttons or small timers	D4.2) Show informa-tion about automatic doors that have unreachable buttons or small timers	
C5) Handling of non-automatic doors		D5.1) Calculate paths without non openable manual doors	D5.2) Show informa-tion about non openable manual doors	
C6) Avoidance of revolving doors		D6.1) Calculate paths without revolving doors	D6.2) Show informa-tion about revolving doors	
C7) Indication of stair lifts			D7.1) Show informa-tion about stair lifts	
C8) Indication of toilets for disabled persons			D8.1) Show information about disabled toilets	
C9) Indication of emergency exits and security zones			D9.1) Show informati-on about emergency e-xits and security zones	D9.2) Provide path to security zone
Transient and abso-lute requirements:				
C10) Monitoring of elevator status	D10.1) Determine elevator status	D10.2) Calculate paths without broken elevator D10.3) Calculate alternative paths	D10.4) Show information about elevator status	D10.5) Provide alternative paths
C11) Wheelchair localization	D11.1) Monitor wheelchair localization			
Transient and mitiga-ble requirements:				
C12) Indication of POIs			D12.1) Show informa-tion about PoI	D12.2) Provide path to PoI
C13) Recording of opening hours		D13.1) Calculate paths considering opening hours of doors		

Permanent and mitigable requirements:

C4) *Handling of automatic doors* involves the identification of the opening mechanism (if the door opens by pressing a button, it can be a problem depending on the button position) and how long the door is kept open. As this requirement is mitigable, the user can use these doors if he has assistance, otherwise the path planning component should avoid these doors while calculating paths. Similar to previous requirements, this is another kind of information that the representation component should also consider.

C5) *Handling of non-automatic doors* requires the evaluation of the strength the user needs to open the door as well as its opening direction. These doors lead to the same requirements as automatic doors.

C6) *Avoidance of revolving doors* also constrains the way path planning component calculates paths. The representation component should also provide information about revolving doors.

C7) *Indication of stair lifts* should be included in the representation component. As stair lifts usually need an activation key or the assistance of a staff member, this information should be provided in advance to avoid unnecessary delays.

C8) *Indication of toilets for disabled persons* is a requirement for the representation component. It could also include additional information, such as the need for a key and its location.

C9) *Indication of emergency exits and security zones* presents a requirement for the representation component as well as for the interaction component, since the interface should include the functionality to ask for the path to the security zones.

Transient and absolute requirements:

C10) *Monitoring of elevator status* defines requirements for all the components. The user localization component can monitor the status of elevators by monitoring users' movements. For instance, it is possible to determine that an elevator is working if users' location change from one floor to another floor not resorting to stairs. The representation component should also provide information about elevator status, while the interaction component should include an additional functionality to calculate an alternative path, if a user finds out that an elevator he was about to use is after all out of order. Consequently, besides calculating paths without broken elevators, the path planning component should calculate alternative paths, i.e., paths including another elevator.

C11) *Wheelchair localization* is a requirement that the location component should accomplish.

Transient and mitigable requirements:

C12) *Indication of PoIs* is a requirement for the representation component. In addition, the interaction component should also provide the functionality to ask for paths to specific PoIs.

C13) *Recording of opening hours* presents an additional constraint for the path planning component as path calculation should also consider which doors are open in each period of the day.

Table 1 systematizes the developer requirements (D-requirements) for each of these C-requirements, considering the four main components of an indoor navigation system.

3.2 Identifying Environment Barriers

After identifying C-requirements and D-requirements for an indoor navigation system for reduced mobility users, we need to analyse the specific environment and its barriers. The following list enumerates the information about the building that we need to obtain:

1. Stairs: number of steps and their height, to distinguish absolute from mitigable situations.
2. Ramps: inclination of ramps to distinguish steep ramps from the ones that are specially designed for wheelchair users.
3. Doors: door widths, including elevators' doors.
4. Automatic doors: button position and how long the door is kept open.
5. Non-automatic doors: door strength and opening direction.
6. Stair lifts: location of key and staff assistance.
7. Location of revolving doors, toilets for disabled persons, emergency exits, security zones, and elevators.
8. Opening hour of doors.

