Faculty of Electrical Engineering
Department of Computer Graphics and Interaction

A prototype of mobile application for geographical data crowdsourcing in urban environments

Bachelor thesis

Degree program: Software Engineering and Management
Field of study: Web and Multimedia

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ZADÁNÍ BAKALÁŘSKÉ PRÁCE

Student: Michaela Riganová

Studijní program: Softwarové technologie a management
Obor: Web a multimedia

Název tématu: Prototyp aplikace pro mobilní zařízení pro komunitní sběr geografických informací v městské zástavbě

Pokyny pro vypracování:

Navrhněte a vytvořte prototyp aplikace pro mobilní zařízení, která umožní komunitě uživatelů z běžné veřejnosti přispívat do geografická data pro navigaci osob se specifickými potřeba (nevidomí a vozíčkáři). Seznamte se s datovými strukturami pro navigaci osob se specifickými potřebami, metodikami jejich navigace a orientace, technikami a metodami komunitního sběru dat a jeho motivací (např. tzv. gamifikace). Analyzujte schopnosti běžné veřejnosti v úlohách sběru geografických dat, použijte metodu 'focus group' se skupinami účastníků různého věku. Vypracujte scénáře a pro vybrané scénáře vytvořte 'storyboardy'. Vytvořte papírové 'mockupy' a získejte zpětnou vazbu účastníků metodou 'design probe'. Zpětnou vazbu reflektujte do low-fidelity prototypu vytvořeného ve vhodném nástroji. S low-fidelity prototypem proveďte a vyhodnoťte test použitelnosti alespoň s pěti účastníky z cílové skupiny v exteriéru na cílovém zařízení. Na základě výsledků testu použitelnosti low-fidelity prototypu vytvořte ve vhodném nástroji high-fidelity prototyp. Popište interakční, herní, vizuální a user experience design, definujte funkční požadavky. Proveďte a vyhodnoťte test použitelnosti high-fidelity prototypu alespoň s pěti účastníky v exteriéru na cílovém zařízení.

Seznam odborné literatury:

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Vedoucí: Ing. Jan Balata

Platnost zadání: do konce zimního semestru 2018/2019

Declaration

I declare that I worked out the presented thesis independently and I quoted all used sources of information in accord with Methodical instructions about ethical principles for writing academic thesis.

Prague, 26.5.2017

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Firstly, I would like to express my sincere gratitude to my supervisor Ing. Jan Balata for the continuous support, aspiring guidance and invaluable advice during the whole period. Secondly, I would like to thank all the people who participated in the research and the usability tests for their cooperation and feedback. I am also grateful to my family, especially my mom for her unconditional love and support. At last but not least, I would like to thank Anton for being my biggest fan.

Abstrakt

Vytvoriť spoľahlivý navigačný systém je komplexné zadanie, ktoré so sebou prináša nové výzvy, ak tento systém vytvárame špeciálne pre ľudí s obmedzenou schopnosťou pohybu. Ľudia s obmedzenou mobilitou majú omnoho vyššie nároky na informácie o dostupnosti trás. Pre navigáciu potrebujú podrobnú znalosť existujúcich orientačných bodov, prekážok a vlastností peších komunikácii. Riešením je použiť profesionálne vytvorenú geodatabázu, avšak profesionálny výskum v teréne je príliš časovo a finančne náročný. Jedným z návrhov ako tieto dáta získať je geo-crowdsourcing ako alternatíva k profesionálnemu zberu dát. V tejto práci prezentujeme výsledky výskumu zameraného na návrh užívateľského rozhrania mobilnej aplikácie pre zber informácii o dostupnosti peších komunikácii. Tento zber bude prevádzaný širokou verejnosťou, čím znížime čas a náklady, ktoré sú potrebné pre zber dát prevádzaný profesionálmi. Výsledky prevádzaného výskumu naznačujú aplikovateľnosť tohto prístupu do praxe, ak užívateľom poskytneme správne vedenie v podobe podrobných inštrukcii a ilustračných obrázkov, ak užívatelia použijú odporúčané meracie techniky a ich úsilie je podporované a odmeňované gamifikovanou vrstvou aplikácie.

Kľúčové slová

crowdsourcing, navigačné systémy, ľudia s obmedzenou mobilitou, geodáta, gamifikácia

Abstract

To create reliable navigation system is a complex task but creating one for people impaired in mobility brings even more challenges. People impaired in mobility have much higher requirements regarding information about accessibility. Detailed knowledge about the presence of existing landmarks, obstacles and properties of pavement segments are needed. Usage of professionally created sidewalk-based geodatabase is a solution, however, the professional geographical onsite reconnaissance is highly time and cost demanding. One of the proposal is to achieve this data mining by geo-crowdsourcing approach as an alternative to professional reconnaissance. In this thesis, we report on results of the research focused on designing the user interface of mobile application for collecting accessibility attributes by non-expert crowd which will reduce time and cost of the professional data collection. The research results suggest the feasibility of this approach when the users are provided with a proper guidance, i.e., detailed instructions and illustrative images, use suggested measuring techniques, and their effort is supported and rewarded by gamified layer.

Keywords

crowdsourcing, navigation systems, impaired people, geodata, gamification

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1. Introduction

Navigation to remote destinations is especially difficult for people with limitations in mobility who have much higher requirements regarding information about route accessibility. According to Sammer et al. (2012), almost 16% of the population is limited in mobility, namely visually impaired, hearing impaired, mobility impaired and people with impaired ability to walk. Although there are many navigation systems on the market, most of them are working with roadway-based geodatabases and are designed primarily for cars. There is a significant need for a navigation system with professionally created sidewalk-based geodatabase. This system should provide people limited in mobility with the obstacle notation and important accessibility attributes of existing landmarks and pedestrian segments. This will allow people limited in mobility to move freely and independently. To address this issue, CTU in Prague is developing navigation system called Naviterier[1] which uses a sidewalk-based geodatabase Route4All[2]. This geodatabase contains pedestrian segments like sidewalks, crosswalks, obstacles and landmarks, and their attributes, e.g., sidewalk slope, material, light signalization, corner shape or passable width. Pedestrian segments are drawn into the geodatabase by professionals using resources such as satellite images or maps of town utilities. Attributes are assigned to the pedestrian segments via professional onsite reconnaissance which is highly cost- and time-consuming. One of the proposal is to reduce these costs and speed up the data collection by crowdsourcing approach.

The main objectives of this thesis are to research capabilities of the public in collecting geographic data and identify incentives which can motivate people to participate in the crowdsourcing. The ambition of this work is to design a prototype of mobile application which will use a crowd as a tool for collecting accessibility attributes of existing pedestrian segments and landmarks. This crowdsourcing application will fill the geodatabase with data gathered by non-experts for a fraction of time and cost of the professional onsite reconnaissance. The research questions are: How to accommodate the expert language to be well understood by non-experts? What methods will non-experts use for measurements? How non-expert collected geodata will differ from data collected by professionals? How to efficiently visualize pedestrian segments and landmarks on a map? How to increase motivation to participate in the geo-crowdsourcing?

This thesis is divided into 5 sections. In the second section, we present the analysis of the most relevant resources about crowdsourcing, its advantages, disadvantages and possible incentives. We analyze navigation and orientation methodologies of wheelchair users, blind and visually impaired people, and we present data structure which can be collected via crowdsourcing approach.

In the third section, we perform the qualitative research to examine crowd´s possibilities of collecting geographic data. Based on the research we define first design recommendations for the geo-crowdsourcing application. We present first paper mockups of application design, low fidelity and high fidelity prototypes.

[1] http://www.naviterier.cz/
[2] http://www.route4all.eu/en/

In the fourth section, we describe all usability tests performed during the whole design process, present their results and discuss their impact on the final design.

In the final fifth section, we summarize the outputs of this thesis and present the future work on this topic.

2. Problem description

This chapter discusses crowdsourcing as a way of gathering geographic data, examines gamification as one of the incentives for participation in the crowdsourcing, analyzes navigation and orientation methodologies of wheelchair users, blind and visually impaired people and describes data structure which can be collected via crowdsourcing approach.

2.1. Geo-crowdsourcing

In this subchapter, we focus on geo-crowdsourcing as an alternative approach to professional data collection, describe its state of art, highlight the possible problems that are inherently related to non-expert data collection and search for possible ways how to encourage people to get involved into geo-crowdsourcing.

2.1.1. Definition

Crowdsourcing generally provides an alternative approach to professional data collection which might be very time- and cost-consuming. More specifically, geo-crowdsourcing specializes on collection of spatial data. Instead of inviting experts to provide accessible annotations for millions of geographic features, we ask ordinary people (crowd) to provide these geodata (outsourced) for us. The term crowdsourcing was coined in 2006 by Jeff Howe, contributing editor of Wired Magazine, as meaning “the process by which the power of the many can be leveraged to accomplish feats that were once the province of a specialized few” (Howe, 2008). Armstrong builds upon this definition and further improve it as follows: “a way to use the combined power and wisdom of large groups or people to accomplish tasks that would otherwise be too cumbersome, large, or impractical for any one person or organization to attempt” (Armstrong, 2014).

2.1.2. State of art

The leading global example of geo-crowdsourcing effectiveness is the OpenStreetMap[3] project which was launched in 2004 with the goal of generating a free, editable source of map data through the work of volunteers as an alternative to traditional GIS systems and map data providers (Chilton, 2009). Today OpenStreetMap has over three million registered users and in many parts of the world has already compiled more detailed mapping than traditional mapping suppliers. OpenStreetMap provides users with accurate and current geodata which are helpful for navigation and orientation in space but does not take special needs of handicapped people into consideration. In recent years, several applications have been developed to gather also information about accessibility of pedestrian communications and points of interest by crowdsourcing approach. One of the successful projects dealing with accessibility is WheelMap[4], system based on OpenStreetMap. It adds accessibility information of points of interest (POI) for wheelchair users. Anyone can contribute and

[3] https://www.openstreetmap.org/
[4] https://www.wheelmap.org/

mark public places around the world according to their wheelchair accessibility. The criteria for marking places are based on a simple traffic light system - green light stands for fully wheelchair accessible, yellow light stands for partly wheelchair accessible and red light stands for not wheelchair accessible. Very similar to WheelMap is the VozejkMap[5] application, which gathers accessibility information for wheelchair users and provides maps, navigation and information about barrier-free sites in the Czech Republic. Locations are categorized according to their purpose and contain information about the type of wheelchair access, availability of toilets and parking spaces for wheelchair users. All data collected through this application are checked by administrators, who are also wheelchair users. Another slightly different application is SideWalk[6], which enables you to travel virtually through cities and search for accessibility features and problems in the environment, including curb ramps, missing curb ramps, sidewalks obstacles or surface problems and label them directly on the map from the comfort of your own home.

2.1.3. Concerns and fears

Modern technology makes it very easy for anybody to collect and share geodata and accessibility information. Thanks to geo-crowdsourcing we are able to gather a big volume of hard-to-obtain data in short time with minimal investment and update them very quickly and easily. Despite having a lot of advantages, there are also some serious challenges which we need to be aware of and possibly overcome. Selected main concerns and fears regarding geo-crowdsourcing are following (Armstrong, 2014):

1. Non-expert contributors cannot produce the same quality of data as legitimate professionals.
2. Non-expert contributors use amateur equipment and tools, so their results cannot be as precise as those of professionals.
3. Every contributor has a different motivation for participating in crowdsourcing. Some of contributors might intentionally abuse the system with wrong data.

But are these concerns legitimate? See et al. (2013) performed a controlled study in 2011 to find out if the non-expert contributors can generate results as well as experts in the field. They concluded that if training, feedback, and monitoring are provided, contributions from volunteers could rival to those of professionals. This claim is also supported by the case study of Zeng, Kühn and Weber (2016), which was investigating how users including elderly people, wheelchair users, blind and visually impaired people as well as volunteers annotate environmental accessibility information in their journey. They found that "subjects from different user groups had different behavior while annotating accessibility information and volunteers who do not have a disability are not good at spotting environmental accessibility issues". With these findings, Zeng, Kühn and Weber concluded a series of insights about how to collect collaborative environmental accessibility. They confirmed that people without disabilities can play the role of a volunteer who contributes environmental accessibility information as well as people with disabilities, however, they need appropriate

[5] http://www.vozejkmap.cz/
[6] http://sidewalk.umiacs.umd.edu/

guidance from the crowdsourcing systems unlike people with disabilities, who would initiatively make accessibility annotations. According to Armstrong (2014) we cannot expect that the data measured and provided by non-expert contributors without professional equipment will be exactly the same as data measured by professionals with hi-tech equipment but the most important thing is to treat these collected data as data which are collected by ordinary people and accepted to have a larger margin of error. On the other hand, crowd can not only provide data, but also provide their validation. Goodchild (2012) points out that the concept known as Linus´s Law applies to geo-crowdsourcing. It states that "given enough eyes, all bugs are shallow". That means that if enough people review collected data, all of the mistakes can be found and corrected.

2.1.4. Incentives

When Mooney and Corcoran (2012) analyzed the OpenStreetMap database for the United Kingdom and Ireland, they concluded that majority of geodata is often contributed by minority of users. In order to collect enough relevant data, we must encourage people to get involved into geo-crowdsourcing. There are several ways to do so and often include more than one of the following incentives:

a. Monetary Payments. For some tasks in the field of geodata collection, it might be very difficult to find a large number of volunteers who are willing to accomplish them for free, mainly because of difficulty or time-consumption. Therefore, special crowdsourcing platforms which handle recruitment and payment of paid crowdworkers began to emerge. However, the test which was performed with more than a hundred crowdworkers registered in the commercial crowdsourcing platform microWorkers[7] doesn't prove that the monetary payment influences the quality of collected geodata:

   > "The results are very promising and the quality of the data was even outperforming our expectations in many cases. However, the tests show also that the quality of the collected data vary significantly. Some crowdworkers collected the data with very high quality whereas other crowdworkers collected completely incorrect data" (Walter, Laupheimer, Fritsch, 2016).

b. Altruism. Crowdsourcing projects that are based on the work of unpaid volunteers need an active community, whose members are convicted about the importance of the project and are willing to expend significant time and effort for the right cause. Altruism itself should be enough of a motivator since it appeals to people's desire to help, but this can only work if participants actually think the problem being solved is interesting and important which is in most cases hard to achieve (Goncalves et al., 2013).
c. Amusement. Crowdsourcing experience might be enhanced by making it more immersive and compelling through the integration of key game mechanics. Gamification is an effective approach for increasing motivation, participation and output quality of collected data (Morschheuser, Hamari, Koivisto, 2016).

