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Public participation in GIS via mobile applications

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ABSTRACT

Driven by the recent trends in the GIS domain including Volunteered Geographic Information, geo-crowdsourcing and citizen science, and fostered by the constant technological advances, collection and dissemination of geospatial information by ordinary people has become commonplace. However, applications involving user-generated geospatial content show dramatically diversified patterns in terms of incentive, type and level of participation, purpose of the activity, data/metadata provided and data quality. This study contributes to this heterogeneous context by investigating public participation in GIS within the field of mobile-based applications. Results not only show examples of how to technically build GIS applications enabling user collection and interaction with geospatial data, but they also draw conclusions about the methods and needs of public participation. We describe three projects with different scales and purposes in the context of urban monitoring and planning, and tourism valorisation. In each case, an open source architecture is used, allowing users to exploit their mobile devices to collect georeferenced information. This data is then made publicly available on specific Web viewers. Analysis of user involvement in these projects provides insights related to participation patterns which suggests some generalized conclusions.

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1. Introduction

The evolution over the last decade of Web applications dealing with geospatial contents has been burgeoning. The dawn of GeoWeb 2.0 (Maguire, 2007), the geographic counterpart of the well-known phenomenon of Web 2.0 (O'Reilly, 2005), has turned nearly-static, limited functionality and poorly interactive GeoWeb applications to dynamic, highly-performing ones capable of providing a rich user experience.

This widening GeoWeb *2.0* shift is, to a large extent, the result of a sequence of notable technical and technological developments. Besides the increased computational power of computers and broadband Internet communication, technologies such as AJAX and the first mapping APIs (from e.g. Google and Yahoo!) enabled a new, successful player enter the GeoWeb scene: The Crowd. Other ingredients like the development of Web standards (e.g. by W3C and OGC) and the diffusion of GPS devices ushered in the new era of neogeography (Turner, 2006) in which mapping became a discipline within reach for anyone.

The revolution brought by this new trend has been traditionally associated with the term Volunteered Geographic Information (VGI), that Goodchild coined (2007a) and explained (2007b) by comparing humans to "intelligent, mobile sensors" able to acquire precious geospatial information of unparalleled depth in both a spatial dimension (i.e. it may relate to very specific places) and a temporal dimension (i.e. it may come with a very high frequency). Another successful term that is widely used in GIS literature is geo-crowdsourcing (see e.g. Goetz and Zipf, 2013) or simply crowdsourcing (see e.g. Hudson-Smith et al., 2009; Havercroft, 2009), which, from the concept originally coined by Howe (2006), outlines work – involving the collection of geospatial information – performed by an undefined network of people. However, even though VGI and crowdsourcing have a slightly different underlying meanings, they are usually treated as synonyms or even combined (e.g, "crowdsourcing geographic information"; see e.g. Sui et al., 2013).

A number of issues have emerged which highlighted the difference between the new crowdsourced geographic information (heterogeneous, highly undocumented, and incomplete in space and time) and the traditional authoritative one (standardized, documented, complete and regularly updated). Literature has widely

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addressed all these topics, which include the assessment of VGI quality (see e.g. Foody et al., 2013), the absence of standards for VGI contributions (see e.g. Wiemann and Bernard, 2014), legal issues involved with VGI (see e.g. Scassa, 2013), and user participation patterns (see e.g. Antoniou and Schlieder, 2014). The latter include the key issue of so-called digital divide (Norris, 2001), which was pointed out by Goodchild (2007a) – in the same paper where he coined the term VGI – to highlight that this new trend would have been only "the preserve of those fortunate to have access to the Internet". A second kind of digital divide has also emerged in literature (see e.g. Hargittai, 2001) which, among people having access to the Internet, further looks at those being actually able to exploit its full potential. Besides basic technological reasons, van Dijk (2006) outlined a set of immaterial, material, social and educational barriers which together shape the issue of digital divide. However, due to the vastness and complexity of all these VGI-related aspects, many open questions still remain and will constitute fruitful ground for future research.

This paper is focused on the subset of VGI practices known as geographical citizen science, i.e. the range of scientific activities in which amateurs voluntarily participate in data collection, analysis and dissemination of scientific projects (Cohn, 2008; Silvertown, 2009). Referring to Haklay's (2013) classification of geographical citizen science practices, attention is placed on the so-called cyberscience and especially on its sub-category of participatory sensing (Burke et al., 2006) which is centered on data collection using the modern mobile phones as scientific instruments.