This environment study should be done *in loco* and preferably with the assistance of a wheelchair user.

4 THE w4all SYSTEM

This section describes w4all, an indoor navigation system for users with normal and reduced mobility, whose development started with the requirement analysis presented in the previous section.

The environment of the w4all is a four-floors building with 23,992 m^2 of a university campus, identified by the name "C6".

Figure 1 illustrates the interface of the w4all system.

Figure 1: The interface of the w4all indoor navigation system.

4.1 Identifying Barriers of the w4all Environment

To identify the barriers of the building, we use the list of section 3.2 and the experience of one of the authors, who is a wheelchair user. The results of the environment study are listed in the following:

1. Stairs: all stairs are unusable for wheelchair users as they have too many steps. The building has inside stairs and some steps in the ground floor.
2. Ramps: the ramps are specially designed for wheelchair users, as an alternative to the steps of the ground floor.
3. Doors: door widths are adequate for wheelchair users.

4. Automatic doors: elevators have automatic doors whose button position and door open time are also adequate.

5. Non-automatic doors: exterior doors are non-automatic doors, whose strength make difficult their opening. We also identified that one of the exterior doors is nearby the security zone, where a staff member can provide assistance.

6. Stair lifts: the building does not have stair lifts.

7. The building does not have revolving doors. We identify the location of bathrooms for disabled people, emergency exits, security zones, and elevators. The emergency exits, in the ground floor, present a problem because they include some steps.

8. Opening hours of exterior building doors: from 8 p.m. to 8 a.m. and during weekends only one building entrance is open.

4.2 The w4all Architecture

The w4all uses the client/server model, as illustrated in Figure 2. The user interacts with the w4all client, which communicates with the w4all server through the HTTP protocol. The information the w4all needs (for instance, fingerprints) is saved in a database. We used the Where@UM application (Matos et al., 14) to get the fingerprints from the environment.

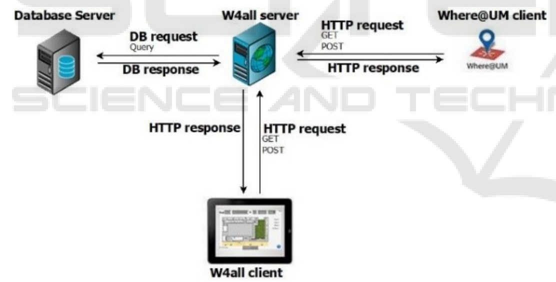

Figure 2: The w4all architecture.

4.3 The w4all Prototype

This subsection presents details about the implementation of the w4all considering its four main components. For each of them, when applied, we detail how we handle specific requirements of reduced mobility users.

4.3.1 User Localization

We use the Wi-Fi fingerprint technique for user localization. This component takes advantage of the already installed eduroam Wi-Fi network, a world-wide roaming access service developed for the international research and education community. Despite existing many other APs in the building, the w4all ignores them because they are not permanent. Each eduroam AP is used to realize two APs (virtual APs), which w4all uses in conjunction, a technique that reduces location estimation errors (Fallah et al., 13).

In some areas of the building, user location is not accurate, due to the reduced number of APs in fingerprintings. To overcome this problem, we only use fingerprints with at least five APs (including virtual APs), assuring that each fingerprint includes at least three different APs (physical APs). Without this restriction, the user localization is error prone, and consequently, the information provided to the user may be potentially misleading. This way, the system presents outdated information rather than an incorrect one, an option that we conclude users prefer after performing some tests. However, the navigation system is not compromised, since interception areas have enough Wi-Fi fingerprints and only some halls in the building present insufficient Wi-Fi fingerprints.

To populate the fingerprint database, we collected fingerprints near the door of each room, in halls interception points, stairs, near elevators, and PoIs. We used the Where@UM application (Matos et al., 14) to handle fingerprints, i.e., to collect, store and compare fingerprints. Presently, the database includes 113 spaces with at least 10 fingerprints each.

