Smart Data at Play: Improving Accessibility in the Urban Transport System

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Abstract. Human mobility is one of the most important concerns in smart city initiatives and is especially relevant when combined with accessibility issues. This paper describes work in the context of the Access@City Research Project, which seeks to improve the accessibility in the public transport system by using available information (open data, semantic-aware knowledge) provided by transport organizations. However, these organizations provide partial data, and a lot of information is still available only on their websites, or simply does not exist. This absence can be tackled using a playful approach - the use of gaming apps to obtain and update accessibility information. In this paper, we describe the use of a hybrid reality game (HRG) to enrich information regarding the accessibility of subway stations. In turn, the player improves her score, which is included as part of the game. The correlation between these observations is able to provide, in a relatively short time, an accurate description of the accessibility of these stations. In summary, this playful approach makes it possible to recover a set of accessibility data that ultimately provide these smart capabilities, which are the core of this "accessible city" endeavour.

Keywords (3-6 words): smart city; crowdsourcing; gamification; smart data.

1. Introduction

Smart cities have been conceived as the next step in the evolution of the adaptation of physical space to human needs. Their purpose is to use information technologies to improve everyday life in urban environments by obtaining and processing data concerning behaviour in the city and applying this additional intelligence in order to overcome the limitations imposed by their traditional static structure. Human mobility is among the most important concerns in these initiatives, particularly when it is integrated into the main infrastructure that cities provide to support it, namely the urban transport system (Kapenekakis & Chorianopoulos, 2017).

This is especially relevant when it is combined with *accessibility* issues: although the public transport system is critical for all citizens, it is of vital importance for groups with restricted mobility. These encompass not only the obvious groups of disabled people, but also citizens with any kind of special mobility needs, such as parents with a pushchair, or an injured person using a crutch.

Our research is, therefore, focused on improving the accessibility in increasingly smarter cities, using the urban transport system as the mainstay of this initiative. The basic idea is to obtain and compile all the information available about the transport system, rephrase it in the form of linked data, and provide the semantic annotations required to transform this structure into knowledge. By processing these *smart data*, citizens are now able to plan and schedule their mobility in the urban transport system. In general terms, this will immediately improve its efficiency, and in this specific case it will also improve accessibility, as it will provide the groups of interest with prior knowledge regarding whether or not a certain route is accessible.

However, most of the data sources concerning public transport are *static* in nature, and this limits their usefulness. One of the biggest initial issues when compiling this information was that it was often incomplete, a lot of effort had to be made, and many sources had to be combined to achieve a thorough description of the transport system in several representative cities. Accessibility data were among the most difficult to obtain; even IFOPT (CEN/TC278, 2012), the working standard employed to describe nodes in the transport network (i.e. stations and other “fixed objects”), provides only a part of the relevant information, while many accessibility features are not clearly represented.

But this incompleteness is not the only problem; an additional issue is that these data do not evolve easily, but the actual city does. Even a well-studied subway station, at which every line is defined, every platform has been listed, and even accessibility-related elements (i.e. lifts, escalators) have been described, can change without notice, thus affecting both the topology of the transport network and the accessibility of the node. In general, all the elements in the system can be affected by several *incidences*, which could mean a blocked bus line, a closed subway station, or simply a broken escalator.

The solution as regards both filling the gaps in the network description and reacting to many potential incidences is the use of *smart devices* in the connected city. The idea is to involve the citizens themselves in the process of capturing and providing the required information, by using their own smartphones in a *crowdsourcing* process. Partial data, as provided by open data sources, will, therefore, not only be checked but also *completed* by the users themselves. This signifies that accessibility elements (i.e. lifts, escalators) will not be considered until they have been confirmed by a significant number of citizens. Furthermore, incidences can easily be reported using the same mobile app.

However, crowdsourcing requires a motivation: in this model, the users themselves provide the system with the information required, by making a cumulative effort and dividing the job; but they should receive something in return. With respect to accessibility in urban mobility, the related groups of interest (and disabled people, in particular) may have an obvious incentive, and some people among the general public might consider their participation as a contribution to the greater good. But previous experience shows that it is difficult to build a community on top of this foundation; and when the group of users does not reach a critical mass, crowdsourcing results in failure.

In this paper, we suggest exploring another option: that of defining the application as a *serious game* to be played by citizens for their own amusement. The idea is to design the mobile app as a videogame, in which the users will provide the required data as the means to advance in the game dynamics. Each user will have the relevant pieces of information as their goal within the game, and their interaction with these elements will, therefore, serve either to discover new data or to confirm previously captured information. This is the same smart data referred to above, and each record will have a definite meaning, even within the game, thus becoming *smart data at play*.

2. Related work

Crowdsourcing takes advantage of the Internet, thus allowing large numbers of people to contribute to some kind of common objective, and many organisations and initiatives have employed it as part of their strategies (Morschheuser, Hamari, & Maedche, 2019). One of the definitions of crowdsourcing states that it is "the act of taking a job traditionally performed by employees and outsourcing it to an undefined, generally large group of people in the form of an open call" (Howe, 2008, p. backcover). Crowdsourcing is a "multifaceted phenomenon and appears in many different forms" (Morschheuser et al., 2018, p. 8), or is "just a rubric for a wide range of activities" (Howe, 2008, p. 18). In fact, the growth and expansion of the Internet and mobile phones has also expanded the possibilities of crowdsourcing. The flexibility of the crowdsourcing model makes it possible to apply to a broad range of activities (Prandi et al., 2018), and some of its initiatives have achieved major results when large groups of crowdsourcees have taken part in the process (Wikipedia, Open Street Maps, Waze…)(Morschheuser et al., 2019).