[7] https://microworkers.com/

d. Useful information. People are more likely to participate in crowdsourcing projects when the collected data are useful, helpful or interesting for them, e.g., geo-crowdsourcing is an effective approach to gather subjective relations to space. Study of Silvia Klettner (2013) showed that people do not simply decide for time- or distance-optimized routes but take other aspects into consideration. Most people preferred to take route with highest emotional ratings over the shortest route (69% vs 31%). Collecting subjective relations to space contributes to the improvement of pedestrian route planning, which might be a big incentive for people to get involved in a crowdsourcing project.

For our application, we have decided to explore gamification as a motivation tool further in depth. It is lower in cost in comparison to monetary payments, does not clutter application with subjective data which might be redundant for navigation of impaired people, and it acts on competitive side of human nature.

2.2. Gamification

In this subchapter, we focus on gamification - a new phenomenon which is recently spreading in a mobile application development industry as a powerful tool of user motivation, engagement and loyalty. Many of today's mobile applications use the feeling of winning as a motivator to get users to return to their applications again and again by employing gamification.

2.2.1. Definition

Gamification is defined as "the use of game design elements in non-game contexts" (Deterding et al., 2011). Gamification reflects two related concepts. The first is the increasing adoption, institutionalization and ubiquity of games in everyday life. The second is that game elements should be able to make non-game products and services more enjoyable since they can easily entertain and motivate users to engage with them (Deterding et al., 2011).

2.2.2. Game design elements

Using gamification to motivate and increase user activity and loyalty has rapidly gained popularity in interaction design. To get gameful experiences in interaction design special design elements must be used: "elements that are found in most (but not necessarily all) games, readily associated with games, and found to play a significant role in gameplay" (Deterding et al., 2011). People are naturally competitive, strive for validation and achievement, and enjoy being part of a community. Therefore, gamification in mobile application design reflects human competitive nature and appeals to human desires, for reward, self-expression, achievement, competition, and status (Zichermann, 2011).

Reward

Encouraging people to earn rewards for using mobile application can be beneficial for both parties. Rewards bring increased user engagement as people are more inclined to complete actions if they know that their efforts will be rewarded. There are many possible types of application-based rewards. Users can be rewarded for making in-application purchases, spending time in application or providing some data. The most suitable type of reward for each application should be chosen carefully. The chosen type of reward must bring value to application users (Abrosimova, 2016).

Self-expression

Self-expression is a natural human desire which must be taken into consideration when designing mobile application. Users need to differ from other users, be unique. This desire can be fulfilled with providing users with avatars, badges or any other virtual goods with which they can identify (Abrosimova, 2016).

Achievements

Mobile applications can challenge users by sending them on a mission with a certain goal to achieve. When the mission is accomplished, the achievements applications provide act as a visual proof of completing a challenge. In gamified mobile applications, every user´s achievement, big or small, should be rewarded to support and encourage users. Users can be rewarded with digital badges, trophies, points, a new status or with unlocking a new level. Applications should also provide users with option to share their achievements on social networks. This option would please users since people like to share their achievements, especially if they weren't easy to achieve, and it would also help the application acquire more users (Abrosimova, 2016).

Competition

People have competitive nature and like to compare themselves to others. Sometimes "to participate" is not enough, the more important is to win. Achievements scored by users can be illustrated on the leaderboards which increase users´ motivation and engagement: "Points can be used to denote achievements, whereas leaderboards can actually rank users and their accomplishments. Leaderboards motivate users to become players, which encourages competitiveness and can be especially useful for driving a desired user behavior." (Abrosimova, 2016).

Status

Statuses provide digital equivalent of a rank in the army or a title on a business card. People like to prove their statuses by putting them on a display. Statuses can increase user engagement and can be also represented by levels or user ratings (Abrosimova, 2016).

2.3. Navigation and orientation methodologies of impaired people

In this subchapter, we introduce navigation and orientation methodologies of wheelchair users, blind and visually impaired people through the analysis of guides and manuals of organizations for people with disabilities - SONS and POV.

2.3.1. SONS

SONS[8] (United Organization of Blind and Visually Impaired of the Czech Republic) was founded in 1996 and is currently operating in most districts in the Czech Republic and brings together more than 10 000 members. The mission of SONS is to gather visually impaired citizens, defend their interests and provide services leading to their integration into society, i.e., promoting employment of blind and visually impaired people, popularization and raising awareness about the visual impairment, training of guide dogs, personal assistance services, removal of architectural and information barriers for visually impaired citizens.

Visually impaired people uses two main senses, touch and hearing, for navigation and orientation in space. To identify the tactile guidelines and obstacles of outdoor environment the technique of long white cane is used. For acoustic orientation, special audio technologies are used, such as voice synthesizers or beacons.

Tactile guidelines

The basic tactile elements are natural and artificial guiding lines and tactile landmarks. Natural guidelines are formed by successive landmarks that are part of the route vicinity. These natural landmarks with indicative characteristic consist mainly of walls, corners of buildings, paving and curbs of pedestrian communications. In a place where there is no natural guideline and the transition distance between two reference points is too large, the artificial guidelines are used. A special case of artificial guidelines is a warning strip which indicates a place permanently inaccessible or hazardous and a signal strip which indicates places important for orientation or leads person in the walking direction. Each type of tactile guidelines has specified width and surface (see Fig. 1) (Lněnička, 2015a).

	width	**surface**
artificial guideline	100 mm	groove
warning strip	400 mm	protrusions
signal strip	800 mm	protrusions

Fig. 1 *SONS. Characteristics of artificial guide lines, warning and signal stripes*

Obstacles

To mark an obstacle, tactile elements must be used to ensure safe and unambiguous identification using white cane technique. When the obstacle is recognized correctly visually impaired people can choose the right methods and techniques for overcoming it. For each obstacle, the minimum passable width is required. Obstacles may have permanent or temporary character. Permanent obstacles include public lightning, advertising pillars, public transportation stops, mailboxes, vending machines, payphones, railings, benches or fences. When positioning permanent obstacles, the passable width of 1,5 m must be kept. Temporary obstacles include construction works performed

[8] https://www.sons.cz/

on public roads and areas. For marking temporary obstacles special barriers or scaffolding pipes are used (Dudr, Lněnička, 2000).

Acoustic guidance elements

There are natural and artificial acoustic guidance elements which have orientation and information functions. The natural acoustic guidance elements include murmur of water or rustling of leaves but mainly an echo when using the white cane. The artificial acoustic guidance elements include acoustic orientation beacons (AOB), digital voice beacons (DVB) and acoustic signalization on pedestrian crossings. AOBs provide important orientation information about the given location. DVBs provide useful and important information about given facilities, services or departures and arrivals of vehicles of public transport. Acoustic devices on pedestrian crossings are used for distinguishing between red and green traffic light. The red traffic light is expressed by an acoustic signal with a frequency of 1.5 Hz and green traffic light is expressed by an acoustic signal having a frequency of 8 Hz. These devices are either in continuous operation or can be remotely activated by using the special walkie-talkie owned by every visually impaired person (Lněnička, 2015b).

2.3.2. POV

POV[9] (Prague Wheelchair Organization) was established at the initiative of wheelchair users themselves and their families in 1991. Through its projects, work and attitude, POV aims to create a favorable social environment, in which every person with disability can freely decide on how to ensure his basic needs. POV provides social counseling, organization of educational and leisure events and also manages program *Through the Barrier*, a set of activities relating to the removal and mapping of architectural barriers. In connection with architectural barrier mapping, POV defines following methodology for categorizing routes and communications in terms of their accessibility to provide better navigation and orientation to wheelchair users (Novotná, Tomandl, 2014):

Slope, width and quality of communications

For categorizing slope, width and quality of communications, simple traffic light system is used:

a. green - fully wheelchair accessible

Routes that have a hard and flat surface, or continuous surface with regular joints in maximum width 2 cm designed for less experienced, unaccompanied or electric wheelchair users. Longitudinal slope should be up to 6% for an unlimited length, or 6-8% with a maximum length of nine meters. Cross slope should be up to 4%. Road width should be at least 150 cm and short direct crossings should be at least 120 cm.

b. yellow - partly wheelchair accessible

Routes that have a hard and flat surface, or continuous surface with regular joints in maximum width 2 cm designed for proficient, accompanied or electric wheelchair users.

[9] http://www.pov.cz/

Longitudinal slope should be up to 8% for an unlimited length, or 8-12% with a maximum length of nine meters. Cross slope should be up to 7% to a maximum 4% of the longitudinal slope or up to 4% for 4-12,5% longitudinal slope. Road width should be at least 120 cm, the short direct crossings should be at least 100 cm wide.

c. red - not wheelchair accessible

Routes may not have a hard and flat surface; continuous surface can have regular joints larger than 2 cm. Longitudinal slope is greater than 8% in unlimited length or greater than 12.5% if length is less than 9 meters. Cross slope is greater than 7% for a maximum of 4% longitudinal slope or greater than 4% for 4-12,5% longitudinal slope. Road width is less than 120 cm, the short direct crossings are less than 100 cm wide.

Barriers

For categorizing barriers including height difference, narrowing, longitudinal and cross slopes, red and yellow pictograms are used for different range of values (see Fig. 2):

Height difference

a. yellow - height difference from 2 cm to 5 cm
b. red - height difference bigger than 5 cm

Narrowing

a. yellow - narrowing less than 80 cm, but minimum 70 cm
b. red - narrowing less than 70 cm

Longitudinal slope

a. yellow - 12,5 % – 16,5 % (maximum length 3 m)
b. red - more than 16,5 % (length more than 3 m)

Cross slope

a. yellow - 4 % – 7 % (longitudinal slope 4–12,5 %, maximum length 3 m)
b. red - more than 7 % (length more than 3 m)

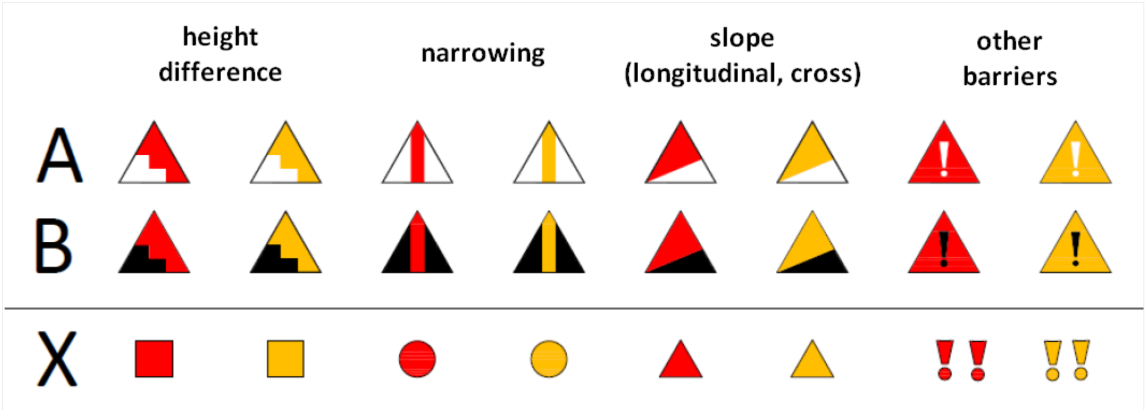

Fig. 2 POV. The sets of barrier pictograms (A, B, X) used according to size, color and contrast of graphic background

Pedestrian crossings

Simple traffic light system is used for categorizing of each part of a pedestrian crossing (see Fig. 3):

a. green - lowered curb (max. 12.5%)
b. yellow - fold curb (max. 40%) or insufficiently adjusted lowered curb (max. 5 cm)
c. red - pedestrian crossing without adjustment

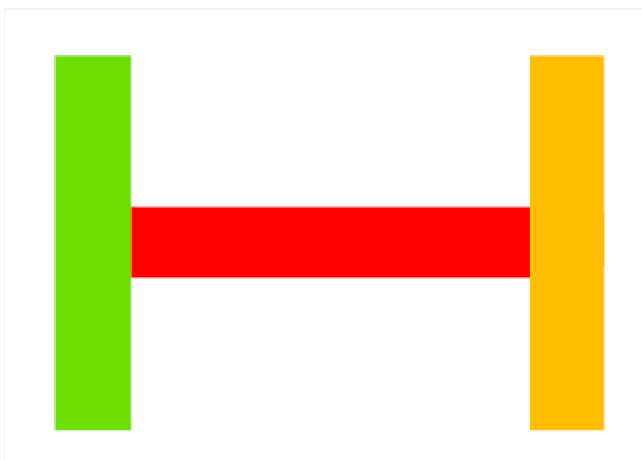

Fig. 3 POV. Categorizing the accessibility of pedestrian crossings

2.4. Data structure

Based on the analysis of data provided by project Route4All[10] and the methodologies of POV and SONS, we have identified information that is necessary for a successful and safe navigation of impaired people. Data necessary for navigation of handicapped people which are supposedly

[10] http://www.route4all.eu/

measurable in terrain without any special tool needed and can be collected via crowdsourcing application are listed in the following scheme:

Pedestrian segments: width, longitudinal slope, cross slope, surface type, surface quality, vicinity

Street: pavement location

Footpath: sidewalk location, opening hours

Vertical Transition:

Stairway: railings location, number of steps, step height, step depth, tactile guidelines, color contrast, spin type and direction

Incline: length, railing location and height, tactile guidelines, platform size, spin type and direction

Crossing: crossing type, control type, number of islets, direction of traffic flow, tactile guidelines, tramlines, length

Entry points: curb height and slope, curb surface quality, platform, passable width, tactile warning, tactile guidelines

Stop place: type, name, traffic direction, platform location, boarding barrier type, tactile guidelines, tactile warning, audio

Landmarks and Obstacles: type, description, contrast

Landmark: height, material, passable width, duration

Obstacle: gap/raise, number, vertical size, horizontal size, slope, duration

Corner: shape

Points of Interest: public toilettes, tram/bus stop, subway entry/exit

3. Analysis and design

The aim of this chapter is to examine possibilities of collecting geographic data by a crowd through qualitative research. Based on the results of the research, we suggest the main use-cases for our future application. We present first paper mockups of application design, low fidelity and high fidelity prototypes which illustrate defined use-cases.

3.1. Qualitative research

The qualitative research was conducted with four main objectives:

1. To verify how people really behave during the crowdsourcing process which includes recognizing, naming and measuring special features and properties of pedestrian communications.
2. To verify how participants´ results differs from the results of professionals.
3. To find out whether the terminology used by the participants will tally with the terminology we used to describe our data structure (see Subchapter 2.4).

We will answer these questions through qualitative research in form of focus groups which will help us to get an insight into the behavior of our intended users.