User location is calculated by comparing current fingerprints with the ones saved in the pre-built database applying the Manhattan distance (Torres-Sospedra et al., 15). When the system is not able to obtain the current location, the interface provides the information about the last known location (while Figure 1 shows the information about the current position of the user, Figure 3 illustrates the scenario where the system could not determine the current position and shows the information about the last known location - see the information in the bottom left side of the Figure 3 and compare with Figure 1).

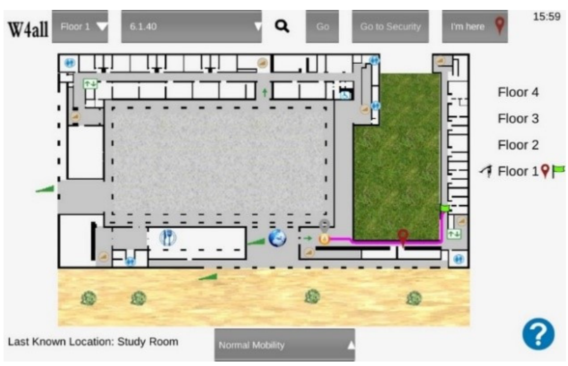

Figure 3: User Location Information.

4.3.2 Path Planning

The path component has two modes: one for users with normal mobility and one for users with reduced mobility. Users can choose the mode they want to use as explained in section 4.3.4.

In normal mobility mode, paths between floors only include stairs, following the environment and energy-saving policy of our university.

Considering the results of the environment study that section 4.1 presents, the reduced mobility mode uses elevators to avoid inside stairs and ramps to avoid the steps of the ground floor. In addition, we classify non-automatic exterior doors as a mitigable requirement because an assistant can help the wheelchair user to bypass the door – this assistant can be the security person of the building. Therefore, in this mode, the path planning component only provides paths whose entrance match the entry door near the security workplace.

Finally, the restriction related to the opening hours of the exterior doors is applied in both modes.

The maps of the building floors are built with Blender (https://www.blender.org), which is fully compatible with Unity3D (http://unity3d.com/pt), the tool we chose for the development of the prototype. These options were made due to the previous experience of the team on using these tools as well as to facilitate the future possibility of including 3D representations in the interface. To calculate path, we used the A* Pathfinding project plug-in for Unity3D with a grid-based approach.

Our algorithm for path calculation is based on the approach of Bian et al. (2014), who consider the cross-storey problem of buildings. In normal mobility mode, paths between floors only use stairs. When the origin and the destination are not in the same floor, our algorithm has the following phases:

1. for every stair repeat
   - 1.1. use the A* to find the path between the origin and this stair
   - 1.2. use the A* to find the path between this stair and the destination
   - 1.3. the results of steps 1.1 and 1.2 give a feasible path
2. choose the best feasible path (the shortest one)

In the reduced mobility mode, the algorithm replaces inside stairs by elevators. In addition, by assigning high weights to the steps of the ground floor, the calculated paths include ramps adequate for wheelchair users.

4.3.3 Representation

The central element of the w4all interface is an orthographic top projection of a floor in the C6 building, and, naturally, there is one map for each one of the 4 floors.

Matching the results of the work we perform during the identification of the barriers of the buildings with the D-requirements for the representation component, the maps of each floor show stairs, elevators, and bathrooms for disabled people. The ground floor map also contains ramps and the location of the main entrance where there is always an element from the security staff that can open the door when required.

We do not represent emergency exits due to the steps they have, as previously mentioned.

Maps also include some PoIs, such as "the globe" (a big 3D model of the Earth that exists near one entrance of the building), the bar, the study room, libraries, and department secretaries. To identify the most popular PoIs we used questionnaires, whose respondents were a set of regular users of the building. The only reduced mobility user that contributed to this phase was the one in our team because, presently, he is the only wheelchair user that frequents the building

The colour we use to represent some kinds of information changes according to the type of mobility the user chooses. For instance, stairs changes to grey in reduced mobility mode, being orange in normal mode (see the difference between Figure 3 and Figure 4).