The users' participation is a relevant factor in this kind of applications and others, such as health or gambling areas, and can determine the success or failure of a proposal. Moreover, the users' continuous intention is not always guaranteed. There are consequently some interesting proposals (Lehto & Oinas-Kukkonen, 2015; Mohadis, Mohamad Ali, & Smeaton, 2016) based on the Persuasive System Design (PSD) model (Oinas-Kukkonen & Harjumaa, 2009), which offers systematic means of understanding and analysing the persuasion context and enlists persuasive design principles. The research core of persuasive technologies are behaviour change support systems (Lehto & Oinas-Kukkonen, 2015), which provide their users with many benefits. However, when used for this purpose, they need to guarantee the success of the systems in order to retain their users.

Expanding on this, a playful approach would also appear to be a good incentive by which to stimulate participation. The crowdsourcing approach fits very well with the gamification philosophy (Hamari, Koivisto, & Sarsa, 2014). Gamification is "the use of game design elements in non-game contexts" (Deterding, Dixon, Khaled, & Nacke, 2011, p. 10) and can motivate users and, therefore, help to increase the number of the crowdsourcees. Gamification techniques have expanded from start-ups to traditional companies (Hamari et al., 2014). When applying gamification to some applications, it is necessary to take into account certain principles. For example, developers should enhance activities through gamification while maintaining the focus on the activities themselves; developers should, therefore, also consider the playful aspects that will be emulated by means of gamification (Knaving & Staffan, 2013).

Several works deal with the use of gamification in urban mobility and smart cities, an example of which is one that implements a game that motivates users to stand up on very crowded public transport (Kuramoto, Ishibashi, Yamamoto, & Tsujino, 2013). Other examples are, on the one hand, a service-based gamification framework that can be used to develop games on top of existing systems in a Smart City (Kazhamiakin et al., 2015) and, on the other, the personalization of urban paths across heritage sites in the sharing of multimedia resources (Prandi et al., 2018). Others are related to seeking an improvement in the use of bicycles, thus improving public transportation (Vieira et al., 2012; Weber, Azad, Riggs, & Cherry, 2018). Yet another focuses on obtaining a pedestrian cartography in cities through mobile gamification, given that digital maps usually focus principally on routes followed when using vehicles (Kapenekakis & Chorianopoulos, 2017). However, to the best of our knowledge, there are currently no software applications dealing with public transport and its accessibility features, while also using crowdsourcing and gamification techniques to update their data.

3. Motivation and context

This work is developed in the context of a research project denominated as Access@City (Vela et al. 2017a). It is a coordinated project that defines a technological framework in which to process, manage and use open data concerning public transport with the goal of promoting accessible mobility. In this **respect**, we have **produced** some previous works. The Regional Consortium for Public Transport in Madrid (CRTM, 2019), the Madrid public bus company (EMT Madrid, 2019) and the Spanish National Society for the Blind (ONCE, 2019) have all expressed an interest in the results of our Access@City project.

One of its subprojects is Multiply@City (Vela et al. 2017b), which focuses on processing and harmonizing public transport accessibility data in a semantic manner by means of an ontology, taking into account that data are provided by different sources and have different formats. Figure 1 provides a general depiction of this latter project.

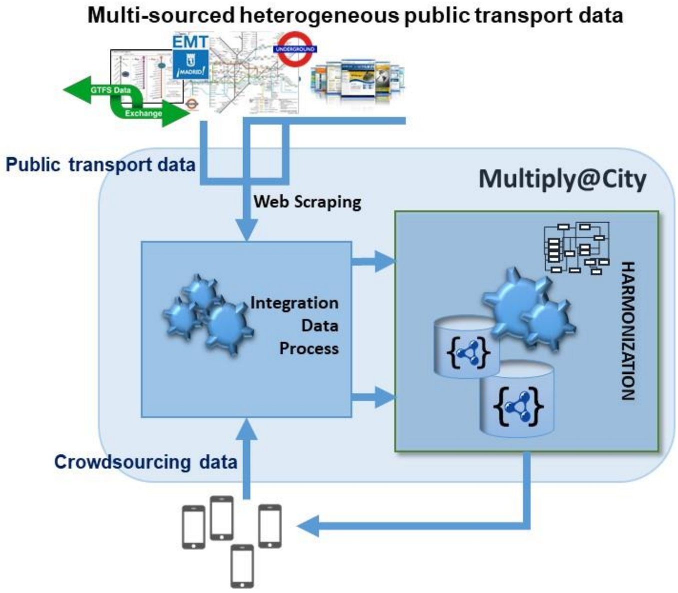


Figure 1. Multiply@City project architecture.

The public transport infrastructure and its accessibility elements (lifts, escalators, etc.) are obtained from open data by means of web scraping. This infrastructure does not usually change, and neither does its open data. However, the working state of the accessibility elements (ACEs) can frequently change (i.e., whether or not a lift or an escalator works) and consequently, ACEs data have to be updated. We, therefore, collect these data via crowdsourcing techniques.

Crowdsourcing initiatives involve groups of people in order to solve distributed problems (Morschheuser et al., 2019) and are a correct way in which to classify and mark content (Geiger & Schader, 2014). These studies are interesting for our purpose because it is necessary to annotate the working state of ACEs. But we also need to motivate people to participate as crowdsources and we, therefore, define our proposal according to a gamification strategy.

The principal objective of gamification is to design features with which to produce feelings similar to those experienced when playing games. Several research works have shown that gamification could be an effective means to increase motivations and influence behaviour (Hamari et al., 2014). Our intention is, therefore, to use a game in order to involve a significant number of people in the process of capturing and confirming existing information concerning accessibility in the transport network and, by extension, in the city itself. This crowdsourcing process should provide sufficient data to allow informed decisions to be made regarding mobility and life in the city. These data assist when making smart decisions about these issues, signifying that these smart data are helping to build our smart city.

In this context, we have developed an Android app for smart devices (denominated as Access ’n’ Go!) with which to enrich the accessibility information concerning the public transport network through the use of crowdsourcing and gamification, thus improving accessibility in increasingly smarter cities, even within the game, and consequently making the data *smart data at play*.