Mobile phones have played a significant role in shaping the aforementioned technological innovation which is at the heart of GeoWeb 2.0. Being directly connected to the Internet and equipped with not only a GPS receiver but also a huge number of other sensors, they allow users to easily acquire and share geospatial contents and thus represent the foundation of many VGI and participatory sensing activities.

Another term that is worth mentioning is Public Participation GIS (PPGIS), coined in the '90s to point out the new role of GIS as tools to broaden public involvement in decision-making processes by promoting the goals of non-governmental organizations and grassroots groups (Sieber, 2006). In other words, GIS became a "social process" (Sheppard, 1995) in the belief that its powerful technology could form an essential part of an informally-enabled democracy (Obermeyer, 1998). In this sense, PPGIS can be regarded as a GIS-based expression within the broader discipline of public deliberation, i.e. the process through which deliberative democracy occurs (Delli Carpini et al., 2004). PPGIS shall be distinguished from PGIS (Participatory GIS) which, instead of the outcome of a GIS-based decision-making process, is focused on simply making GIS available to less-favored societal groups (Rambaldi et al., 2006).

Web 2.0 tools have been recognized as crucial for facilitating public participation (Tait, 2012) and GeoWeb 2.0 technologies nowadays represent the foundation of most PPGIS practices (see e.g. Hall et al., 2010; Brown et al., 2012). Therefore the line of distinction between PPGIS and VGI theorized in literature (Tulloch, 2008; Boulton, 2010) appears sometimes blurred (Lin, 2013). To summarize, although both VGI and PPGIS are centered on user participation and currently make use of Web technologies, VGI is individualized and dynamic (Zook and Graham, 2007), voluntarily and citizen-initiated; instead, PPGIS respond to the needs of particular organizations or communities (Elwood and Ghose, 2001), imply agency-driven data-collection campaigns performed on purpose (Brown et al., 2012) and specifically aim at achieving social change.

Thus, this paper fits in this heterogeneous context with the goal of analyzing public participation in GIS in the field of sensor-enabled mobile devices. The main objective driving the study is to supply a GeoWeb 2.0 system for potential use by a number of entities and organizations (ranging from public authorities to citizen associations) able to manage general-purpose data-collection campaigns addressing the public. This is achieved through the development of an open source software architecture that is then applied to a number of case studies. Their outcomes make it possible to derive some general observations on public participation patterns in contributing VGI.

The remainder of the paper is structured as follows. In the next section some further background on VGI, citizen science and mobile devices is provided. This is followed by a description of the developed mobile-based applications, which are first addressed from the technical perspective and then by looking at their outcome in terms of user participation. The paper concludes by discussing the findings and offering directions for future research.

2. Background

In this Section an excursus is provided on the latest evolutions of mobile phones technology and their exploitation within GIS-based citizen science applications.

As mentioned above, Goodchild (2007b) explained the concept of VGI highlighting human capability to use the five senses for acquiring geospatial information (like place names, topographic features and transport networks) that can neither be extracted from aerial or satellite imagery nor collected with a GPS receiver. Human capacity of capturing, integrating and interpreting geospatial knowledge in the almost-everyday life has been tremendously increased by the growing number of mobile phones (or smart phones) which, in addition to the possibility of being connected to external sensors, can utilize up to nine integrated sensors including different transceivers (mobile network, WiFi, Bluetooth), FM and GPS receivers, accelerometer, camera, digital compass and microphone (Haklay, 2013).

Exploiting the potential of these sensors, over the last decade mobile phone applications (or simply apps) participatory sensing has emerged (Burke et al., 2006) involving people in an increasing variety of disciplines. For instance, specific apps like GeoPaparazzi (http://geopaparazzi.github.io/geopaparazzi), Kort (http://play.kort.ch) and OSMTracker (http://wiki.openstreetmap.org/wiki/OSMtracker_%28Android%29) have been developed to enable VGI collection for OpenStreetMap (OSM), the most globally popular geo-crowdsourcing project (Bennett, 2010; http://www.openstreetmap.org). In a similar way, Mapillary (https://www.mapillary.com) was designed for the crowdsourced collection of street-level photos.