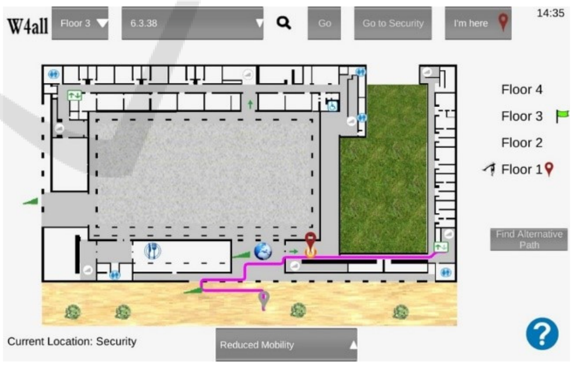

Figure 4: The w4all interface.

4.3.4 Interaction

Based on the results of requirements analysis, the interaction component provides some additional functionalities. Reduced mobility users have the *alternative path* functionality to handle the scenario when one elevator is not working (button in the right side of Figure 4). In addition, the w4all system also has the functionality to provide the path to the security staff workplace which is near the main entrance (button "Go to security" in the top of Figure 4). Finally, it also provides the possibility to change the type of mobility (see the button in the bottom of Figure 4).

The interaction component uses tactile techniques for user input and visual techniques for system feedback. The central element of the interface is a map of one floor. On the top of the interface there is a set of buttons to define the destination, for instance *Floor 3, room 6.3.38*, as depicted in Figure 4 (all the examples we provide inside brackets in this paragraph refers to this figure). On the right side, it has an ordered list of floors with three symbols: an eye that identifies the floor whose map is currently shown in the screen (Floor 1) and a red racket pin and a flag pin, marking the departure floor (Floor 1) and the destination floor (Floor 3), respectively.

The pink line represents the calculated path. As the user moves to the destination, his position is updated. This movement is illustrated in Figure 4, where the grey racket pin represents the departure position and the red racket pin represents the current one. Figure 5 shows the help interface that summarizes the w4all functionalities.

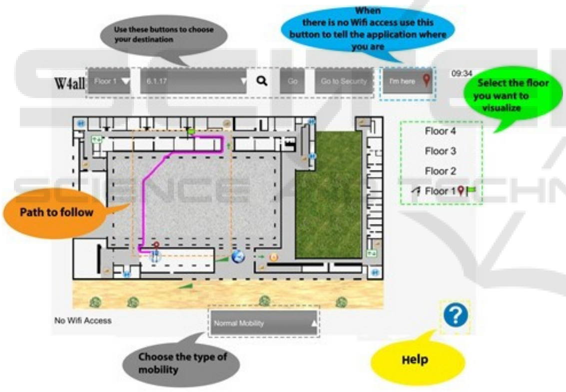

Figure 5: The w4all help interface.

5 EVALUATION

The application w4all was evaluated in two phases: a preliminary one to test the first version of the prototype and to obtain feedback from a small set of users, and a second phase, to test a more mature version that corrected some details and included, among other features, the ones that those users suggested. In both phases, users: i) received a short explanation about w4all and answered to a short list of questions that allows us to trace their general profile; ii) tried the application *in loco* using a tablet and following a guide with tasks to fulfil; iii) afterwards, they answered to a questionnaire.

5.1 Preliminary Tests

The first prototype of the application was tested by three persons: two of them, women aged around 20, that do not usually use the building and by one expert in human-computer interfaces, women aged 50, a regular user of the building. None of them had reduced mobility.

The overall feedback obtained was positive and the opinions they expressed were used in the subsequent process of fine tuning the interface. The adjustments that were made to the interface they tested concern the graphical symbols (for instance, they suggested to use a pin instead of a star, the symbol that originally represented the current position of the user) as well as the position of the buttons in the interface. We also realized that an extra representation was needed to enumerate the complete set of floors, highlighting the current floor of the user, the destination floor, and the one that is on the screen (see right side of w4all current interface, Figure 4).

5.2 User Tests

The second phase of the tests involved two groups of participants that volunteered to participate in the study: 47 users with normal mobility (group 1) and three reduced mobility users (group 2), all distinct from the co-author of this paper.

Before testing w4all, the participants received the following explanation about it:

"w4all is a mobile application that calculates paths in the interior of a building and is intended for users with or without reduced mobility; the application obtains automatically your current location in the building, calculates the shortest path to reach the destination you choose and displays it visually on a map on the device screen. The interface allows you, among other options, to choose the destination, the type of mobility and an alternative path (for instance if you verify that the elevator you were supposed to use in your path is out of order)."