4. Our proposal: Access ’n’ Go!

As mentioned previously, the eventual objective of the Access@City project (Vela et al. 2017a) is to support new social accessibility services, such as calculating public transport routes, which will be made accessible to all, by taking into account the users’ needs (i.e. someone moving with a twin baby carriage or who has a phobia **about** escalators). These routes must be based on stable data regarding the infrastructure of the transport network (i.e. stations, lines and stops) and on continuously updated data related to accessibility features (i.e. whether or not a lift or an escalator works).

The need to consider these last features has led us to develop the proposal presented herein, which also includes information concerning the current working state of the public transport network. This has been done using a gamification and crowdsourcing approach. The relevant aspect of this work is that of identifying the working state of each existing ACE in the public transport network, along with capturing new ACEs that are not registered within the current information that we have previously collected from different open sources.

Access ’n’ Go!, a game for Android smartphones, makes it possible to update all the accessibility features of public transport (its working state) using crowdsourcing and gamification techniques.

In this section, we first introduce the game design, after which we describe the fine details and decisions made. Finally, we present the technological infrastructure and the architecture developed.

4.1. Game design: strategy and workflow

Having made the decision to design a crowdsourcing and gamification solution, we then had to select the most appropriate strategies for this proposal.

Motivated and active crowd operators of crowdsourcing approaches must also continually attract new participants in order to compensate for crowdsourcee churn (Morschheuser et al., 2019). It is, therefore, important for active users to invite others to participate in the system. Crowdsourcees benefit from an increasing number of supporters and these reciprocal benefits may motivate people to invite others to participate in crowdsourcing. We consequently decided that the game would permit the creation of teams and that more players would be allowed to join it.

Some works on gamification design address the question of whether it is better to use competition-based or cooperation-based designs. One of the individualistic strategies of the competitive game design is “when individual actions obstruct the actions of others (negative interdependence; e.g. competitions in which player compete with each other)”, while the cooperative strategy is “when individual actions promote the goals of others (positive interdependence; e.g. shared challenges for a team of players)” (Liu, Li, & Santhanam, 2013, p. 22). Moreover, being part of a team that works together towards a shared goal has been identified as motivational gratification for players of online games with cooperative features (Rigby & Ryan, 2011). Cooperative play allows players to overcome challenges that it would be impossible to meet when playing alone. We are, therefore, of the opinion that the inter-team competition design is probably best for our purposes, because “inter-group competitions may be particularly effective for supporting intrinsic motivation and behaviour in crowdsourcing, compared to pure cooperative or competitive gamification designs” (Morschheuser et al., 2018, p. 11). This kind of design is: (a) collaborative between the team members, providing specific aims in groups and (b) competitive between groups, creating clear barriers between groups. We have consequently decided to follow an inter-team competition strategy in this work.

The main objective of the game is to update information related to the ACEs in the public transport network. The complete dynamics of Access ’n’ Go! is the following: the app shows the ACEs on a map and checks the player’s proximity to an ACE; if the player is close to the ACE, s/he can capture it and must then indicate its working state. The app then verifies whether a level has been achieved. A level is achieved when a station and/or line in the public transport network is completed. The app subsequently awards the corresponding points and/or badges to the player and to his/her team (a badge is awarded to a team if the badge is new for the team; a team will never have duplicated badges; however, a player can accumulate duplicated badges and exchange them later).

Figure 2 shows the game workflow employed to capture an ACE by means of a UML (UML, 2019) activity diagram.

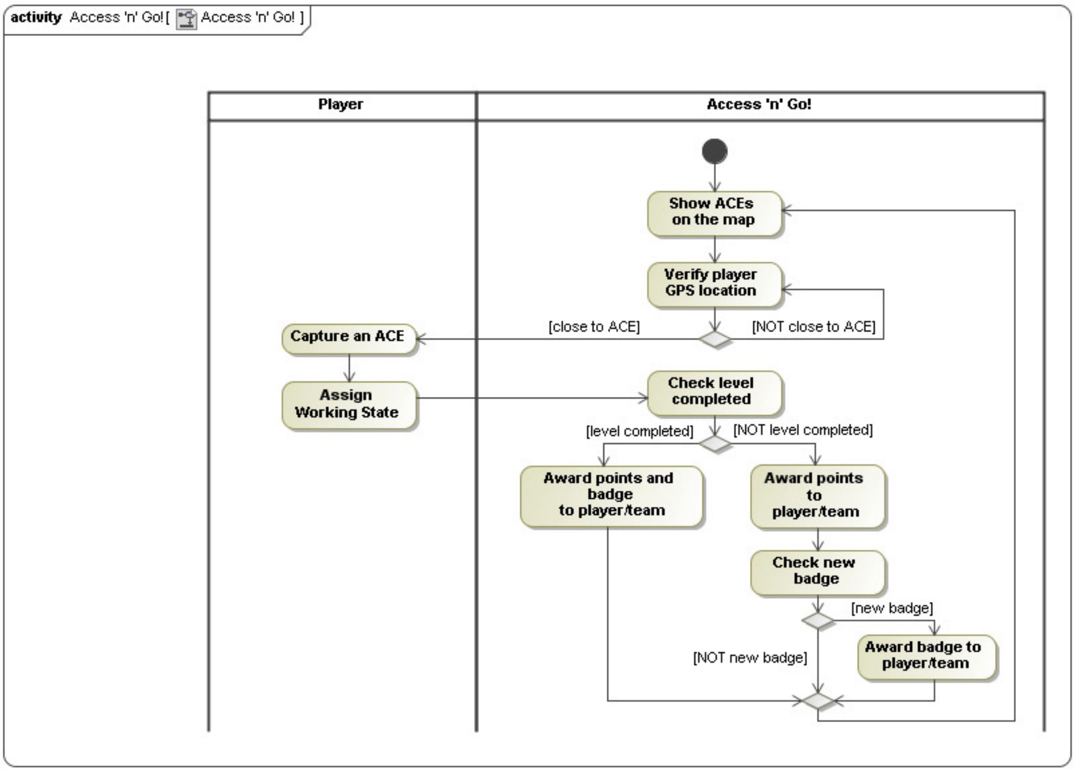


Figure 2. Capture an ACE! workflow.