3.1.1. Focus group

Focus group is a form of qualitative research which can assess user needs, feelings and opinions. In focus group, we bring together from six to nine users. We ask questions regarding a target product or service in an interactive group setting where participants are free to talk with other group members. The focus group usually lasts about two hours and is run by a moderator who maintains the group´s focus. The outcome of this method should be users' spontaneous reactions and new ideas about the target product or service. For successful realization of the research focus groups must be complied with the following rules (Nielsen, 1997):

- For participants, the focus-group session should feel free-flowing and relatively unstructured.
- The moderator must follow a preplanned script of specific issues and set goals for the type of information to be gathered.
- The moderator must keep the discussion on track without inhibiting the flow of ideas and comments.
- The moderator also must ensure that all group members contribute to the discussion and must avoid letting one participant´s opinions dominate.
- Focus groups require several representative users.
- More than one focus group should be run, because the outcome of any single session may not be representative and discussion can get sidetracked.

3.1.2. Experiment set-up

Participants

Participants of the experiment are young adults and middle-aged persons, both females and males, who are experienced in the use of smartphones and mobile applications. We invited 11 people to participate in the experiment. The participants were divided into 3 focus groups by their age. The first group consisted of young adults aged between 22-26. The second group consisted of young adults aged between 27-35. The third group consisted of middle-aged persons aged between 36-51.

Location

For our experiment, we selected quiet area in the city center of Prague, Czech Republic. Our route was approximately 200 meters long and consists of 1 stop place, 2 obstacles, 3 landmarks and 4 pedestrian segments, where segments refer to all pedestrian sections where pedestrians can move, i.e., pavements, crossings etc.

Equipment

The participants were not equipped with any special technology or measuring tools besides their own smartphones and their personal belongings which they usually carry with them.

Data collection

In each session, we recorded one video stream of the participants' activities which was used for later detailed analysis.

Procedure

The experiment consisted of one session with every focus group which lasted about one hour. Every group received a simplified hand-drawn map with marked objects of our interest (see Fig. 4). We were mainly interested in the shape of corners and features of pedestrian crossings such as presence of tactile pavement, audio signalization, and accessibility for wheelchair users. We were also interested in measurements and positions of obstacles, passable widths and slopes of pedestrian segments and accessibility of a tram stops.

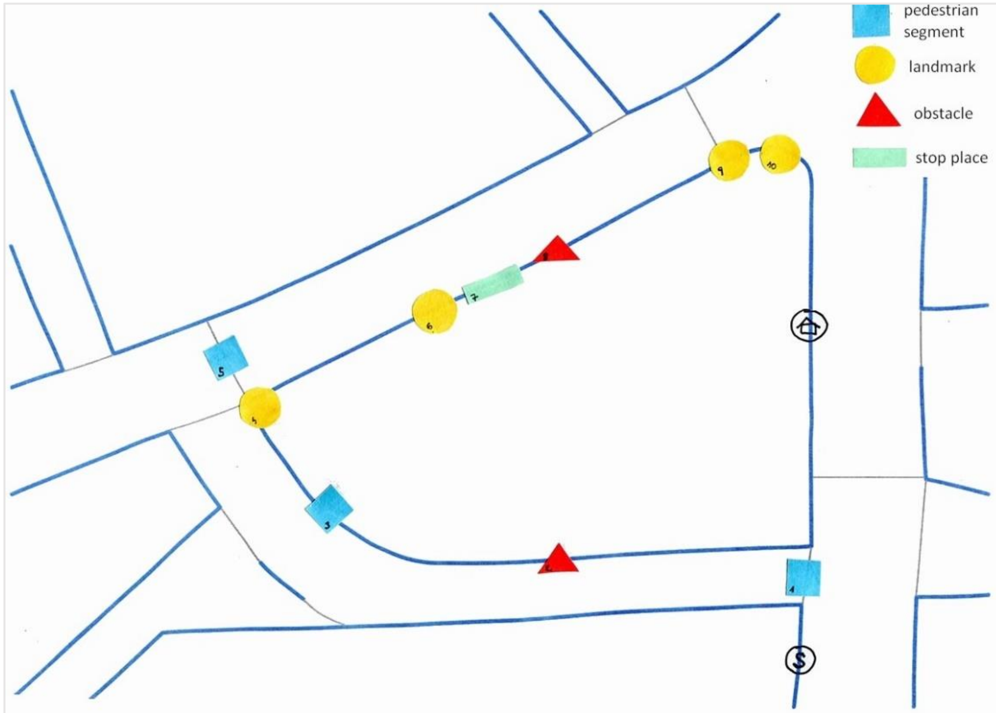

Fig. 4 Experiment set-up. The simplified hand-drawn map with marked objects of our interest

The participants were asked to perform the following task:

> *"Paul, a friend of yours, is planning to visit Prague. Unfortunately, he has broken his leg during a skiing accident, just two weeks before his visit. Paul doesn't want to disappoint you and he still plans to come. You've already sent him the instructions on how to get from the Airport to your apartment. You have already checked, that the both entry and exit subway stations are wheelchair accessible, but you also want to make sure that his journey from the subway stop right to your apartment will be smooth and without any complications even in a wheelchair."*

They were asked to go from place to place and discuss the terminology for the marked object, write down all its noticeable attributes and find a best way how to measure them. They were instructed to focus not only on navigation of wheelchair users, but also take into the consideration blind pedestrians, seniors and parents with strollers.

3.1.3. Experiment results

Recognition

The participants of the experiment struggled to identify all the necessary features for navigation of impaired people. They couldn't identify what objects on the street are the real obstacles for them and which properties are exactly needed for safe navigation. For identification of more than a half of required properties, an assistance of the moderator was needed (see Fig. 5).

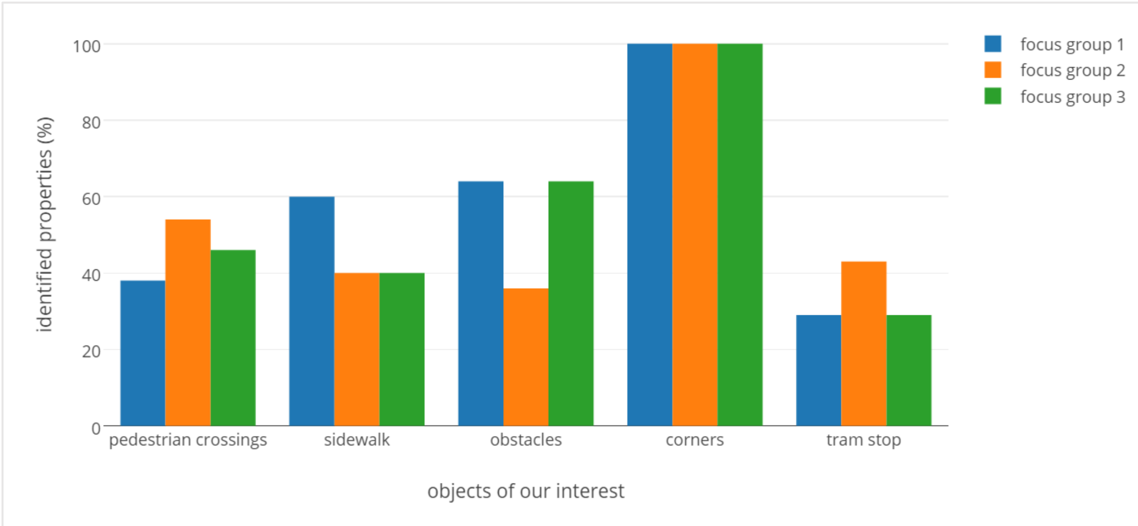

Fig. 5 *Experiment results. The percentage of identified properties without an assistance*

Terminology

The participants had no problem with naming pedestrian segments and landmarks. There was a high amount of consistency between the groups. All participants were able to agree usually on a single term for the given segment or landmark. On the other hand, the participants struggled to correctly name some of the attributes of pavement segments and landmarks. They struggled to properly name different kinds of corner shape. They also found very hard to find a proper terminology for different kinds of slope. Finally, all three groups agreed on terms *direct* for longitudinal slope and *side* for cross slope.

Measuring

Since the participants were not provided with any special tools for measuring required properties such as width, length, depth and slope of pedestrian segments and landmarks, they used alternative techniques. The most common technique for measuring length, width and depth, was stepping or using their feet. They also used credit cards and squared paper as a replacement for meter (see Fig. 6). On the other hand, the participants struggled to measure an exact slope of pavement segments, they tried to use mobile applications but they were not accurate enough, so they just used terms as *gentle, small, smooth* or *slightly uphill*.

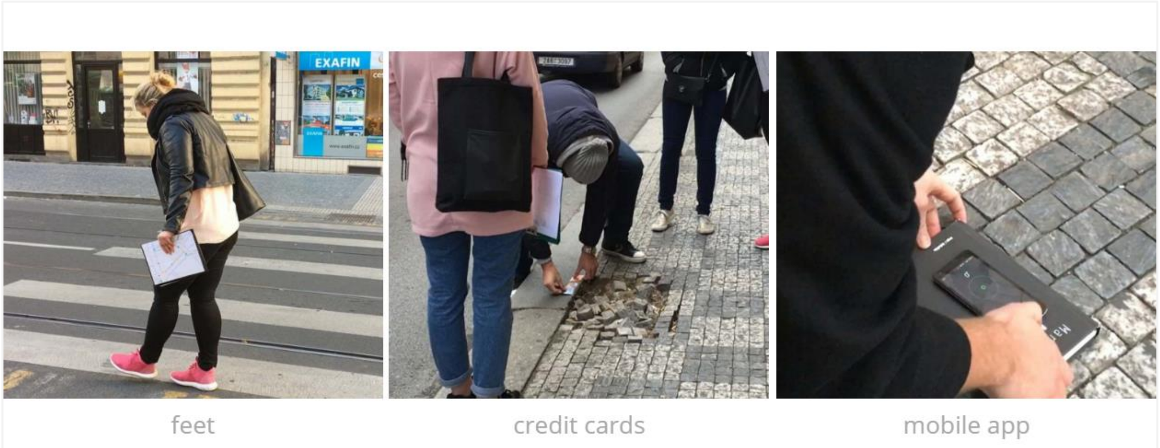

Fig. 6 Experiment results. The measurement techniques

Deviations in measurements

We compared the results of measuring with values obtained with professional tools. The values measured by participants only slightly differ from the actual values (see Fig. 7), that means that the measurement methods chosen by participants were quite accurate.

group 1	w: 47.3	l: 73.1	w: 400	l: 750	h: < 2	l: 600
group 2	w: 48.0	l: 70.0	w: 450	l: 720	h: 1.5	l: 600
group 3	w: 50.0	l: 70.0	w: 400	l: 750	h: < 2	l: 600
actual values	w: 50.0	l: 70.0	w: 400	l: 770	h: 1.6	l: 560

Fig. 7 Experiment results. The comparison of values measured by participants and actual values of attributes

Motivation

After the experiment had finished, we made a short post-interview with the participants. The participants were asked whether they are motivated to gather the data for the navigation of handicapped people or what would increase their motivation if it's lacking. Some participants do not feel motivated at all, mostly because they do not have any relative or friend who would be handicapped, therefore the whole topic seems rather distant for them. On the other hand, those who has relative or a friend with a disability, confirmed that their motivation is much higher. They also suggested that element of gamification could help or if the data gathered could be somehow useful even for non-handicapped people, for example information about the traffic noise or attractiveness of the route, they would be more likely to participate.

3.1.4. Design recommendations

According to the results of the experiment we have made a few recommendations for our future crowdsourcing application, which might help to collect requested spatial data more efficiently and more precisely:

1. The application should provide contributors with proper guidance and instructional pictures of what and how to measure, so that even non-expert contributors are capable of producing data of acceptable quality.
2. Contributors should provide only objective information about the requested pedestrian segments and landmarks, such as width, height, depth, slope, material etc. While non-expert contributors are not familiar with special need of each end-user group, they should not subjectively evaluate the accessibility or safety of the requested pedestrian segments and landmarks.
3. We need to raise public awareness about lives and certain needs of people with disabilities, so that people do not feel distant from this issue.
4. To attract more users, we should consider gamification of the application.
5. The application should also collect subjective data on the attractiveness of routes, so that we motivate to participate also people without disabilities.

3.2. Application design

Based on the gathered information from the previous sections we designed the initial draft of the application. This subchapter introduces three main use-cases which we implement in our application. All three use-cases are outlined in storyboards. We present elementary system model described by a detailed hierarchical task analysis (HTA) and scenarios. Furthermore, we introduce first paper mockups of application design, the low-fidelity prototype and the high-fidelity prototype.

3.2.1. Use-cases

We have identified three main use-cases which we implement in our application and describe them in the storyboards. These use-cases are as follows: collecting new data on undocumented objects (see the storyboard in Fig. 8), marking new obstacles (see the storyboard in Fig. 9) and validation of collected data (see the storyboard in Fig. 10).