Then, participants answered to a set of questions with the purpose of defining their profile. They were asked about age, genre, type of mobility, and usage of mobile equipment (GPS and Google Maps).

We also inquired users about their level of familiarization with the interior space of the building. Three classes were considered:

▪ familiarised (F) - they have been inside several rooms in distinct floors and they feel confident in finding other rooms elsewhere in the building;

▪ not-familiarised (NF) - despite having been inside a small set of rooms in the building, they do not feel confident in finding rooms elsewhere in the building;

▪ never entered the building before the day they performed the tests (NEB).

This classification was used to discriminate some of the answers in the questionnaire, as we explain further on.

Next step in the evaluation process was to use w4all inside the building. Users in group 2 had to use always the option "reduced mobility", obtaining a path involving the use of an elevator whenever they had to go to a different floor. Users in group 1 were asked to begin using "normal mobility" (the default mode of the application) but, at a certain point, they changed to the "reduced mobility" mode. All the users tried the option "alternative path".

After trying w4all, participants answered to a questionnaire with three parts.

Part 1 is a System Usability Scale (SUS) questionnaire to conclude about the usability aspects of the application (Brooke, 96).

In part 2, participants had to give a score to each symbol in the interface concerning how easily they understand its meaning (from 1- very difficult to 5 - very easy). With the same scale, they were asked to classify the usage of the "I'm here" button. This button was conceived to deal with sporadic failures in the Wi-Fi signal and permits the user to introduce in the application its current position that he can obtain just by consulting the label in a nearby door. This way, it is possible to go on using w4all to obtain asking for a path inside C6.

Besides, we asked if they considered necessary to have a 3D representation of the interior space of the building (a yes or no question) and the following set of open questions:

▪ what aspects did you find difficult to use or to understand?
▪ what aspects did you find easy to use or to understand?
▪ what did you like the most?
▪ what did you dislike the most?
▪ which additional functionalities do you suggest?

The main objective of part 3 is to obtain the opinion of the users about w4all. We asked them to give a score in a 5 points Lickert scale (from 1- strongly disagree to 5- strongly agree) to express their level of agreement with the following statements:

▪ the application fulfils my anticipated objectives;
▪ the application is useful.

Finally, we collected general observations and, on a scale of 1 (bad) to 5 (excellent), users' overall assessment (global appreciation) of the application.

Following subsections detail the results obtained in each one of the two groups: users with normal mobility and users with reduced mobility.

5.2.1 Users with Normal Mobility

Among the 47 participants in group 1, there are 36 (77%) with ages between 20 and 35 (10 women and 26 men); and 11 users (23%) aged above 35 years old (9 women and 2 men). They all feel comfortable using mobile equipment (tablets, smartphones or both) and use on a regular basis GPS services and Google Maps.

Considering the level of familiarization with the building, 7 users (15%) classified themselves as "familiarised" (F), 26 users (55%) as "not-familiarised" (NF) and 14 users (30%) had "never entered before" (NEB) in the building.

The value obtained in the SUS questionnaire, part 1 in the questionnaire, was 75, a value over 68, the value that represents the average of this questionnaire (Sauro, 09). According to Bangor et al. (2009), this result can be objectified as "Good".

Analysing the results of part 2, we start by identifying the symbols of the interface that received lower scores: the stairs, the ramps and the security person (average score around 3,6). All the other symbols received average scores above 4.

The "I'm here" button raised several questions. Despite being explained in the help area of the app, several users did not process this information and got confused with it, thinking that they should use the button to obtain the current location. As a matter of fact, 12 users (26%) mention negatively this button: 10 considered it difficult to use or confusing and 2 included it in the items they dislike the most.

Relatively to the 3D representation of the space, 6 users (13%) considered it would be important to help the orientation process of people that do not know the space. Among these 6 users, 4 were NF users, 1 was F and another NEB.

The aspects found more difficult to use or to understand were the button "I'm here" (discussed ahead), and 2 users mentioned the fact that the map does not rotate according to the current position of the user, making difficult to know, in some points of the path, if the user should turn right or left.