4.2. Fine Details and Decision Making

In this subsection, we describe the game elements, the screen design and the Access 'n' Go! functionality.

First, we introduce the details of the game elements according to an inter-team competitive strategy:

- There is a set of 12 badges. Each badge has a different colour. The badge icon is represented as the Access 'n' Go! logo (a train).
- Each player can collect points, levels and badges. These elements make up the player and team score. A player collects points when s/he captures an ACE. A player collects a badge when s/he attains a specific number of points. A player reaches a level when s/he completes a station, that is, when s/he attains the whole set of ACEs associated with a station. A player also achieves a level when s/he

completes a line, that is, when s/he attains the whole set of stations associated with a line. In both cases, the player obtains special points.

- A player can attain duplicated badges, a team cannot. The player can exchange a duplicated badge for a new one. New badges will automatically be awarded to the player and the team score.
- There is a ranking only between teams. This ranking shows the team score, that is, the number of points, levels and badges associated with each team. However, there is no ranking between players.
- A team comprises more than 2 people. A team receives points when an individual player joins it. A team is complete when it has 5 players, in which case it also receives a badge.

In Table 1, we describe the game score.

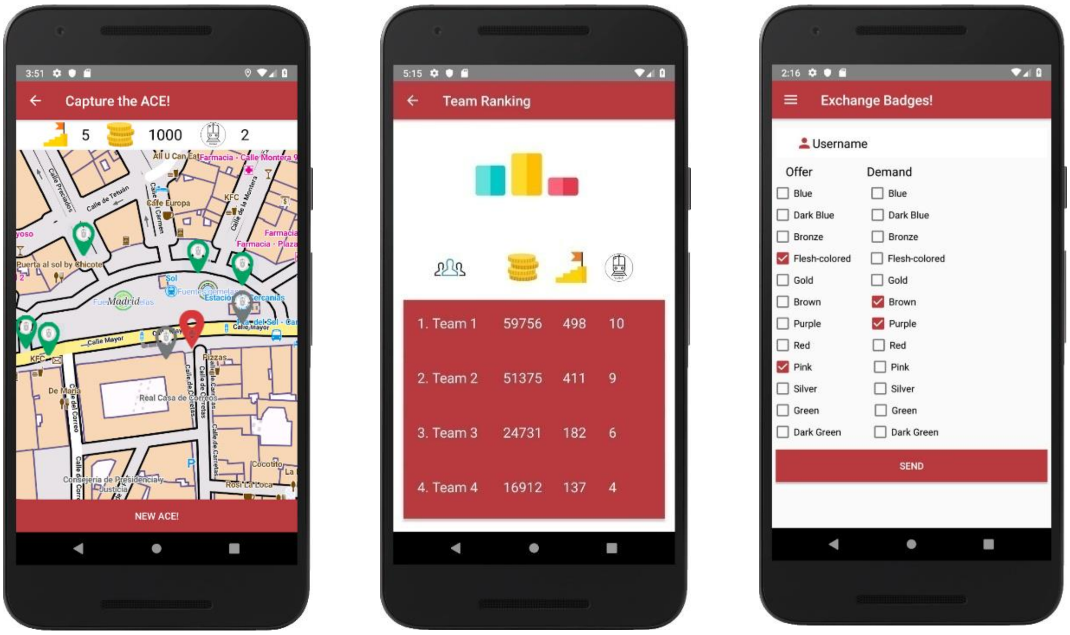
Event	**Points**	**Badges**
Capture an ACE	points += 25	N/A
Establish a NEW ACE	points += 500	Award a badge
Join a player	points += 50	N/A
Complete the team (5 players)	points += 100	Award a badge
Exchange a badge	points += 75	N/A
New badge	points += 50	N/A
Reach 6 different badges	points += 100	N/A
Reach all badges	points += 500	N/A
Complete a station	points += 100	N/A
Complete a line	points += 250	Award a badge
Reach 10.000 points	N/A	Award a badge

Table 1: Scores in the game

With regard to the screen design, three different ones are presented in this paper. The first shows the ACEs on a map. ACEs are the entrances to a station (lifts, escalators, stairs or ramps) and have geographical coordinates (latitude and longitude), thus enabling their representation on a map. A player can capture an ACE when s/he is close to it. We consequently represent ACEs and the player's current position on the map with different colours: the player’s current position is a red pin, the ACEs captured are grey and the ACEs that have not yet been captured are green. The scores (points, levels and badges) are shown at the top of screen. Figure 3a depicts the screen employed to capture ACEs.

The second screen presents the game ranking. As our proposal follows an inter-team competition strategy, we have created a ranking only between teams. This represents a list of teams and their scores (points, levels and badges achieved). Figure 3b shows the game ranking screen.

In order to revitalize the game, a player can exchange his/her duplicated badges with other players. The screen presents two lists of badges, as is shown in Figure 3c: the list on the left presents the badges offered by the player, while that on the right presents the badges required.



(a) Capture anACE!　(b) Team ranking　(c) Exchange badges

Figure 3. Access ’n’ Go! screens

Finally, we describe the Access ’n’ Go! functionality. The objective of the game is to conquer a means of transport by capturing all the ACEs on it. The functionality is supported by a dataset containing public transport information. In previous works

(Cáceres et al. 2017), (Cáceres et al. 2019), we designed a public transport network dataset (*infrastructure dataset*) of the metro (MetroMadrid, 2019) in Madrid, Spain. This dataset resides in our server (Coruscant server) and contains information about stations, which includes stops and accessibility elements, and lines and their corresponding stops. Each element in the dataset has geographic coordinates (latitude and longitude), thus allowing them to be represented on a map. As mentioned previously, ACEs are lifts, escalators, ramps and stairs. In order to identify all the ACEs in any public transport network, we have carefully studied the Identification of Fixed Objects in Public Transport (IFOPT) reference datamodel (CEN/TC278, 2012), a standard that defines a model for the main *fixed objects* related to the access to Public Transport (e.g., stop points, stations, entrances, etc.). Moreover, IFOPT includes specific structures with which to describe accessibility data concerning the equipment at stations, among others. The accessibility elements of a public transport network make it possible for any user with a special need to move through that network (i.e. someone who has a phobia about escalators, or is able only to use stairs, ramps or lifts).