But the rise of participatory sensing targets a far broader range of scientific areas and disciplines. Some examples (which do not claim of being exhaustive) of VGI-oriented mobile apps and the related fields of application are the following: EpiCollect (Aanensen et al., 2009; http://www.epicollect.net) in the field of ecology and epidemiology; Decoro Urbano (http://www.decorourbano.org) for urban monitoring; NoiseTube (Maisonneuve et al., 2010; http://noisetube.net) and Noise Battle (Garcia-Martí et al., 2013) for noise monitoring; Skywatch Windoo (http://windoo.ch), which requires the phone to be connected to an external sensor for weather monitoring; Mappiness (http://www.mappiness.org.uk) for behavioral analysis (MacKerron and Mourato, 2010); ODK Collect (https://opendatakit.org/use/collect) and GeoODK Collect (http://geoodk.com), providing a framework for generalized data collection which is usable e.g. for agricultural monitoring (Quinn et al., 2011) and other information services in developing countries such as monitoring of deforestation and school attendance, documentation of war crimes and health programs (Anokwa et al., 2009).

Regardless of the field of application and the technical features of the apps (e.g. the platform they are built on, the mobile sensors they use, and the way user interaction happens), two aspects strictly related to their VGI nature are worth further discussion.

The first concerns how contributed geospatial data is made accessible. Apps are designed so that VGI – after being contributed – can, or cannot, remain stored on the user device. In both cases VGI is also sent to the central project server in order to be shared with the project users, whose nature and number can highly vary according to the way VGI is made available. Additionally, sometimes VGI can be only accessed by the users of the specific app that was used to contribute it (e.g. in the standard use of ODK Collect, see Section 3.1) or by the sole people managing the VGI project (e.g. in the case of Mappiness, which, as a research project, does not have the goal of creating publicly shared data). Alternatively, other apps are specifically conceived to allow an interoperable reuse of VGI data from the general public. This can happen either through the use of standard formats and protocols (e.g. in the case of NoiseTube, which makes data available in the KML format) or, alternatively, through the use of specific APIs and related open data licenses (see e.g. Decoro Urbano and OSM).

The second element of interest in this discussion is the strategy adopted to ensure and foster user engagement within participatory sensing projects. Clearly, this depends first on the specific user group a project seeks to involve. Besides the geographic extent, project managers need to figure out as precisely as possible the profile(s) they want to target, e.g. in terms of age, gender, cultural background and occupation. An initial distinction is therefore between those applications targeting the general public, which in turn can be geographically bounded (e.g. Mappiness, primarily focused on UK) or unbounded (e.g. OSM), and those involving specific user groups (doctors, farmers, epidemiologists, etc.). Once the target public has been defined, the best channels to advertise and promote citizen participation must be identified as well.

Depending on the amount and type of data the project seeks to collect, two further strategies can be applied to increase participation. The first consists of special events, limited in both space and time, where usually a small number of people are involved to cover some specific needs of data (e.g. to map the street addresses of a localized area). These events are also known as "mapping parties" and are widely exploited in the OSM project (see e.g. Perkins and Dodge, 2008). Instead, participatory sensing initiatives aiming to be maintained over the long run and/or to collect large amounts of data can adopt a gamification approach (Zichermann and Cunningham, 2011). This strategy is useful to engage users in performing repetitive tasks over time and is used by such applications as Kort and Noise Battle (Garcia-Martí et al., 2013) as well as in the more popular Google's multiplayer game Ingress (Hodson, 2012) and the social network Foursquare (Lindqvist et al., 2011).

Due to its primary role among worldwide VGI projects, OSM is extensively analyzed to determine how collected VGI can reflect user participation patterns. Several studies (e.g. Girres and Touya, 2010; Haklay, 2010; Zielstra and Zipf, 2010) focused on OSM outcomes in terms of quality, typically through comparisons between OSM and authoritative datasets. Results suggest that the quality of OSM is higher in urban areas, characterized by large numbers of contributors who actively edit and update the dataset. Other OSM studies investigated how many volunteers intervene in the OSM mapping process and quantified their contributions. Both Mooney and Corcoran (2012) and Neis and Zipf (2012) show that a very large part of OSM edits is performed by a very small number of volunteers. What also can be surprising to some is that more than half of the OSM users have never edited the map. However, this finding is in line with similar studies on Wikipedia (e.g. Anthony et al., 2007) and supports the 90:9:1 rule for participation inequality observed by Nielsen (2006) for open contribution system: 90% of the users only consume the information, 9% contribute occasionally, and only 1% is constantly active in contributing information.