The aspects more appreciated were, for the large majority of the users, the simplicity of the interface and the possibility of obtaining paths for people with reduced mobility.

The aspects that the users dislike the most were related to the design of the interface; 8 users (17%) referred this, saying for instance, that it should be more appealing and colorful.

The suggestions for additional functionalities were the following:

▪ support the possibility of choosing a destination room by the name of a professor that occupies it; this was the most frequent suggestion, 5 users (11%) mentioned it.

▪ adjust the orientation of the map according to the relative position of the user while navigates in the building; 4 users (9%) mentioned this functionality.

▪ support input by voice command (for instance, some users with reduced mobility have also some limitations interacting with the touch screen); 4 users (9%) mentioned this feature.

▪ show the length of the path; this was referred by 2 participants (4%), one of them a NEB user.

▪ produce an alert to the user when he just arrived at his destination, for instance by vibration or drawing a specific symbol or text in the interface; this was mentioned by 1 participant (2%).

Figure 6, Figure 7, and Fig. 8 summarize the results obtained in part 3. The strong majority of users in class F, 57%, scored with 4 and 14% with 5 the statement "the application fulfils my anticipated objectives"; scores 2 and 3 received the remaining percentage, 14% equally divided; nobody used score 1. Considering the statement "the application is useful", 71% used the value 5 and the remaining 29% the value 4; nobody used score 3 or 2.

In class NF, 42% scored with 4 and 35% scored with 5 the statement "the application fulfils my anticipated objectives"; scores 3, 2 received the remaining percentage, 19% and 4% respectively; nobody used score 1. Considering the statement "the application is useful", 35% used the value 5, 62% the value 4; 1 user out of 26 (4%) gave score 3 and nobody used score 1 and 2.

In class NEB, 36% scored with 5 and the same percentage with 3, while 21% scored with 4 the statement "the application fulfils my anticipated objectives"; score 2 received 7% (1 out of 14). Considering the statement "the application is useful", 43% used the value 5, 50% the value 4; and 7% (the same user out of 14) gave score 2. Nobody used scores 1 or 3.

Concerning the global appreciation (see Fig. 8), and like in the previous statements, score 1 never occurred. In class F, 14%, scored with 5, 43% with 4, 29% with 3 and, 14% with score 2. In class NF, the majority, 73%, gave score 4 while the remaining percentages are 12% to score 5 and also to score 3 and only 4% to score 2. In class NEB, the large majority, 79%, gave score 4 being the remaining percentages 7% to score 5 and 14% to score 3.

The final observations made by participants reinforce the opinions given in the open questions. However, we obtained a curious one, by a NF user: "the application is really important because people get frequently lost in this building. While I was testing the application, I helped a person who was lost. This app is useful."

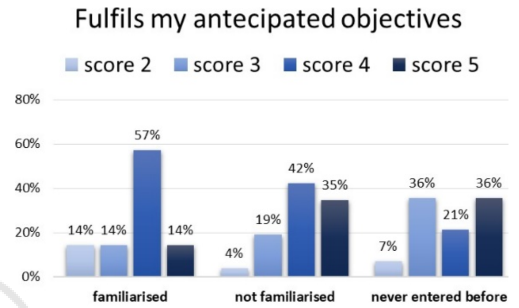

Figure 6: Percentage of score values (between 1- strongly disagree and 5- strongly agree) given by users with normal mobility concerning the statement: the application fulfils my anticipated objectives.

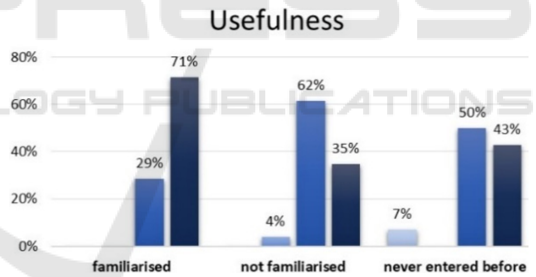

Figure 7: Percentage of score values (between 1- strongly disagree and 5- strongly agree) given by users with normal mobility concerning the statement: the application is useful.