We have established the correspondence between ACEs in public transport and users' needs, and we summarize them in Table 2. We have, therefore, identified the kinds of ACEs that must be taken into account in this paper.

ACEs of public transport (based on IFOPT)	Users' accessibility needs (based on IFOPT)			
	Auditory and visual	Mobility	Phobia about lifts	Phobia about escalators
Lift	✓	✓	✗	✓
Escalator	✓	✗	✓	✗
Ramp	✓	✓	✓	✓
Stairs	✓	✗	✓	✓

Table 2: Relationship between ACEs and Users' Needs

In this game, we work solely with the ACEs. We periodically update this *infrastructure dataset,* but it is possible that some new accessibility elements (lifts, escalators, etc.) were incorporated into the network after the dataset was updated. It is for this reason that Access ’n’ Go! makes it possible to add new ACEs and to modify the working state of the existing ones.

When the app starts, it queries the *infrastructure dataset* in the Coruscant server. Access ’n’ Go!, therefore, extracts the existing ACEs from this dataset and represents them on a map. However, the information about new ACEs and the working state of each of the ACEs captured will be incorporated into a different dataset (the *event dataset*), which will be sent to the server to be integrated.

The dynamics and complete behaviour of the game have been structured into the following use cases:

- *Capture an ACE!* This use case represents the main game functionality (the associated workflow has been previously described by means of the UML activity diagram shown in Figure 2 in section 4.1). The player has to indicate the working state of the ACE captured. Access ’n’ Go! should then determine whether a station or line has been completed and add points to the team and player’s score, while randomly awarding badges to the player. It is for this reason that a player may have duplicated badges. A badge will be added to the team if the ACE is new for the team. The working state of the captured ACE represents an event in the public transport network and Access ’n’ Go! should, therefore, send this event to the Coruscant actor.
- *Establish a new ACE!* This use case permits a player to add a new ACE. This situation occurs when the player finds an ACE on the street that is not shown on the map. In this case, the app asks the player to take a picture of the ACE (with the aim of establishing its geographic coordinates) and to establish its working

state. This occurrence also represents an event in the public transport network and has the same behaviour as that of the previous use case.

- *Exchange badges*. This use case permits a player to exchange duplicated badges, thus allowing the player to attain new badges for the team.
- *View team ranking*. This use case makes it possible to see the ranking between teams, showing the points, levels and badges attained by each team.
- *Create a team*. This use case permits a player to create a team if s/he does not yet belong to one.
- *Join a player*. This use case allows a player to join a team. Access 'n' Go! adds points to the score, and when the team is completed (5 players), it adds extra points.
- *Chat*. This use case permits a player to enter the game chat. Access 'n' Go! incorporates a chat in which players can chat with each other.
- *Register*. This use case permits a user to register in Access 'n' Go! The app requests an email address and a password.
- *Login*. This use case permits a player to log into the game.
- *Recover password*. This use case allows players to recover their passwords.

In order to support these use cases, we had to develop a specific backend for Access 'n' Go! On the one hand, it was necessary to manage the game elements (players, points, levels and badges), and we consequently selected Firebase to manage this information, signifying that Access 'n' Go! has to interact with the Firebase actor. On the other hand, it is necessary to send the events concerning the working state of the ACEs, generated by the players when capturing them, and we have, therefore, developed a specific system in a server (named Coruscant). Access 'n' Go! must, therefore, interact with the Coruscant actor.

Figure 4 represents the most representative use cases of Access ’n’ Go! by means of a UML use case diagram.

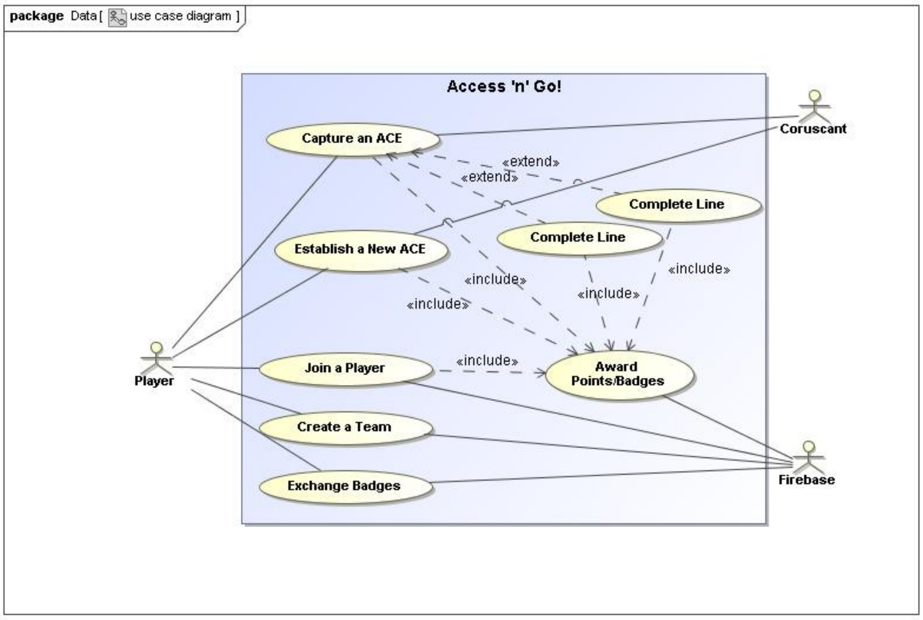


Figure 4. UML Use case diagram of Access ’n’ Go!