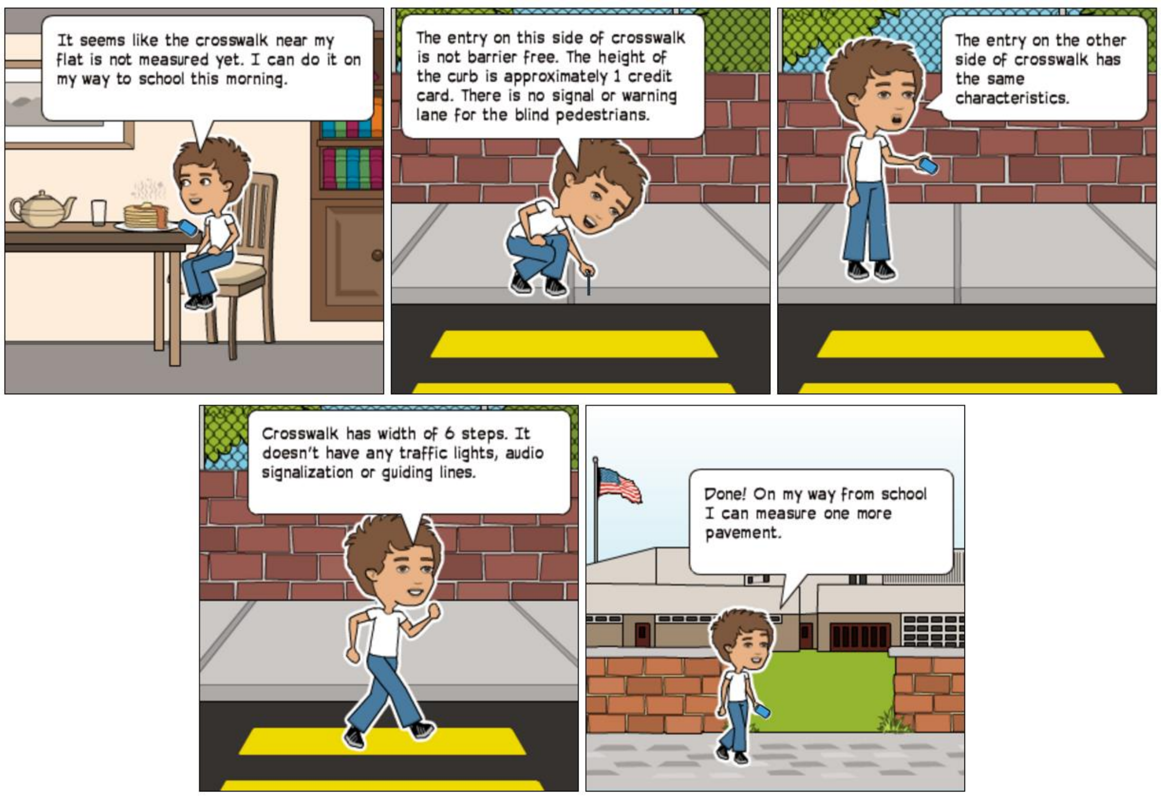

Fig. 8 *The storyboard for collecting new data on undocumented objects*

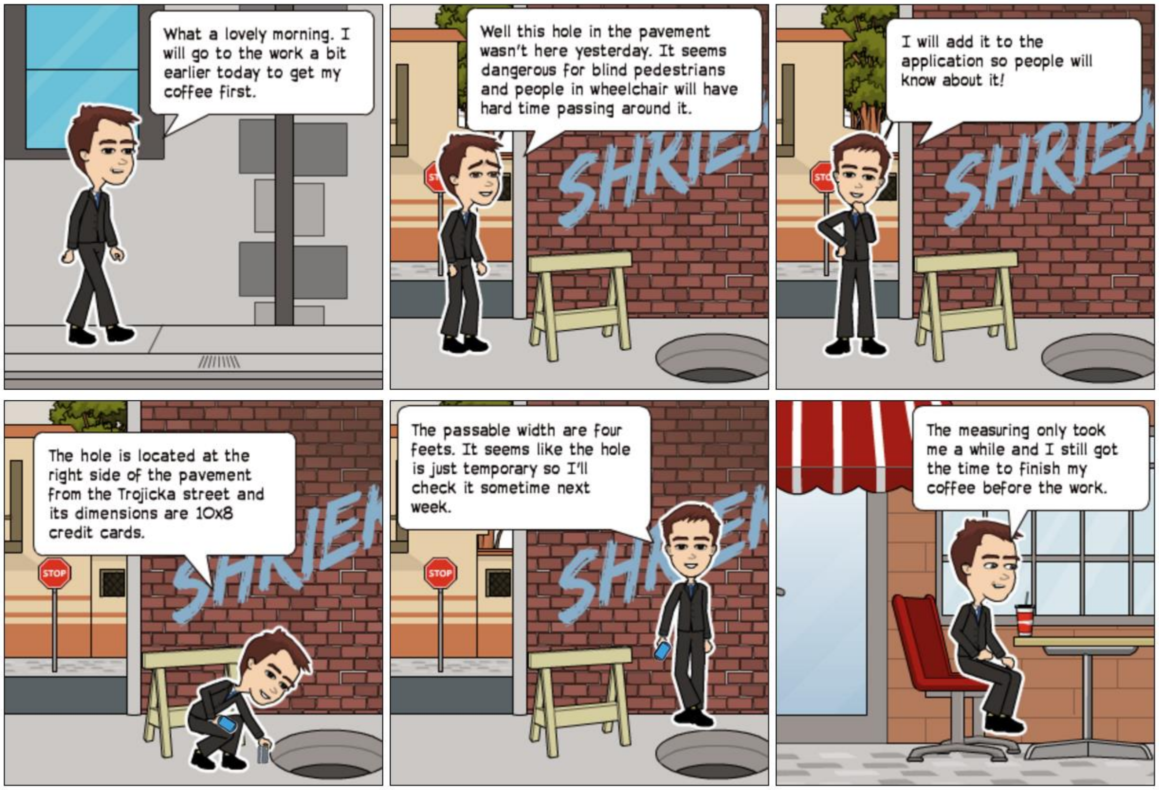

Fig. 9 *The storyboard for marking new obstacles*

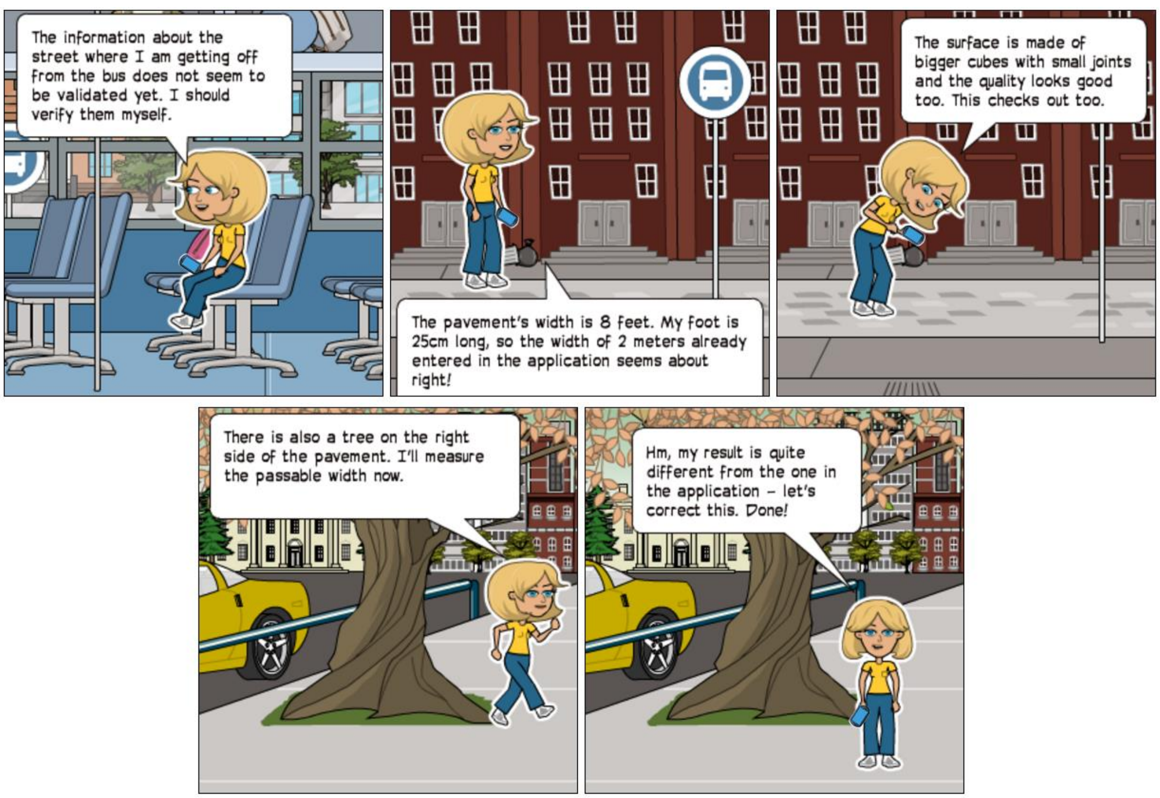

Fig. 10 *The storyboard for validation of collected data*

3.2.2. System model

Based on identified use-cases we have created elementary system model described by a detailed HTA and scenarios to give a clear understanding of the use-cases' high-level steps. We have broken the use-cases down into subtasks, expressing the relationships between the parent task and its subtasks through a numbering scheme (see Fig. 11-15). For each HTA we have defined plans for carrying out the task. To illustrate user´s interactions with the system we have defined scenarios for each use-case.

Case 1: Collecting new data on an undocumented sidewalk

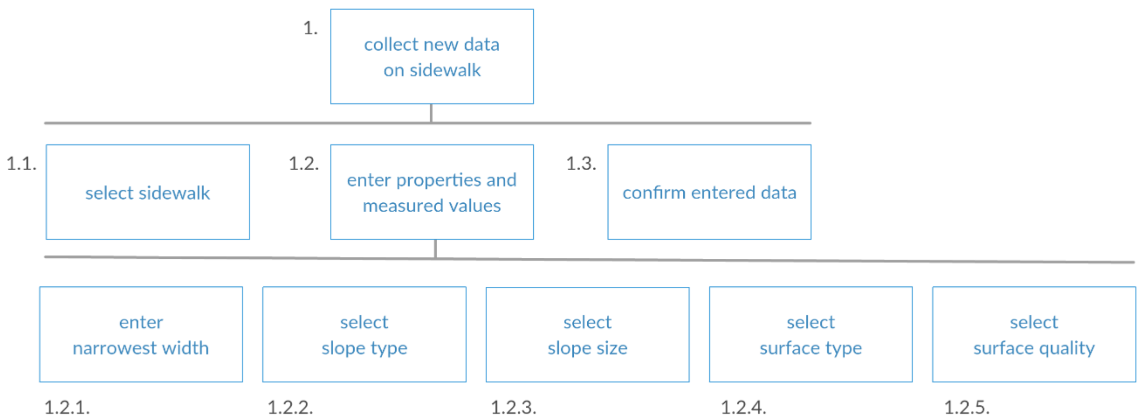

Fig. 11 *HTA for collecting new data on an undocumented sidewalk*

Plans:

PLAN A – collecting data on a sidewalk without a slope: 1.1., 1.2.1., 1.2.2., 1.2.4., 1.2.5., 1.3.
PLAN B – collecting data on a sidewalk with a slope: 1.1., 1.2.1., 1.2.2., 1.2.3., 1.2.4., 1.2.5., 1.3.

Scenario:

1. The user selects the sidewalk on which he/she wants to collect data.
2. The user enters a narrowest width of the sidewalk.
3. The user selects a type and size of the sidewalk slope.
4. The user selects a type and quality of the sidewalk surface.
5. The user confirms the entered data.

Case 2: Collecting new data on an undocumented pedestrian crossing

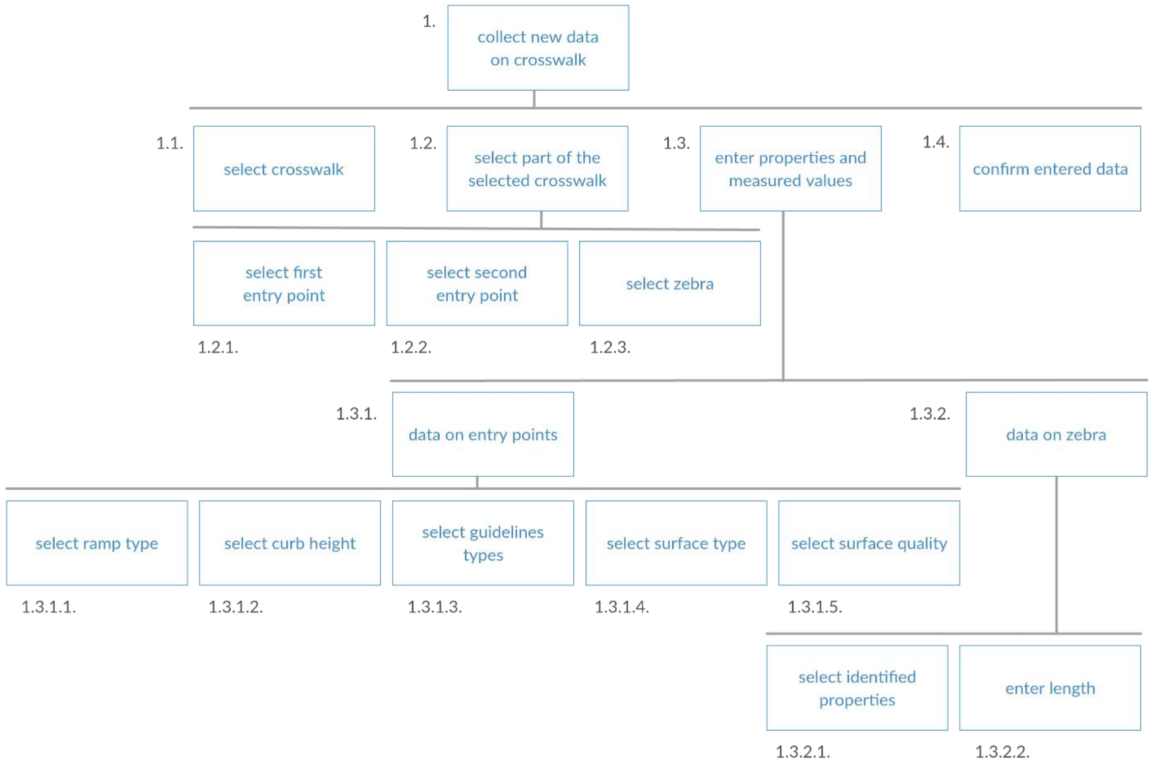

Fig. 12 *HTA for collecting new data on an undocumented pedestrian crossing*

Plans:

PLAN A – collecting data on an entry point with a curb of a pedestrian crossing: 1.2.1 or 1.2.2., 1.3.1.1., 1.3.1.2., 1.3.1.3, 1.3.1.4., 1.3.1.5.
PLAN B – collecting data on a barrier-free entry point of a pedestrian crossing: 1.2.1 or 1.2.2., 1.3.1.1., 1.3.1.3, 1.3.1.4., 1.3.1.5.
PLAN C – collecting data on a zebra of a pedestrian crossing: 1.2.3, 1.3.2.1., 1.3.2.2.
PLAN D – collecting data on a pedestrian crossing: 1.1., (PLAN A or PLAN B) *2, PLAN C, 1.4.

Scenario:

1. The user selects the pedestrian crossing on which he/she wants to collect data.
2. The user selects an entry point of the selected pedestrian crossing.
3. The user selects a type of the entry point ramp.
4. The user enters the curb height.
5. The user selects types of guidelines which are present on the entry point.
6. The user selects a type and a quality of the surface.
7. The user confirms the entered data.

Alternative scenario:

1. The user selects the pedestrian crossing on which he/she wants to collect data.
2. The user selects an entry point of the selected pedestrian crossing.
3. The user selects a type of the entry point ramp.
4. The user selects types of guidelines which are present on the entry point.
5. The user selects a type and a quality of the surface.
6. The user confirms the entered data.

Alternative scenario:

1. The user selects the pedestrian crossing on which he/she wants to collect data.
2. The user selects the zebra part of the selected pedestrian crossing.
3. The user selects properties of the zebra crossing.
4. The user enters length of the zebra crossing.
5. The user confirms the entered data.

Case 3: Collecting new data on an undocumented corner

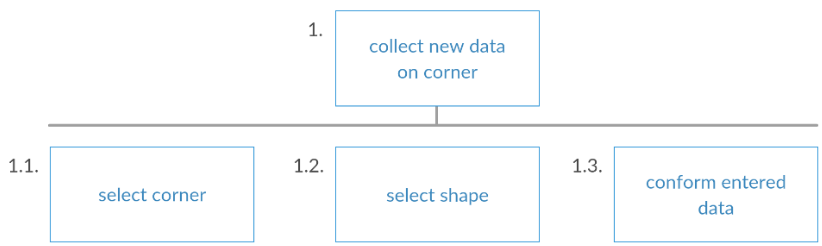

Fig. 13 *HTA for collecting new data on an undocumented corner*

Plan:

PLAN A: 1.1., 1.2., 1.3.