3. Methodology and results

In this section, we turn to a discussion of our own implementation of the GIS mobile-based applications aimed at fostering user participation. As mentioned above, the main objective underlying the development was the creation of a stable and multi-purpose platform able to assist organizations willing to involve citizens in data collection campaigns. This has become a tremendously popular trend even in the public sector, which is typically hesitant or slow to change its traditional approaches.

The technical architecture of this developed system, which allows users to manage geospatial data collected from the public through a mobile app, is described in Section 3.1. Its practical application for three participatory sensing projects, related to different disciplines and addressing different user profiles, is presented in Section 3.2. This is followed by a comprehensive discussion on the emerged characteristics of user participation addressed in Section 3.3.

The classification of these projects falls inside the complex framework about VGI, crowdsourcing, citizen science (specifically participatory sensing) and PPGIS depicted in Section 1. The projects exploit GeoWeb 2.0 technologies and – especially the first one – pursue a crowdsourced involvement of the public; VGI and participatory sensing data is created from users' mobile devices, and clearly there is an agency-driven data-collection campaign which is typical of PPGIS (although a decision-making process is outside the scope of the work).

3.1. Mobile collection and management of geospatial data

A modular system is designed to assist multi-purpose participatory sensing projects by enabling the management of geospatial data from the initial on-field collection up to the final Web publication. The system is entirely built with open source GIS technology. Fig. 1 provides a graphical representation of all the server and client software components of its architecture.

The architecture builds upon and extends the one presented by Brovelli et al. (2014). Data collection from mobile devices is achieved through the Open Data Kit (ODK) suite (Brunette et al., 2013; https://opendatakit.org), which is mainly composed of the ODK Collect and the ODK Aggregate modules. ODK Collect is a customizable mobile app for Android devices which, as mentioned in Section 2, allows collection of geospatial punctual data. It downloads form templates from, and sends user compiled forms to, ODK Aggregate, a Web application running under an Apache Tomcat server (http://tomcat.apache.org). ODK Aggregate manages forms and users (including their permissions on data access and download) and stores collected data through a synchronization with a PostgreSQL database (http://www.postgresql.org).

As stated in Section 2, in a standard ODK configuration, collected VGI data can be only accessed by the same users of the app through a connection to the Aggregate server. Conversely, to make data available to the general public, the system utilizes the PostGIS spatial extension (http://postgis.net) to connect to the PostgreSQL database. This transforms user-generated contents into real geospatial data, allowing the GeoServer package (http://geoserver.org), also running under Apache Tomcat, to effectively read and publish it according to the OGC WMS (Web Map Service; Open Geospatial Consortium, 2006) and WFS (Web Feature Service; Open Geospatial Consortium, 2005) standard protocols. A number