A more detailed description of the backend of this game is provided in the following subsection.

4.3. Technological Infrastructure and Architecture

As mentioned above, our framework implements a client-server architecture with some additional features.

This proposal applies a client-server architectural style, with features akin to the microservices approach. On the client side, our software is able to update the accessibility information and send it to the server. On the server side, we have developed and deployed a datastore, which holds the relevant information about the transport network and its accessibility features, listens to and processes different notifications from our client software (and other sw clients and returns to them any data which is requested by the same client).

The client is an Android app denominated as Access ’n’ Go! that offers crowdsourcing software with which to capture the accessibility elements of public transport and to update their working state (for example, whether or not a lift is working).

At the backend, we use two different infrastructures. The first of these supports the game management by means of Firebase technology in the cloud. Firebase provides authentication in a simple and secure manner, hosting, cloud storage and a real-time database. We, therefore, use this technology to manage the players’ registration and authentication, along with the storage of the game elements, such as the players’ scores, points, badges, etc. The second is implemented in our own on-premise server (denominated as Coruscant) and supports the management of the different public transport accessibility elements and their working state. In this server, we have deployed an architecture based on microservices in order to serve the public transport infrastructure (dataset for the transport network) to the Access ’n’ Go! App and to send new accessibility elements or the updated state of the existing accessibility elements (event dataset) from the app to the server. In order to store these data in the server, we have developed a Jena semantic repository (SR) (Apache Jena, n.d.) with two different datasets. Moreover, so as to attend to the requests from the client side, we have implemented an application server (AppServer), implemented with Spring Boot (SpringBoot, 2019). In order to communicate the updated data (events) collected by the players, it is also necessary to send these incidents to the server, which should simultaneously listen to the (potentially many) notifications of events about the accessibility features that are –or are not- available for the public transport network at that moment. We have, therefore, implemented an Apache Kakfa server (ApacheKafka, n.d.) as a queuing manager (QM). The QM gathers the different events notified from the crowdsourcees, i.e. the players (through their smart devices). This information, once processed, must be stored in the semantic repository, signifying that the AppServer also manages and controls the communication between the QM and the SR.

Figure 5 depicts the main elements and data exchanges in the proposed architecture.

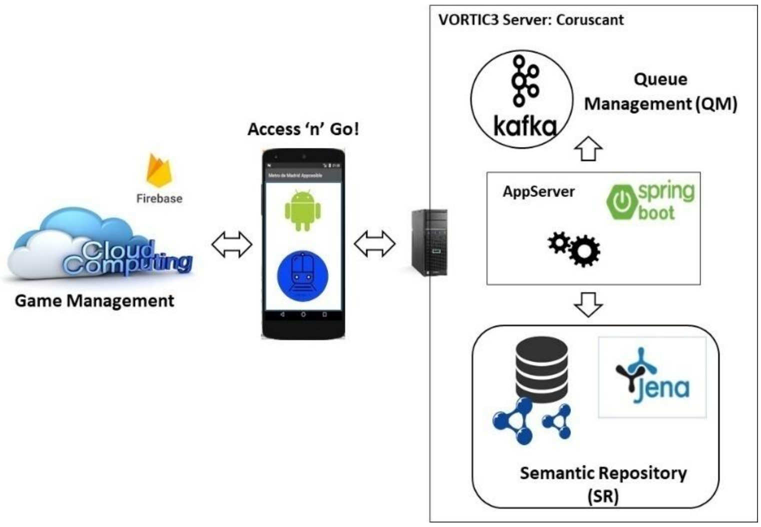


Figure 5. Proposed architecture (smart client-semantic server).

In summary, we have implemented the following elements in the server (Coruscant, an HP multicore high-performance server, with a direct high-speed Internet connection): a Spring Boot as the application server (AppServer), an Apache Kakfa server as a queuing manager (QM) and a Jena semantic repository (SR). The Jena repository maintains two separate data collections, one of which provides the (mostly static) data concerning stations, lines and stops, denominated as the *infrastructure collection* (i), and the other of which provides the (dynamic) data related to the state of the network as regards its accessibility features, denominated as the *events collection* (ii).

5. Empirical Validation

In order to validate this proposal, we had two different, while related, validation targets. Our final goal was to check the proposal itself, that is, the efficiency of the game as a method to capture information about accessibility elements, and to involve people in that task; the intermediate target was simply to test the applicability of the mobile app, which is instrumental to the success of the global approach.

The validation of the proposal was, therefore, designed as two separate stages, each one of which was conceived for these two targets. Specifically:

- In the first stage, the purpose was merely to capture a specific Metro line. Players merely had to traverse the stations on the line, capturing every ACE on them. Each player "won" at this stage by simply capturing the whole line. The purpose of this stage was to define the game dynamics and to test the mobile app. Indeed, the app interface was still evolving during this stage, and different versions of the interface were tested in this phase.
- In the second stage, once the app was considered to be sufficiently satisfactory (while not definitive), the whole game, with its complete set of rules, was completely unfolded, and the app was deployed to be tested in a real competition.

In both stages, the validation was performed by a group of volunteers, selected from among the students on the second year of our Bachelor's degree in Mathematics. Each student had the opportunity to join this group; but only willing volunteers were selected. The activity was never considered mandatory; the idea was that the only incentives for participation were to encourage solidarity and the social relevance of the study. While participation in the initial stage had some minor benefits, we explicitly avoided providing further stimuli in a later stage. The idea was that the game should be sufficiently addictive, thus encouraging the students to choose to continue playing it once they became familiar with it, even when they thought that the experiment had ended.