Scenario:

1. The user selects the corner on which he/she wants to collect data.
2. The user selects the corner shape.
3. The user confirms the entered data.

Case 4: Marking a new obstacle

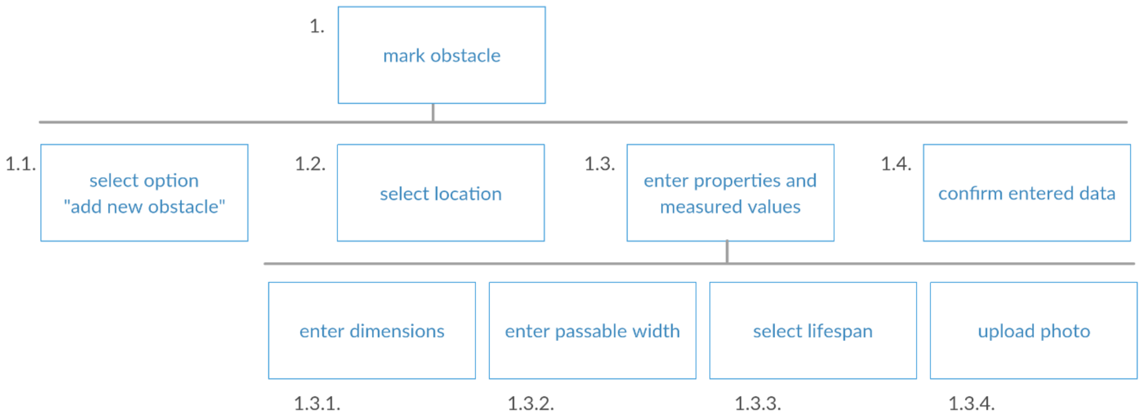

Fig. 14 *HTA for marking a new obstacle*

Plan:

PLAN A: 1.1., 1.2., 1.3.1., 1.3.2, 1.3.3, (1.3.4.) optional, 1.4.

Scenario:

1. The user selects the option "add an obstacle".
2. The user selects a location of the obstacle.
3. The user selects a type of the obstacle.
4. The user enters dimensions of the obstacle.
5. The user enters a passable width around the obstacle.
6. The user selects a lifespan of the obstacle.
7. The user uploads a photo of the obstacles.
8. The user confirms the entered data.

Case 5: Data validation

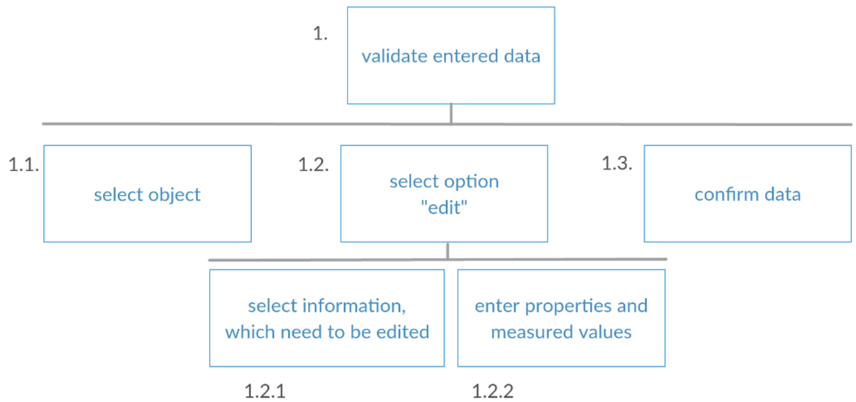

Fig. 15 *HTA for validation of collected data*

Plans:

PLAN A – validation of correct data: 1.1., 1.3.

PLAN B – validation of incorrect data: 1.1., 1.2.1., 1.2.2., 1.3.

Scenario:

1. The user selects the object on which he/she intends to examine the data.
2. The user selects the option "edit".
3. The user selects the information he/she wants to edit.
4. The user enters the recognized and measured information on the selected object.
5. The user confirms the entered data.

Alternative scenario:

1. The user selects the object on which he/she intends to examine the data.
2. The user confirms existing data.

3.2.3. Paper mockups

We have designed paper mockups which illustrate initial screen of the application and screens which implement defined use-cases (see Fig. 16).

The initial screen displays already marked objects - sidewalks, pedestrian crossings, corners, and obstacles. We use gray color for displaying objects for which we do not have any collected data besides their location. Red color is used for displaying the object for which we have only one to two user inputs. Orange color is used for displaying objects for which we have three to four user inputs. Green color is used for displaying objects for which we have more than four user inputs which means they are validated. In the upper right corner, we display a number of times when data collected through the application were used for navigation of handicapped people. In the lower left corner, there is a button for finding user’s current position and in the lower right corner there is a button for marking a new obstacle. For collecting data on objects already marked on the map, user simply clicks on the selected object. When collecting data, users receive proper guidance regarding what and how to collect and measure. Furthermore, simple questions with yes/no answers are for clarification. We mostly ask users for objective information about the requested pedestrian segments and landmarks, i.e., width, height, depth, slope or material. We need users to evaluate only quality of the surface. To ease and speed up the process of collecting the data, we use simple pictograms which act as radio buttons or checkboxes. Gamification features are not present in the paper mockups. This was a deliberate decision because we wanted end users to focus purely on features related to data collection.

The all designed mockups can be found at: https://leyfi.felk.cvut.cz/naviteriercrowdsourcing/mockups

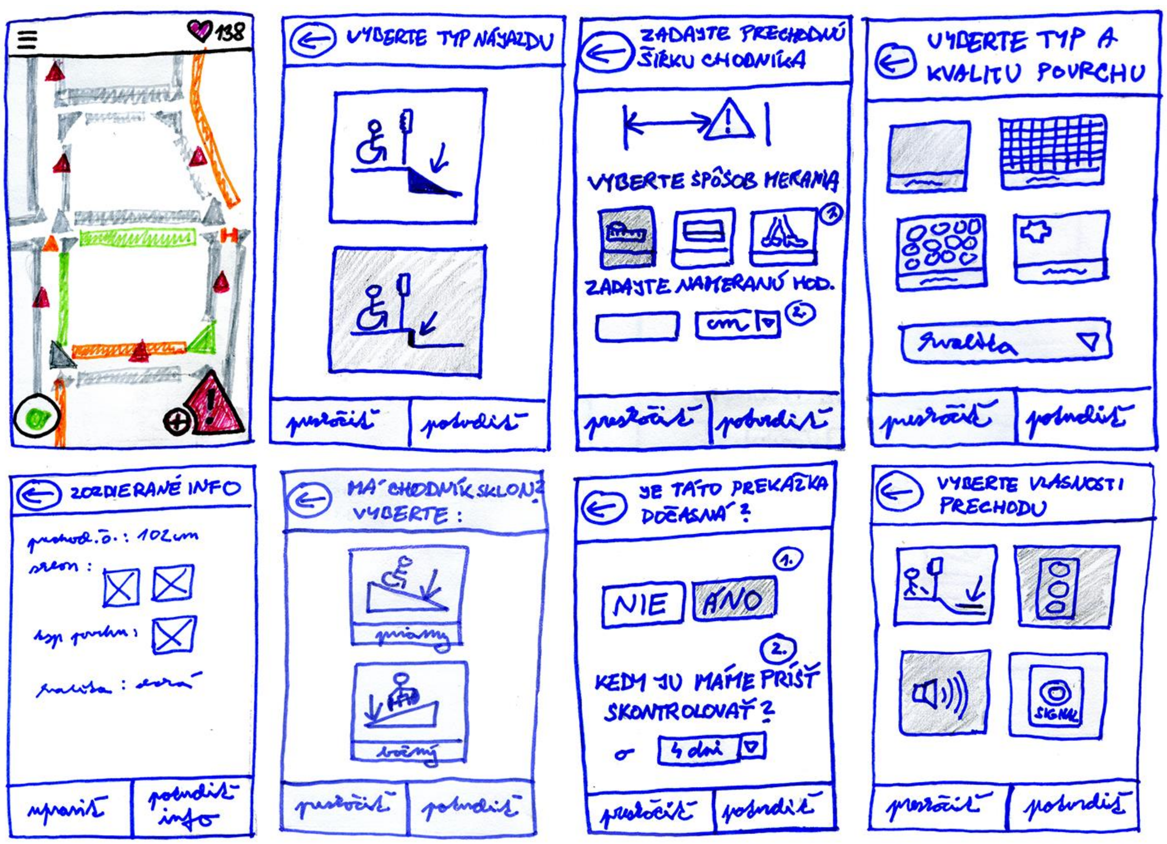

Fig. 16 The paper mockups

3.2.4. Low-fidelity prototype

Based on the comprehensive research introduced in the previous sections and design probe results (see Subchapter 4.1), we have created low-fidelity prototype which is the subject of this subchapter.

The low-fidelity prototype was created using online wireframing tool Balsamiq[11]. The prototype implements all scenarios of the use-cases. The prototype is clickable and all screens can be interactively browsed.

Initial screen

The initial screen (see Fig. 17) of the prototype shows a map with the current location of the user and newly added on/off button for switching the screen to the collecting mode. At the bottom part of the screen we have added the navigation panel which is used for searching addresses or places, viewing game profile and marking new obstacles. Above the navigation panel, on the right, there is a button for map settings and on the left, there is a button for getting current location of the user. We have preserved positively reviewed ideas from the paper mockups, i.e., the way objects are displayed on the map and their color scheme.

Fig. 17 The low-fidelity prototype. Initial screen

In the low-fidelity prototype, we have decided to implement game elements. We have preferred gamification before motivation by collecting subjective data which might clutter application with redundant data for navigation of impaired people and divert user´s attention from the collection of accessibility attributes. Therefore, the prototype can be divided into two layers – the data collection layer for collecting data on marked objects and for marking new obstacles, and the game layer as a motivation and engagement tool.

Data collection layer

For quick and easy data collection, we have preserved simple pictograms and added interactive elements such as sliders, drop-down lists or simple finger gestures (see Fig. 18-19). Similarly as in the paper mockups, users receive proper guidance regarding what and how to collect or measure, and simple yes/no questions are asked. At every step of the collection process, users can return to

[11] https://balsamiq.com/

the previous steps, modify entered values or possibly skip certain steps without entering values. At the end of each collection process we offer the user a summary of the entered information.

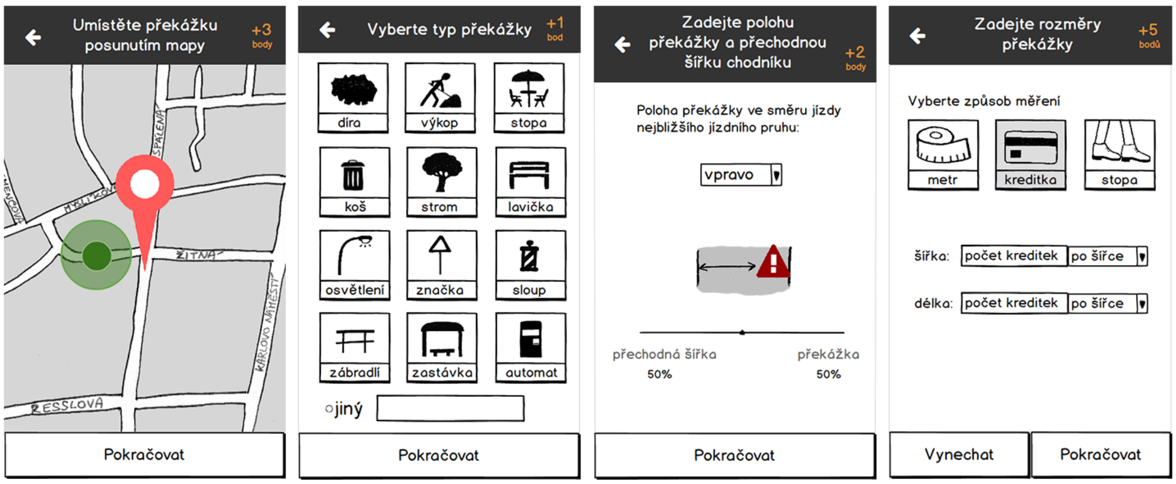

Fig. 18 The low-fidelity prototype. Data collection layer 1

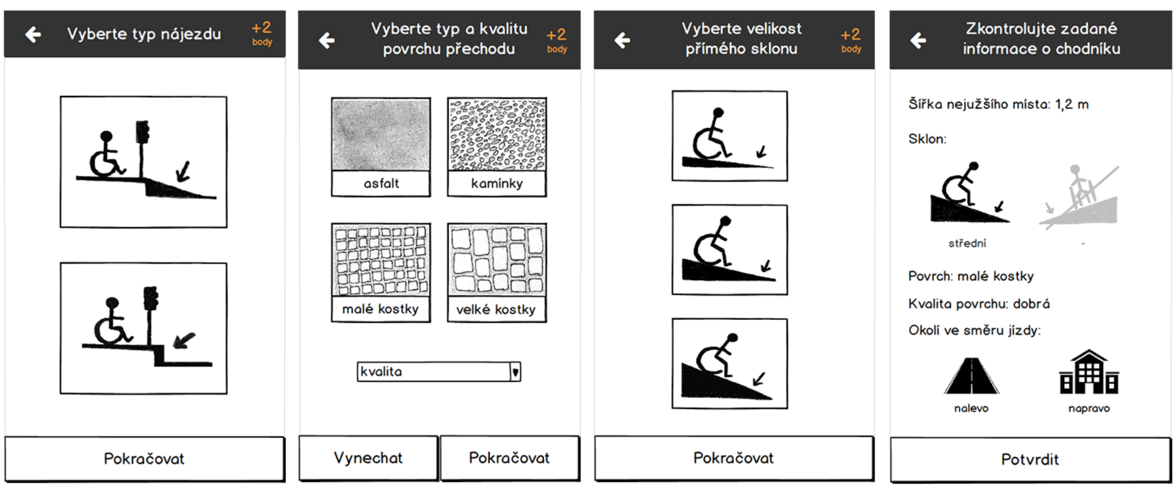

Fig. 19 The low-fidelity prototype. Data collection layer 2

Game design layer

We have implemented game design elements in our prototype in order to support user engagement and increase user contributions (see Fig. 20). Users can choose their usernames, personalize their avatars, gain points, badges and trophies for being active participants and share their success through social networks. Every month there is a special gaming challenge. When the challenge is accomplished, the user gains some extra points. Gained points are shown on monthly, yearly and overall leaderboards. The user´s credibility is expressed by star ranking.