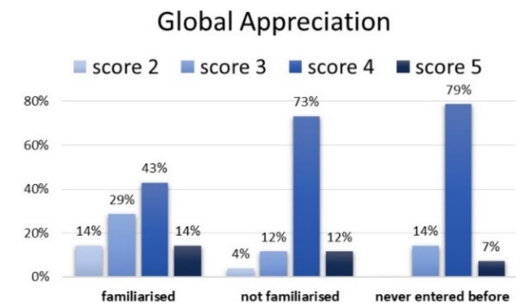

Fig. 8. Percentage of score values (between 1- bad and 5- excellent) given by users with normal mobility concerning their global appreciation about w4all.

5.2.2 Users with Reduced Mobility

The users in group 2 were 1 man and 2 women, all aged between 20 and 35 years old. They had never been inside the building before (NEB users) and are wheelchair users. They all feel comfortable using mobile equipment (tablets, smartphones or both) and use on a regular basis GPS services and Google Maps.

The answers that these users gave in the SUS questionnaire are similar to the ones of group 1.

Considering the symbols in the interface they also mentioned the ramp and the stairs; the "I'm here" button was not problematic. Table 2 summarizes the answers given by these users and their suggestions for new functionalities.

Table 2: Open answers by users with reduced mobility.

	User 1	User 2	User 3
Genre	m	f	f
Age	20-35	20-35	20-35
3D representation?	no	no	no
Most difficult to use	choose the destination	nothing	nothing
Easier to use	know location in the building	know location in the building	all
Like the most	the map of the building	know the way without losing myself	find the shortest path; alternative paths
Dislike the most	the design	nothing	wc positions are not highlyghted enough
Additional Features?	navigation by voice	bilingue version	more places ready to choose as a desti-nation; path to the nearest wc

Table 3 shows the scores concerning the items in part 3. The general opinion obtained two 5-scores and one 3-score; usefulness has a slightly better result, two 5-scores and one 4-score. While the sentence "the app fulfils my anticipated objectives" obtained two 5-scores and one negative 2-score. Curiously, this negative score was given by user 2 who scored with 5 the other two items.

Table 3: Scores by users with reduced mobility.

	User 1	User 2	User 3
Fulfils my anticipated objectives	5	2	5
Usefulness	4	5	5
General opinion	3	5	5

Considering the observations, one of these users said: "It's good to have something that reassures when I need to find a path in a building that I do not know; besides it gives me the shortest path. It is a good feeling to know the way without losing myself".

5.2.3 Discussion

As explained before, two groups of users tested the w4all application *in loco:* a group of 47 normal mobility users and a small group of three users with reduced mobility.

The first group comprised persons that covered the three levels of familiarization with the building. Therefore, we tried to discriminate all the answers according to this characteristic. As we can observe in Fig. 6, Fig. 7, and Fig. 8, results are quite positive: users in classes F, NF and NEB considered it, respectively, 100%, 97% and 93% useful (scores 4 and 5); respectively 71%, 77% and 57% considered that w4all fulfils their anticipated objectives (scores 4 and 5). In the overall appreciation, and using the same order, the application received 57%, 85% and 86% of scores 4 and 5. Score 1 never occurred and score 2 is rare.

Nevertheless, we are aware that improvements have to be made in the interface, namely in the symbols related to ramps and stair, extremely important because they are used in the paths. Also, the functionality of the button "I'm here" must be clarified.

6 CONCLUSION AND FUTURE WORK

This paper presents the results of each step of the development process of an indoor navigation system for reduced mobility users. It describes the requirement analysis focusing on each component of the system: user localization, path planning, representation and interaction. After eliciting C-requirements, we detail D-requirements for each component. We also enumerate the relevant information to gather from the indoor environment to instantiate the requirements to a particular building space. Finally, we overview the w4all prototype and its evaluation with users with normal and reduced mobility.

Beyond the interface aspects referred previously, usability tests involving more participants, mainly wheelchair users, are also planned. Future work also includes fine-tuning the user localization component and the implementation of some D-requirements, namely, monitoring and showing information about the elevator status and tracking wheelchair users.

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