Our test group was initially limited to 20 people; the reason for limiting this number was to maintain the first tests within a manageable size, and also to use scarcity as a minor incentive (i.e. we noticed that if only some students were included in the experiment, it became more desirable to be chosen for it). These students were used during the first stage to refine the mobile app (as already noted), and became familiar with the interface, the purpose of the game and group dynamics. This initial stage lasted approximately one month; students were assigned a Metro line close to their home address and were tasked with capturing every identified ACE in this line. By the second week, they were allowed to begin the formation of teams – mostly chosen by personal affinity, by geographical closeness, or both. By then end of the month, most of the students had completed their assignment, but only 17 decided to continue in the experiment. As a significant note, only the students who had become part of a team continued in the game.

Therefore, in the second stage, the remaining players were already grouped in stable teams. The size of a team was designed to be within the rank of 3-5 people (again, to have manageable teams). In the final stage, there were four teams, namely Team 1 (a team of 5 people), Team 2 (4 members), Team 3 (5 members) and the smaller, but still committed Team 4 (composed of just 3 people).

Metro Madrid has 12 lines (there are, in fact, 13 lines, but the remaining one has a particular design and was not considered). With regard to distance, the longest ones are probably Line 7 (Orange) and 10 (Blue), which have 30 and 31 stations, respectively; but Line 1 (Cyan) has the most stations, with a total of 33. Not surprisingly, most of the teams chose the most centric lines as their playground. The most popular choices were Line 2 (Red, 20 stations), Line 3 (Yellow, 18 stations), Line 6 (Circular, 28 stations) and Line 12 (South, 28 stations). The first two are basically confined to the city centre and provide access to some of the most popular places in the city. The third surrounds the central area in the city and provides easy connections between different locations, and the last was geographically convenient for most of the students.

During the first stage, the students had to capture the ACEs at the stations on Metro Line 1 (which is also centric and convenient). All 33 stations on Line 1 were, therefore, captured during this stage. However, not every volunteer was able to complete this challenge; in fact, those who did not finish this stage were the three people who left the game. The remaining players had, simultaneously, already formed groups, even though groups were not relevant at this stage. This led us to confirm our initial belief; that is, that belonging to a team is a powerful motivation. At the beginning of the second stage, everybody was now a member of a group, and we thus had a fully-fledged inter-team strategy. We intended to take advantage of this, and in order to test the actual impact of stimulating participation by presenting a competition, we decided to use two different approaches in the design of the second stage of our game.

- In the first approach, two Lines (the aforementioned 3 and also Line 4, Brown, 23 stations) were selected as the playground. The team that was able to capture all the ACEs first would be considered the winner. In this case, all the teams completed every station and ACEs on the Yellow Line, but only three of them were able to complete the stations on Line 4. Once a team (Team 1) had been proclaimed as the winner, the rest of the teams decided to stop. The experience was nonetheless a great success: we were able to achieve independent confirmation of every known ACE on Line 3 from every team, and about 80% of the elements on Line 4 had at least 3 confirmations. This phase of the experiment lasted almost two weeks (14 days).
- In the second approach, which defined our final stage, every Line in the Metro network was considered as part of the game board; but we now decided to limit the time. Essentially, the team that was able to achieve the highest score before

the time ended was considered the winner. This phase of the game lasted one month, and in this stage, every rule in the game had now been applied.

In this (last) part of the experiment, the players had now become accustomed to capturing ACEs as part of their routine, independently of the game itself. For instance, several players captured stations on lines that were never completed, but which were close to their home address. However, competition became the main driver for them to remain in the game. Team loyalty was also important – several members remained in the game to support their team, and conversely, Team 3 was the first to abandon the game, after it became clear that they were not attaining the same scores as their rivals. The remaining teams began to compete to complete Line 6 (Circular), which they chose by themselves: we did not need to intervene in this part of the process. The last stations on this Line were captured in a matter of hours, despite the fact that several of the teams' members were geographically distant from it, and this Line was completed by the three remaining teams, thus providing a significant amount of information and proving that the motivation was now the game itself.

Table 3 provides a summary of some of the figures in our experiment, showing some details regarding Phase 1, when the app was still evolving; and more information about Phase 2, which describes the actual validation process. The first row summarizes the number of different elements captured in each phase – for instance, only 4 Metro lines were fully identified in Phase 2, but 148 different stations were, nevertheless, confirmed, including many that were not a part of these four lines. Our 17 players combined simultaneously captured 1529 stations in this Phase, signifying that there were obviously many confirmations for each ACE and station. This was the desired effect, and the approach was, therefore, a clear success –even considering that at least 5 players left the game before the end, meaning that their figures distort the statistics, particularly the mean values.

	Phase 1	#stations	Phase 2	#stations	#lines	#ACEs	Points
# Players'	20	33	17	148	4	544	206.450
Gender							
Male	11	355	10	776	31	848	114.025
Female	9	272	7	753	24	610	92.425
Age	Mean	SD	Mean	SD	-	-	-
	19	0,45	19	0,22			
Avg time (days)	Phase	Station	Phase	Station	Line	-	-
1st half	23,45	20,32	14	11,50	12,7		
2nd half	-	-	30	14,64	20,8		

Table 3: Global results in the two phases of the experiment

Finally, please note that in the final version of our game, the outcome that defines a "victory" is assigned to the team that achieves all the possible badges. This avoids the negative effects of having a limited playground (as in Phase 1) or a limited duration of the game (which could discourage competition). With badges, the rules and their dynamics define the duration of the game. However, this approach was not included in our experiment (badges were already present during Phase 2, but they did not define the duration), and we have not yet, therefore, validated this particular feature.

We would also like to note that nobody managed to *establish a new ACE* during the validation phase; this is owing simply to the fact that the infrastructure dataset was sufficiently updated, and there were, therefore, no new ACEs to establish. This is not, of course, a problem: it was simply not necessary.

6. Conclusions and future work

One of the major challenges of smart city initiatives is to achieve an inclusive society for all citizens, including those with special needs, such as mobility issues. For this challenge to be met, more thorough information about the means of transport and their accessibility features is required, with the aim of arranging and providing accessible routes for everybody. Although a great effort has recently been made to publish accessibility information about transport networks, a careful examination reveals that this information is still scarce. Specifically, these recent efforts have done good work as regards describing the stable elements in the infrastructure, but information about the most recent updates and the working state of these elements is often difficult to find. However, these data are critical for everyday mobility, and even more so for people with special needs.