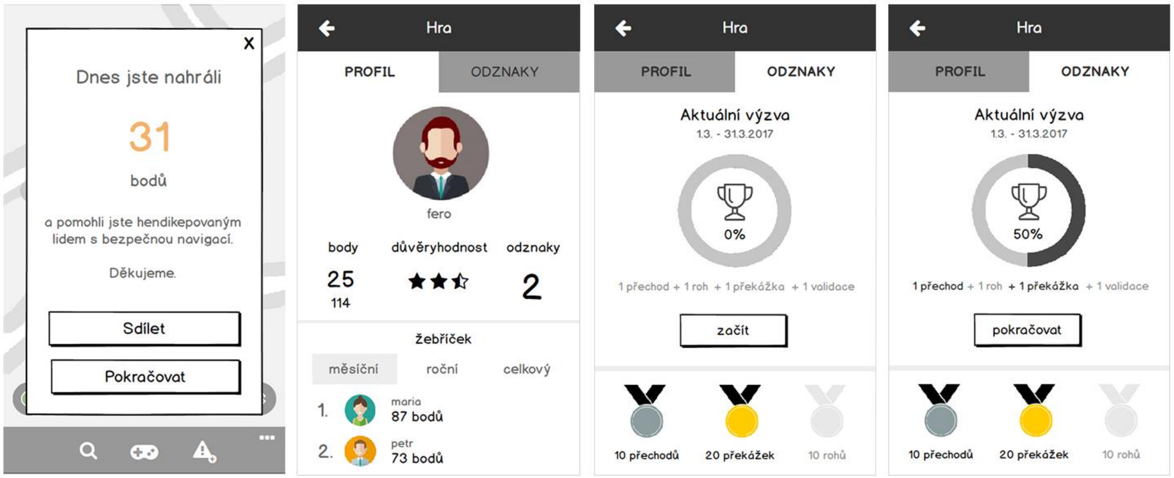

Fig. 20 *The low-fidelity prototype. Game layer*

The prototype is available at: https://leyfi.felk.cvut.cz/naviteriercrowdsourcing/lofi/lofi_prototype.pdf

3.2.5. High-fidelity prototype

This chapter focuses on the high-fidelity prototype which was created based on the results of the low-fidelity prototype evaluation. It describes its implementation, interactive design, visual design, user experience design and game design.

Implementation

When testing the low-fidelity prototype, we have identified several usability issues (see Subchapter 4.2). The recommendations for solving these problems were implemented in the high-fidelity prototype. The prototype is implemented as a web application using open source mobile HTML framework, Framework7[12], which optimizes the HTML code for mobile use. Thanks to this, the prototype can be used directly on mobile devices and it resembles the native mobile application. Integration with maps and geographic data is the key concept of this prototype. For this purpose, we have chosen Google Maps API[13] and its JavaScript integration libraries. Geolocation is not fully implemented, it is only updated on user´s request and it is not updated automatically when the device location changes. For the purpose of prototype testing, we have manually added pedestrian segments and landmarks on the map in the small area in Prague near Karlovo Náměstí and Myslíková Street. The actual GPS coordinates are stored in JSON format and are bundled with the application prototype. For the best user experience, it is recommended to use the prototype near this area. The final prototype was tested with and optimized for Google Chrome 58.0.x only. Locally saved application data can be cleared by clicking on `menu->Sign out`.

The prototype is available at: https://leyfi.felk.cvut.cz/naviteriercrowdsourcing/hifi/index.html

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[12] https://framework7.io/
[13] https://developers.google.com/maps/

Visual design

The high-fidelity prototype has a simple graphics customized for exterior mobile usage (see Fig. 21). We use palette of contrasting colors to increase recognition and readability in exterior conditions. The following combinations are used: gray and black pictograms on white cards, gray and black pictograms with yellow shading, white pictograms on black toolbar, white font and dark yellow font on black background. All buttons are designed in blue-white combination. Buttons that should be used preferentially have bright blue background, round corners and white font color. On the initial screen of the application, we use simple markers with respective pictograms for corners and pedestrian crossings. Crosswalks are illustrated by wide polylines. Markers and polylines are rendered in four colors. Markers and polylines which are used for objects with no known attributes are rendered in gray color. Markers and polylines which are used for objects with known but not validated attributes are rendered in red color. Orange color is used for rendering markers and polylines indicating objects with known but only partially validated attributes. And finally, green color is used for rendering markers and polylines indicating objects with verified attributes. Obstacle markers are rendered in dark red color. On the initial screen, the level of validation of pedestrian segments and landmarks is indicated only by the different colors of the corresponding markers and polylines. However, when the user displays segment or landmark details the level of validation is also present in a textual form.

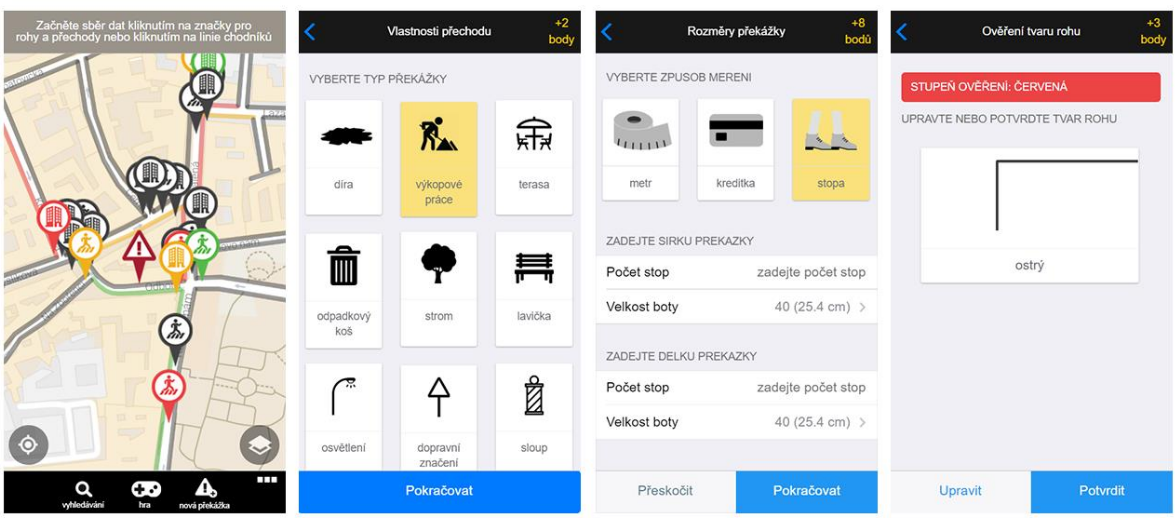

Fig. 21 The high-fidelity prototype. Visual design

Interactive design

The high-fidelity prototype has a responsive HTML layout suitable for mobile use. The page control elements are selected and positioned for optimal one-hand usage. The prototype is controlled by finger gestures – tapping, dragging, sliding, pinching or spreading. The prototype interacts with users either in the form of a dialogue – i.e., it asks user simple questions and the user answers them, or the prototype gives the user instructions for completing simple tasks (see Fig. 22). The prototype asks only one question or gives maximum of two tasks to be performed at a time. The user answers the questions with simple yes/no buttons or selects attributes, inserts numbers or names. At the end of collection process, the prototype provides a feedback by informing the user about gained points, changed status of the selected object or by adding a new obstacle marker on the map.

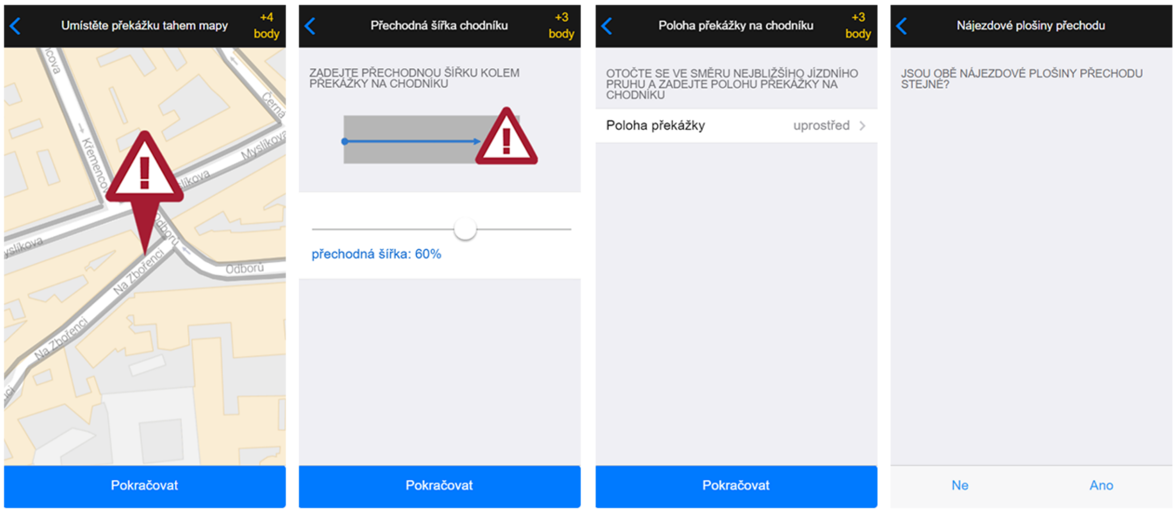

Fig. 22 *The high-fidelity prototype. Interactive design*

User experience design

The aim of the high-fidelity prototype is to present easy to use system, which will provide the best possible user experience (see Fig. 23). The process of collecting object data was divided into several small sub-tasks. To ease and speed up the data collection, some of them can be skipped because they do not provide data of such importance but are still helpful for navigation, e.g., a sidewalk vicinity, photos of obstacles, or a material and a quality of surfaces. The others are essential for successful navigation and orientation of people with disabilities and therefore they are required, e.g., passable width around obstacles, sidewalk widths, corner shapes or a ramp type of crossings. Throughout the whole experience of using the prototype, we provide users with proper guidance of what data to collect and how the collection should be done. Users are not forced to evaluate the accessibility or safety of the requested pedestrian segments and landmarks. They are only asked to enter objective and measurable data. When collecting data on specific attributes which are not generally recognized, we provide users also with instructional pictures. The task of entering crossing data is the most complex one, so to achieve better user experience we provide predefined pedestrian crossing types which can be selected by the user. These include the most common combinations of crossing attributes. These attributes can be changed if necessary. If none of the predefined type is suitable, user can enter the crossing data completely manually.

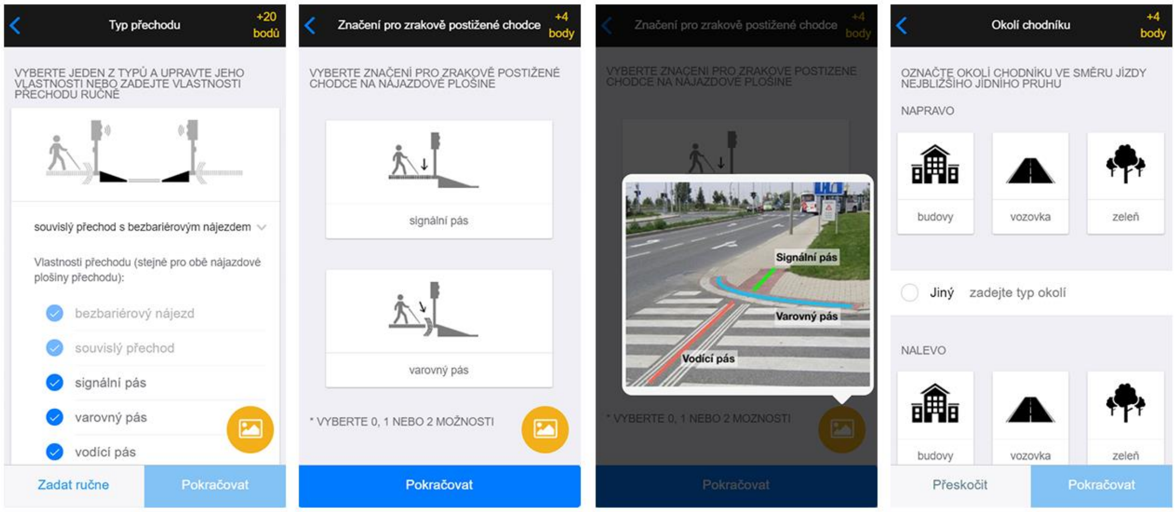

Fig. 23 *The high-fidelity prototype. User experience design*

Game design

To support user engagement and increase user contributions we designed an additional gamified layer of reward and reputation systems with points, badges and leaderboards (see Fig. 24). It is based on the analysis made in *Subchapter 2.2*. The aim of this layer is to create a community whose members are not nameless or faceless, but each of them has a unique profile reflecting his contributions to the main application mission – making navigation easier for handicapped people. Users can choose their usernames, personalize their avatars, decorate their walls with badges and trophies gained for being active participants and share their contributions through social networks. Each time users mark new obstacle, collect or validate data, they receive points which are shown on monthly and overall leaderboards. Every month there is a special gaming challenge. When the challenge is accomplished, the user gains some extra points. The user´s credibility is expressed by star ranking which also affects value of game points which user can potentially gain. For each task, the maximum value of points is set. This value is multiplied by the user's ranking, therefore the user's position at leaderboards is also influenced. The goal of star ranking is to motivate users to enter only valid data but it is also used for validation of multiple input data. If we have collected multiple different input data for just one object, we will decide which data will be stored in the geodatabase based on the users' ranking.