Our previous work, in the context of the Access@City Research Project (funded by the Spanish National R&D Program), has been focused on improving mobility and accessibility in the urban environment, and particularly in the public transport system, by capturing the information available about these issues. Citizens are provided with these data by means of smart adequately processed devices in order to facilitate urban mobility and to serve accessible routes in a dynamic manner, with the goal of achieving a smarter city.

However, the scarcity of information about the working state of accessibility elements (our ACEs) hinders this purpose. Even when dynamically created, an accessible route is useless when a crucial ACE (e.g. the only lift that could help a citizen to reach the surface in the final station on the route) is not working properly (e.g. it is broken). Moreover, when the infrastructure information is not quickly updated, there might be alternative routes that are, in fact, possible in the real world, but are never computed because the relevant information has not yet been captured.

We soon realized that the only way in which to obtain this information was by means of crowdsourcing: citizens themselves are the best source of information about ACEs and their working state. However, even in the context of social needs such as this, it is not easy to involve people who wish to assist in the process. It was for this reason that we considered using a playful approach: not only the process, but also the tool will be a game, and people will provide the required information by playing this game.

We have, therefore, developed an Android gaming app, denominated as *Access 'n' Go!*, which we specifically describe as a hybrid reality game (HRG) openly designed to acquire information about the accessibility of subway stations. The game consists of identifying (and geolocating) accessible spots (i.e. ACEs), and using them to feed a description of the station. In turn, every time that the player provides some information, her score in the game is improved. The correlation between many independent observations makes it possible to provide an accurate description of the accessibility of these stations in a relatively short amount of time. In this paper, we have provided a detailed explanation of both the design of the game itself and the implementation of the gaming app, including the design of its most relevant screens and features. The preliminary results are even better than expected: we have been successful in involving a significant amount of people (with no need for external incentives once the process had been bootstrapped), and we have been able to confirm the information contained in our pre-existing dataset (the *infrastructure dataset*), thus illustrating its accuracy (at least for a substantial subset).

We have defined the game on the basis of an inter-team competitive strategy, as most of the existing literature suggests that this approach is able to achieve the best results. Our own validation process appears to substantiate these claims. In the first stage, when we had individual players, they nonetheless tended to group into teams once they were given the opportunity. It is very significant that those who never became involved in a team were precisely those who decided to leave the experiment. On the contrary, those belonging to a group were highly motivated: players are glad to cooperate with their teammates in order to meet a challenge and are even more compelled to compete with other teams in a constant effort to surpass them. The final stage of our second phase clearly shows that competition serves as an excellent incentive. In summary, it seems clear that the inter-team strategy, as expected, increases the intrinsic motivation and improves the desired behaviour in a crowdsourcing process.

In order to support this process, we not only developed the design of the game and produced the mobile app, but we also had to provide the sustaining infrastructure. Indeed, the game itself would be useless without the underlying architecture; our purpose was really to feed this architecture with updated information.

The architecture defines a set of semantic datastores and combines the information from available datastreams. This results in a complex data processing system, which is made available to the users of the public transport by using smart devices - most frequently, their own smartphones. This processing system also has to be complemented with the elements designed to capture new information (a new crowdsourced datastream of ACE data and working states) and to support the game management (players and scores) itself. With respect to this, we used the Firebase technology to manage both the players' registration and authentication and the storage of game elements. The information captured by crowdsourcing (ACE data and working states) is supported by a Jena semantic repository (SR) (Apache Jena, n.d.) with two different datasets, an Application Server based on Spring Boot, and a microservices architecture that is able to serve the information from the infrastructure dataset to the the Access 'n' Go! App. Moreover, in order to achieve a better scalability, we have implemented an Apache Kakfa server (ApacheKafka, n.d.) as a queuing manager (QM). The QM gathers the different events notified by the players (through their smart devices), and this information, once processed, must be stored in the semantic repository, signifying that the AppServer also manages and controls the communication between the QM and the SR. Our experiments to date show that this infrastructure is able to function perfectly correctly when confronted with a significant workload.

We have already planned to make some extensions to Access ’n’ Go! as future work. One of the most relevant modifications is related to the capability to adapt the application and the dynamics of the game to the specific needs of our experiments and to focus on the hunt for specific information. We, therefore, intend to provide a new version, which can be configured according to different challenges in order to win the game. For instance, we could decide that a team will win when the whole set of 12 badges is acquired (i.e. the current behaviour), but we could also choose other options, such as conquering a concrete sub-network or even the whole network, or attaining a specific number of transport lines, limiting the time or the geographical area, etc. Our actual goal is to enrich the accessibility information dataset, and we should, therefore, be able to adapt the game strategy to our specific needs by defining specific challenges. Another relevant modification is that of improving our app in order to engage and retain the users, following behaviour change proposals (Lehto & Oinas-Kukkonen, 2015; Mohadis et al., 2016). As mentioned in Section 2, the Persuasive System Design (PSD) model (Oinas-Kukkonen & Harjumaa, 2009) is supported by different proposals, and offers systematic ways in which to understand and analyse the persuasion context. Finally, we also plan to perform an additional validation step, which will be carried out by people from different backgrounds, thus avoiding the population being restricted to our student cohort.

As a final conclusion, we are very satisfied with the results of this experiment. Our previous work made it clear that it is very difficult to complement information about the stable infrastructure with updated data and working states. Some previous initiatives with other crowdsourcing approaches were not able to provoke significant interest; this, however, changed when we decided to use a playful approach. We not only captured a much greater amount of information, but it was quickly obtained and integrated, very easily confirmed, and it was also of better quality. In this regard, the experiment has been a total success.

In summary, smart data are better when they are also at play.

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