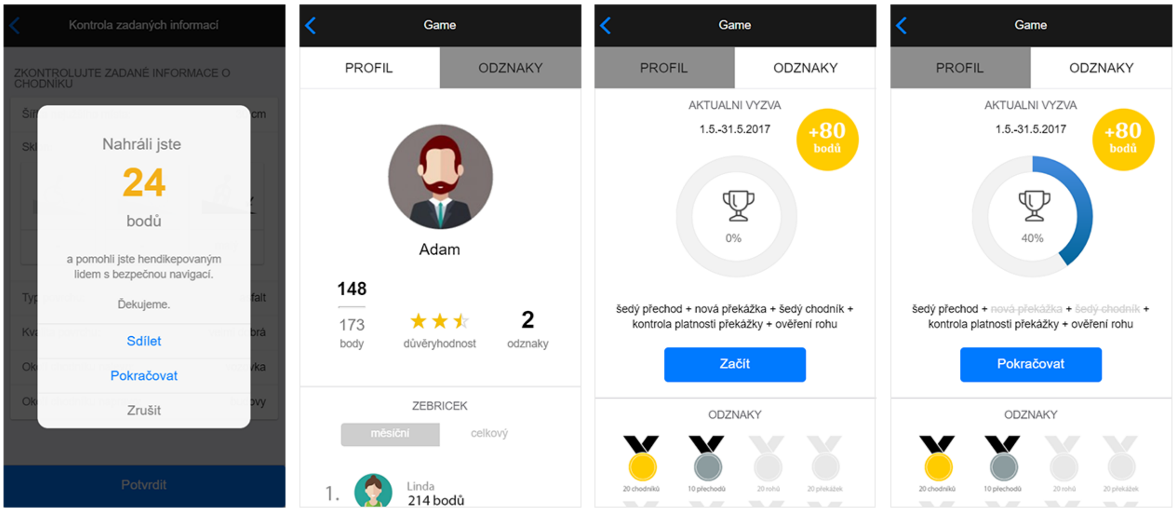

Fig. 24 The high-fidelity prototype. Game design

Functional requirements

Functional requirements are divided into 3 categories by their priority. High priority requirements describe the functionality that is necessary for running the future system. Medium priority requirements extend the application with features increasing the overall user experience. Low-priority functionality is not necessary for the system, but complements the application with extra, non-essential functionalities. The following functional requirements should be implemented when developing the application:

F1 – Adding a new obstacle (high priority)

The system will allow the user to add a new obstacle on a map, i.e., enter its location, upload photos, and collect attributes such as type, dimensions, and durability.

F2 – Collecting data on corners, crosswalks and sidewalks (high priority)

The system will allow the user to collect attributes on already marked corners, pedestrian crossings and sidewalks.

F3 – Validation of entered data (high priority)

The system will allow the user to check correctness of collected data and, if necessary, modify or confirm them.

F4 – Game layer (high priority)

The system will implement game design elements and allow the user to collect points, share content on social networks, rank on monthly and overall leaderboards and choose their personal avatar.

F5 – Geolocation (high priority)

The system will display the user´s actual location on a map.

F6 – Edit of map settings (medium priority)

The system will allow the user to customize map settings for his/her own needs.

F7 – Searching of addresses and places (low priority)

The system will allow the user to search for addresses and locations for remote data collection.

4. Test and evaluation

The aim of this chapter is to describe process of design evaluation and its results, and formulate design recommendations which should be implemented in the next design processes.

4.1. Design probe

For user testing of the paper mockups (introduced in Subchapter 3.2.3), we have decided to use the design probe method. Our aim was to collect experiences and explore a new potential of our application design by including the users in experimenting, commenting, and hatching new ideas with technological potential. We have invited 4 respondents, potential users of our future application.

4.1.1. Characteristics of design probe method

Design probe is an approach of user-centered design for exploring design opportunities and understanding human phenomena. The three main principles of design probes are as follows. Firstly, design probes are based on users and their active participation in the user-centered design process through expressing their thoughts and ideas. Secondly, the aim is to introduce user´s perspective to enrich design therefore design probes look at the user´s personal context and perceptions. Thirdly, probes have an exploratory character, which means that they explore new opportunities rather than solve problems that are known already (Mattelmäki et al., 2006).

4.1.2. Design probe results and discussion

We have received the following feedback from the respondents:

1. The users were discouraged from using application on daily basis due to the large number of steps and complicated measuring of individual tasks. They proposed to simplify the process of measuring dimensions, e.g., by using simple slider. They suggested reducing the number of steps when collecting data on undocumented objects or marking new obstacles. They suggested keeping only steps with tasks that can be solved only with the help of mobile phone while walking to school or work. When marking new obstacles, following tasks should be preserved: select location, select type and enter passable width. When collecting data on crosswalks, following tasks should be preserved: select type of ramp, select type of guidelines and select properties of zebra crossing. When collecting data on sidewalks, following tasks should be preserved: select type and size of slope, enter passable width.

   Solution proposal: We should provide the user with choice of two modes - basic and advanced mode, so that the user can decide whether he/she wants to collect only essential data with a minimal effort or wants to gather all the necessary information for navigation of handicapped people.

2. The users would welcome a presence of illustrative photos of types of guidelines for visually impaired people as an addition to the used pictograms. Solution to add a tooltip for each step did not meet with a positive response, because using a tooltip gives the user impression that he/she is unable to solve a simple task.

   Solution proposal: When solving the tasks to collect attributes which are not generally recognized, we should provide users with photos of the attributes which should be collected.

3. The users have no incentive to use the application however they liked the idea of gamification. They would prefer a conquest game where teams or individuals can compete against each other. The incentive in this case should be the domination over most of the territory or the periodic evaluation of the best users who would win rewards in the form of valuable prizes sponsored by the town government or by private entrepreneurs.

   Solution proposal: Gamification of the application where users would be motivated by the domination over the city or by winning valuable prizes.

The design probe showed us that If we force the users to enter excessive amount of details of the given object, it may discourage them from regular and frequent use of the application. On the other hand, if we would allow them to enter only bare minimum of details the user base of our application might increase rapidly but we might end up with data which are incomplete, imprecise and insufficient for navigation of handicapped people. If we want both, quality data and the large user base, the amount of required data needs to be somewhere in the middle and the way of entering these needs to be extremely convenient and easy. Therefore, the biggest challenge seems to be finding the right balance between the amount of details of required data and the size of the user base. As confirmed by the respondents, adding new gamified layer to the application might also help to enlarge the user base. All this feedback gathered from the design probe was reflected in designing process of the low-fidelity and the high-fidelity prototypes.

4.2. Evaluation of the low-fidelity prototype

To evaluate the low-fidelity prototype we have chosen a qualitative test that will help us detect thoughts, feelings and behavior of the target group. To gain a detailed insight into the user experience with our prototype, we have used the think-aloud protocol, i.e. we asked all participants to think out loud about what he/she was doing and what was possibly causing troubles to him/her.

4.2.1. Goals of evaluation

The main goal of the evaluation is to test prototype functionality on the main use-cases of the application, i.e., collecting new data on undocumented objects, marking new obstacles, data validation, and identify potential problems. The second goal is to find out people's views and opinions on the tested prototype through the think-aloud protocol and the post-test interviews.

4.2.2. Test set-up

Participants

We tested the prototype with 5 participants. Participants were young adults and middle-aged persons, both females and males, who are experienced in the use of smartphones and mobile applications (see Fig. 25).

	P1	**P2**	**P3**	**P4**	**P5**
Age	25	27	25	30	49
Gender	M	M	F	M	F
Experience with crowdsourcing	none	none	none	none	none

Fig. 25 *Evaluation of the low-fidelity prototype. Pre-test questionnaire responses*

Location

The low-fidelity prototype was tested in the exterior, in a quiet area in the city center of Prague, Czech Republic.

Equipment

As the testing mobile device, we used Xiaomi Redmi 3S with Android 6.0.

Data collection

In each session, we recorded one video stream of the participant's activities which was used for later detailed analysis.

Procedure

With each participant one session was held which lasts from 20 to 30 minutes. At the start of each session we used a short questionnaire as a form of obtaining basic data about the participants and their experiences with crowdsourcing. Then we have briefly explained the purpose of the application, showed the two-mode interface and presented game elements to each participant. After that, we gave each participant seven simple tasks which he/she had to perform in the specified order. After the test had been finished, we made a short interview with each participant. We were interested in the answers to these questions: Was the process of testing difficult for you? What do you like/dislike on the application? What exactly was the biggest problem for you? How would you improve the application / what features would you like to see in the application?

4.2.3. Test scenarios

Seven specific tasks were given to each participant. Because of low-fidelity prototype limited functionality, there was no possibility to collect data about any object on the map, all objects were selected for the test beforehand. After completing each task, we showed the participant the next task object and we asked the participant to manually update device location. The starting point for each task was the initial screen of the prototype. The tasks and recommended walkthroughs are as follows:

Task 1: Find out the task for this month for which you get the badge and special ranking points.
Recommended walkthrough:

1. The user displays his/her game profile.
2. The user selects option “badges” to see the current task for this month.

Task 2: Mark the obstacle on the map. Use the following values: size = 8 x 10 credit cards, passable width = 70%, temporary.
Recommended walkthrough:

1. The user updates his/her location.
2. The user chooses option for adding new obstacle.
3. The user locates the obstacle on the map.
4. The user chooses location of the obstacle on the pavement: left.
5. The user sets passable width to 70%.
6. The user selects hole as the type of the obstacle.
7. The user takes a photograph of the obstacle.
8. The user enters dimensions of the obstacle: 8x10 credit cards.
9. The user sets lifespan of the obstacle as temporary.
10. The user confirms entered data.
11. The user receives information about gained points and continues to homepage.

Task 3: Collect necessary information on the pedestrian crossing. Use the following values: number of lanes = 1.
Recommended walkthrough:

1. The user updates his/her location.
2. The user sets the display mode to the collecting mode.
3. The user selects the pedestrian crossing on the map on which he/she wants to collect data.
4. The user selects an entry point of the selected pedestrian crossing.
5. The user selects barrier-free type of the ramp.
6. The user marks the presence of warning and leading stripes.
7. The user selects small cubes as the surface type and very good quality.
8. The user confirms that the information entered are the same for the second entry point of the pedestrian crossing.
9. The user selects none of the offered properties of the crossing.
10. The user chooses that there is one driving lane.
11. The user selects asphalt as a surface type and very good quality.
12. The user confirms the entered data.
13. The user receives information about gained points and continues to homepage.

Task 4: Find out what data you still need to collect to get a badge for this month.
Recommended walkthrough:

1. The user displays his/her game profile.
2. The user selects option “badges” to see the progress on the current task for this month.

Task 5: Collect required data on the corner.
Recommended walkthrough:
1. The user updates his/her location.
2. The user selects the corner on the map on which he/she wants to collect data.
3. The user selects round shape of the corner where x < 1.
4. The user confirms entered data.
5. The user receives information about gained points and continues to homepage.

Task 6: Collect necessary information on the sidewalk. Use the following values: passable width = 1.2 m, present longitudinal slope.
Recommended walkthrough:
1. The user updates his/her location.
2. The user selects the sidewalk on the map on which he/she wants to collect data.
3. The user enters 1,2 meters as a passable width of the sidewalk.
4. The user marks presence of the longitudinal slope and chooses its size.
5. The user selects small cubes as the surface type and a very good quality.
6. The user confirms entered data.
7. The user receives information about gained points and continues to homepage.

Task 7: Adjust the number of lanes from the task 3 to 2 driving lanes.
Recommended walkthrough:
1. The user updates his/her location.
2. The user selects the crossing from the task 3.
3. The user selects the option "edit".
4. The user selects the zebra part of the crossing.
5. The user selects “a number of lanes” as an information he/she wants to edit.
6. The user corrects that there are two driving lanes.
7. The user confirms entered data.
8. The user receives information about gained points and continues to homepage.

During the evaluation, we were measuring two parameters: whether participant finished the task (yes/no) and how many mistakes he/she made which means how many times participant deflected from the recommended walkthrough, e.g., the user selected a wrong option, object or attribute.

4.2.4. Test results

All participants managed to finish all tasks in relatively short time period.

Task 1: Participants had no problem with solving first task. All participants were able to navigate through the game menu and easily found and recognized the task for the current month.

Task 2: All participants identified the correct option for adding a new obstacle. When placing the new obstacle, 4 participants ignored the task description and wanted to place the obstacle by moving marker instead of moving a map. In this case, it may be a prototype limitation because low-fidelity prototype doesn't allow to move a map, so this option did not seem intuitive for participants. Moreover, three participants had a difficulty with specifying the position of the obstacle on the pavement because of inaccurate formulation of instructions in the prototype. The rest of the task solving ran smoothly.

Task 3: When collecting data on the pedestrian crossing all participants had difficulties recognizing clickable elements on the map. At first, all participants were clicking on the legend instead of the actual elements on the map. Participants were confused whether the elements on the map are clickable or not. Two participants had difficulties distinguishing between warning, leading and signal stripes from the graphic pictograms. The rest of the task solving ran smoothly.

Task 4: During the second visit of the gaming profile, all participants quickly and confidently found and identified remaining tasks to gain the badge for that month.

Task 5: When collecting data on the corner, participants easily found and clicked on the corner symbol and selected the shape of the corner.

Task 6: When collecting data on the sidewalk, participants did not know where to click. It was not clear for them that the marked pavement on the map is clickable. Once they managed to click on the pavement the rest of the task solving ran smoothly.

Task 7: Validation of the entered data was managed by all participants without any problems.

Number of mistakes which each participant made during solving the tasks are listed in Figure 26.

	T1	T2	T3	T4	T5	T6	T7
P1	0	2	1	0	0	1	0
P2	0	1	2	0	0	1	0
P3	0	1	1	0	0	0	0
P4	0	1	0	0	0	0	0
P5	0	2	2	0	0	1	0

Fig. 26 *Evaluation of the low-fidelity prototype. Number of mistakes made during the task solving*

4.2.5. Post-test interview

After the test, we talked shortly with each participant. We want to see their opinion on these questions:

Q1: Was testing process difficult for you?
Q2: What have caused you the biggest troubles?
Q3: What do you like most / dislike on the application?
Q4: How would you improve the application / what features would you like to see?

Given answers are listed in Figure 27.

	Q1	Q2	Q3	Q4
P1	No	I did not know which elements are clickable during the data collection.	+ game points - too much required information on pedestrian crossing	I would like to see an option to select from predefined frequently occurring types of pedestrian crossings to speed up the collection.
P2	No	I would need more precise specification of the tasks. I did not know where to click for data collection.	+ badges	I would add an intro on how to control application.
P3	No	I did not know which elements are clickable during the data collection.	+ some steps can be skipped	I would improve clickable elements so that they flickered when passing by.
P4	No	Nothing, I just needed to figure out how it works.	+ intuitive interface + well designed pedestrian crossings	I would highlight elements which are interactive.
P5	No	I would need more precise instructions.	+ game elements + sharing on social networks	I would use more specific instructions.

Fig. 27 *Evaluation of the low-fidelity prototype. Post-test interview results*

4.2.6. Findings and recommendations

Finding no. 1: Unintuitive placement of the obstacle marker on the map
Description: When marking a new obstacle, participants chose to move the marker instead of the map.
Recommendation: This seems like a prototype limitation because low-fidelity prototype doesn't allow to move the map, so this option did not seem intuitive for participants. We recommend keeping this section without changes and test it with the more interactive high-fidelity prototype.

Finding no. 2: Wrong formulation of instructions for specifying obstacle position on a sidewalk
Description: Participants had difficulties with specifying the obstacle position on a sidewalk because of inaccurate formulation of task instructions.
Recommendation: We recommend specifying the instructions for positioning obstacles on a sidewalk and replacing the current label "Position the obstacles in the direction of the nearest driving lane" with a new formulation: "Please, turn in the direction of the nearest driving lane. On which side of the pavement is the obstacle located?".

Finding no. 3: Match of clickable elements with background

Description: Participants had difficulties recognizing the clickable elements on the map.

Recommendation: We recommend highlighting the clickable elements on the map and modification of the legend with symbols of marked objects so that it guide users to click on the elements.

Finding no. 4: Unexplanatory pictograms of stripes for blind pedestrians

Description: Participants had difficulties distinguishing between warning, leading and signal stripes from the graphic pictograms.

Recommendation: We recommend supplementing of the used pictograms with photographs of given stripes for better illustration.

4.3. Evaluation of the high-fidelity prototype

4.3.1. Goals of evaluation

The main goal of the evaluation was to verify the functionality of the improved more interactive high-fidelity prototype on the main application use-cases. The second goal is to verify the functionality of the game layer and its impact on users´ motivation. Thirdly, our goal is to find out people's views and opinions on the tested prototype through the think-aloud protocol and the post-test interviews.

4.3.2. Test set-up

Participants

The high-fidelity prototype was tested with 5 participants. Participants were young adults and middle-aged persons, both females and males, who are experienced in the use of smartphones and mobile applications (see Fig. 28).

	P1	**P2**	**P3**	**P4**	**P5**
Age	25	31	36	26	23
Gender	F	M	M	M	F
Experience with crowdsourcing	none	none	foursquare	none	none

Fig. 28 *Evaluation of the high-fidelity prototype. Pre-test questionnaire responses*

Location

The high-fidelity prototype was tested at the same location as the low-fidelity prototype, in a quiet area in the city center of Prague, Czech Republic.

Equipment

We used the same testing mobile device, Xiaomi Redmi 3S with Android 6.0 on which we ran our application customized for each participant, we used his/her real name and shoe size.

Data collection

In each session, we recorded one video stream of the participant's activities which was used for later detailed analysis.

Procedure

With each participant one session was held which lasts from 30 to 45 minutes. At the start of each session we used a short questionnaire as a form of obtaining basic data about the participants and their experiences with crowdsourcing. Then we have briefly explained the purpose of the application and showed participants short intro (which can be found at `menu->About the application`) to get familiar with the basic control elements. After that we gave each participant one task that was composed of six sub-tasks which he/she had to find out and perform in any order to see how participants work with the complex designed system. After the test had been finished, we made a short interview with each participant. We were interested in the answers to these questions: Was the process of testing difficult for you? What do you like/dislike about the application? What exactly was the biggest problem for you? How would you improve the application / what features would you like to see in the application? Would you participate in data collection through this application and why?

4.3.3. Test scenarios

To each participant, a following task was given:

Main task: Get the badge and special ranking points for completing this month's challenge.

The main task included six sub-tasks:

Sub-task 1: Find out the task for this month for which you get the badge and special ranking points.
Recommended walkthrough:

1. The user displays his/her game profile.
2. The user selects option “badges” to see the current task for this month.

Sub-task 2: Collect necessary information on a pedestrian crossing.
Recommended walkthrough:

1. The user selects the pedestrian crossing on which he/she wants to collect data.
2. The user chooses whether the properties of two entry points of the selected pedestrian crossing are equal.

If properties of both entry points are equal:

3a. The user selects one of predefined types and edits its attributes or the user selects the option to enter data manually (continues to step 3b)
4a. The user selects type and quality of entry point surface.
5a. The user selects number of driving lanes.
6a. The user selects type and quality of zebra surface.
7a. The user confirms the entered data.
8a. The user receives information about gained points and continues to homepage.

Else:

3b. The user selects an entry point of the selected pedestrian crossing on which he/she wants to collect data.
4b. The user selects the type of the ramp and if there is a curb he/she measures the curb height.
5b. The user chooses which stripes for navigation of blind and visually impaired are present on the crossing.

6b. The user selects type and quality of entry point surface.
7b. The user confirms that the information entered are the same for the second entry point of the pedestrian crossing (if not, the user repeats steps 4b – 6b).
8b. The user selects type of the crossing.
9b. The user selects attributes which are present on the crossing.
10b. The user selects number of driving lanes.
11b. The user selects type and quality of the crossing surface.
12b. The user confirms the entered data.
13b. The user receives information about gained points and continues to homepage.

Steps 4a, 6a, 6b, 9b and 11b can be skipped.

Sub-task 3: Mark a new obstacle on the map.
Recommended walkthrough:

1. The user chooses option for adding new obstacle.
2. The user locates the obstacle on the map.
3. The user chooses location of the obstacle on the pavement.
4. The user sets the passable width around the obstacle.
5. The user selects type of the obstacle.
6. The user take a photograph of the obstacle.
7. The user measures and enters dimensions of the obstacle.
8. The user selects a lifespan of the obstacle and if the obstacle is temporary, the user selects also its durability.
9. The user confirms entered data.
10. The user receives information about gained points and continues to homepage.

Steps 6 and 7 can be skipped.

Sub-task 4: Collect necessary information on a sidewalk.
Recommended walkthrough:

1. The user selects the sidewalk on which he/she wants to collect data.
2. The user measures and enters a passable width of the sidewalk.
3. The user selects types of slope which are present on the sidewalk and chooses their size.
4. The user selects type and quality of the sidewalk surface.
5. The user selects the vicinity type of the sidewalk.
6. The user confirms entered data.
7. The user receives information about gained points and continues to homepage.

Steps 4 and 5 can be skipped.

Sub-task 5: Check durability of an obstacle.
Recommended walkthrough:

1. The user selects the obstacle which he/she wants to check.

2. The user checks presence of the obstacle.

If the obstacle has been already removed:

3a. The user confirms that the obstacle has been removed.
4a. The user receives information about gained points and continues to homepage.

Else:

3b. The user confirms that the obstacle has not been removed.
4b. The user selects estimated durability of the obstacle.
5b. The user receives information about gained points and continues to homepage.

Sub-task 6: Validate a corner.
Recommended walkthrough:

1. The user selects the corner which he/she wants to validate.
2. The user checks if collected data are valid.

If data are valid:

3a. The user confirms collected data.
4a. The user receives information about gained points and continues to homepage.

Else:

3b. The user edits collected data.
4b. The user confirms entered data.
5b. The user receives information about gained points and continues to homepage.

During the evaluation, we were measuring two parameters: whether participant finished the task (yes/no) and how many mistakes he/she made, which means how many times participant deflected from the recommended walkthrough, e.g., the user selected a wrong option, object or attribute.

4.3.4. Test results

All the participants managed to finish all the tasks in short time period. Google Maps and used markers, being the core elements of the prototype, proved to be very intuitive to use for all the participants. This was one of the major factors which contributed to the overall positive experience with the prototype. The participant also appreciated gamification features, i.e., sharing achievements on social networks, point system and leaderboards.

Sub-task 1: The participants had no problem with solving first sub-task. All participants could get to game profile through the toolbar easily, and intuitively found and recognized challenge for this month.

Sub-task 2: When collecting data on the pedestrian crossing, all participants chose to select type of the crossing from predefined types, but only three participants expand the option for modifying crossing attributes. Two participants confirmed the data without modification, although the attributes of the predefined type did not match with attributes of given crossing. One participant used the tooltip with illustrative image of signal, warning and leading stripes. Attributes collected later during the process were entered correctly and without problems by all participants. All participants manage to collect all data, none of the pages were skipped. At the end of the collection, participants had difficulties with summary page. They could not identify which data were collected on which part of the crossing and could not check them properly.

Sub-task 3: When marking a new obstacle on the map, all participants correctly identified objects that could be an obstacle for navigation of people limited in mobility. All participants intuitively dragged the map to place the obstacle on the map. Two participants had difficulties to determine the passable with around obstacle when positioning the obstacle to the center of the pavement. They were not sure whether to enter only the right or left passable width or to sum up both widths. There were no more problems with the rest of required attributes. For measuring obstacle dimensions, all participants used steps as the measuring technique. All participants correctly estimated and selected the lifespan of the obstacle. The participants did not have a problem with the summary page and confirmed the entered data without any problems.

Sub-task 4: When collecting data on a sidewalk, all participants used steps as the measurement technique. They all understood the instructions and used pictograms correctly and gathered all the necessary data.

Sub-task 5: To verify whether the obstacle is still present, participants mostly used available photo of the obstacle and did not read collected attributes. All participants correctly confirmed that the obstacle had been removed.

Sub-task 6: When validating a corner, two participants clicked on a gray corner marker and collected data on the undocumented corner. After they had checked their game profile and status of current challenge, they realized that they had not validate the corner but they had collected data on the new one. The rest of the task went smoothly and all participants managed to validate the corners.

The number of mistakes each participant made during solving tasks is shown at Figure 29.

	T1	**T2**	**T3**	**T4**	**T5**	**T6**
P1	0	2	0	0	0	1
P2	0	1	0	0	0	1
P3	0	1	0	0	0	0
P4	0	0	1	0	0	0
P5	0	0	1	0	0	0

Fig. 29 *Evaluation of the high-fidelity prototype. Number of mistakes made during the task solving*

4.3.5. Post-test interview

After the test, we talked shortly with each participant. We want to see their opinion on these questions:

Q1: Was testing process difficult for you?
Q2: What have caused you the biggest troubles?
Q3: What do you like most / dislike on the application?
Q4: How would you improve the application / what features would you like to see?
Q5: Would you participate in data collection through this application? Why?

Given answers are listed in Figure 30.

	Q1	Q2	Q3	Q4	Q5
P1	No	There were too many tasks to solve therefore it was hard to remember them all at once.	+ game layer + illustrative photos + some tasks can be skipped	It would be handy if application would provide user with notifications if he/she is passing next to objects which need to be validated.	Yes, I would participate. The idea of winning prices and helping impaired people at the same time is motivating.
P2	No	When I have something to verify I need to realize that I do not mark a new object but I need to click on the red or orange one.	+ photos of obstacles - too many tasks	I would appreciate if there were more predefined types of pedestrian crossings.	No, I not used to use my mobile phone on street.
P3	No	Nothing.	+ tooltip photos	More predefined types of pedestrian crossings to speed up the collection.	Yes, it seems like a nice project.
P4	No	There were too many tasks to remember them all at once wherefore I needed to go and checked them at game profile a couple of times.	+ some tasks can be skipped	It would be nice if I could see the status of this month challenge on application homepage.	Yes, rewards look attractive.

P5	No	Sometimes there were too long instructions to read.	+ personalization + map settings + obstacle photos	I would like to see a how many and which tasks exactly I still need to solve to get a badge.	Maybe on my way to work or store.

Fig. 30 *Evaluation of the high-fidelity prototype. Post-test interview results*

4.3.6. Findings and recommendations

Finding no. 1: Overwhelming task list

Description: The participants had difficulties to remember all the tasks which must be solved to get the badge. They repeatedly checked the task list in the game profile menu after solving a sub-task.

Recommendation: Although the task list has been so complicated only for the test purpose (the usual task will look like "Mark 10 corners"), we still recommend showing the status of the started challenge in the top drop-down bar of the homepage screen instead of the current instruction on how to start data collection process, which only needs visible when the user interacts with the application for the first time.

Finding no. 2: Undiscoverable option for editing attributes of predefined crossing types

Description: When collecting data on the pedestrian crossing the participants ignored the option for editing attributes of predefined crossing types and confirmed predefined attributes even though they did not match with the actual attributes of the crossing.

Recommendation: After the user selects one of the predefined types, its attributes should be displayed immediately, either by displaying pop-up window or by drop-down menu. The user may or may not alter some attributes if he/she deems it necessary. Also, more predefined types should be provided to speed up the collection process.

Finding no. 3: Unclear summary page for pedestrian crossing attributes

Description: At the end of the crossing collection process, the participants had difficulties to recognize and check entered data on the summary page.

Recommendation: We recommend simplifying and clarifying the summary page by removing the map images and elements that might resemble elements from the pages for data collection, e.g., cards with black pictograms.

5. Conclusion and future work

The main objective of this thesis was to create the prototype of the mobile application which purpose is to collect accessibility attributes needed for orientation and navigation of people with limited mobility. This data collection is performed for a fraction of price and time in comparison to the professional geographical onsite reconnaissance.

In this thesis, we analyzed the methodologies of navigation and orientation of wheelchair users, blind and visually impaired people. We identified accessibility attributes which are needed for their safe and independent navigation. We performed the qualitative research in the form of focus groups to explore the possibilities of geo-crowdsourcing as an alternative tool for geodata collection, examine the capabilities of a crowd in collecting accessibility attributes, and identify motivation of people to participate in geo-crowdsourcing. According to focus groups´ results, if provided training, feedback, and monitoring, contributions from non-expert crowd could rival to those of professionals and if enough people review collected data, their quality should not differ significantly. The results show that we must encourage people to get involved into geo-crowdsourcing by providing another layer to the data collection layer. This can be layer for collecting subjective data on a route or gamified layer.

Based on our research we proposed first application design in form of paper mockups. We conducted 4 design probe sessions based on paper mockups concluding that we must speed up and ease the collecting process by minimizing required amount of data and providing faster input methods.

Based on the design probe results we designed low-fidelity prototype in which the gamified layer was introduced. This approach was chosen instead of layer for subjective data collecting which might clutter the application with redundant data for navigation of impaired people and divert users' attention from the collection of accessibility attributes. The prototype was tested with 5 participants. According to the evaluation results the biggest usability problem was the way the objects were rendered on a map. It was not obvious for participants that these objects are interactive which complicated the start of collecting process. We have improved this in the next prototype, high-fidelity prototype, by using simple markers with respective pictograms and adding instructions explaining how to start the data collection process.

Throughout the whole data collection process, we provide users with proper guidance including precise instructions and illustrative photos about what data to collect and how the collection should be done. Attributes of requested pedestrian segments and landmarks are displayed as simple pictograms in combination with easy-to-understand labels. We use number of input elements, e.g., sliders, drop-down menus and finger gestures, all are easy and fast to use, especially on a mobile device. We do not force the user to evaluate the accessibility or safety of the requested pedestrian segments and landmarks. They are only asked to enter objective and measurable data. Attributes which are essential for successful navigation and orientation of people with limited mobility are required, but those which are not so important but still helpful can be easily skipped. The evaluation results suggest the feasibility of this approach with a few design changes to implement. One of the main challenge was to address attraction of new users and ensuring they are using the application on daily basis. According to prototypes' evaluation, it seems that using gamified layer is a step into the right direction.

For future improvements, we consider expanding the gamified layer of the application by rewarding actual leaders with physical or digital goods at the end of each period, so that we can further increase users´ motivation. We plan to conduct a long-term experiment which will evaluate the quality of collected accessibility attributes in comparison to data obtained by the professional onsite reconnaissance, and will review impact and effectiveness of the gamified layer on users´ motivation to participate in geo-crowdsourcing.

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