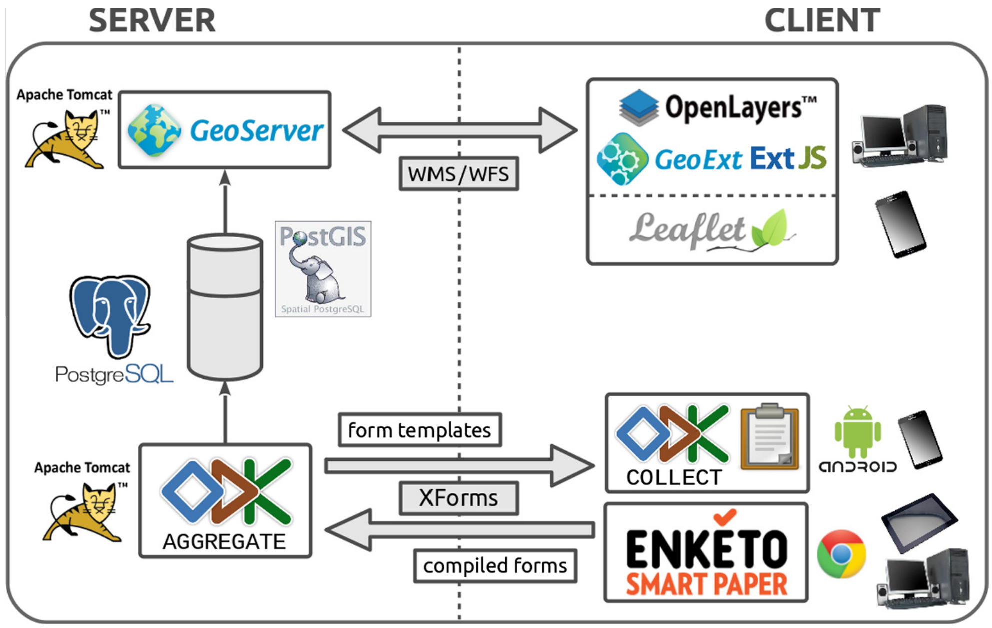

Fig. 1. System architecture suitable for multi-purpose participatory sensing activities (extended from Brovelli et al., 2014).

of freely accessible GIS Web viewers are then built (see for example, Figs. 2 and 5 below) to enable customized data access and interaction not only from traditional desktop computers, but also from mobile devices like tablets and smart phones. The former are achieved through the OpenLayers (http://openlayers.org), GeoExt (http://geoext.org), and ExtJS (http://www.sencha.com/products/extjs) JavaScript libraries, the latter with the Leaflet (http://leafletjs.com) JavaScript library.

Of particular importance in the context of this work is the choice of ODK Collect as the mobile client application through which users can enter data into the system. As mentioned above (and shown by the case studies described in Section 3.2), the proposed architecture is intended to be used for multi-purpose data collection campaigns and can thus address highly diversified user profiles (in terms of age, sex, background, education, etc.). Therefore the User Interface (UI) of the ODK Collect mobile app must provide an adequate degree of usability for any potential user, which in turn represents the foundation for improving participation. This is ensured first by the same nature and purpose of the ODK suite, which was originally created to build information services in developing regions (Hartung et al., 2010) and thus specifically designed to minimize user training (Brunette et al., 2013). ODK Collect was also successfully tested against Nielsen's (1994) popular usability heuristics to verify the suitability of its UI. Apart from this, it is worth mentioning that ODK is currently among the worldwide leading data collection solutions, as it offers a robust infrastructure and can suit the needs of organizations with limited financial and technical resources (Hartung et al., 2010). It is therefore recommended for projects issued by any kind of subjects, involving any kind of public in collecting any kind of data.

Two valuable extensions were made to the system architecture by Brovelli et al. (2014), which as a whole can facilitate, speed up and increase data collection. The first extension allows users, when recording their position from an Android mobile device, to exploit an interactive map where they can manually select their position. This is extremely useful to overcome a set of limitations outlined by Brovelli et al. (2014): GPS coordinates often take significant time or sometimes are impossible to acquire (e.g. in cases where significant overhead sky is blocked, such as in cases of heavy forest canopy or an urban canyons); both positioning precision and accuracy can be very low, thus undermining the quality of the recorded coordinates; and the survey position may not coincide with the position of the object being surveyed (e.g. in the case when it is not physically possible to get close to it). In all these cases, users can exploit the interactive map within the ODK Collect app to manually set a position that would either substitute or refine the one estimated from the GPS.

The second extension is represented by the integration between ODK Aggregate and the Enketo Web framework (https://enketo.org), which allows users to compile and send forms through a simple browser (e.g. from a computer). In this way, the range of potential users of the system is potentially extended also to those not equipped with an Android device (i.e. people using a different mobile operating system and people who do not even own a mobile device) as well as those equipped with an Android device but unfamiliar with this technology.

The proposed architecture makes full use of not only open source software, but also open standards. Besides the OGC WMS and WFS protocols mentioned above, the XForms standard from W3C (World Wide Web Consortium, 2009) is also exploited to manage and exchange data forms. XForms is an XML-based format designed to represent the next-generation of Web forms (Hartung et al., 2010) and providing a number of benefits when used on mobile devices (see http://en.wikipedia.org/wiki/XForms). Being based on open standards, the system has an interoperable, modular architecture where each component is closely linked to the others but at the same time stands on its own, allowing to be seamlessly replaced in case of need (e.g. if a new and better product were to appear on the market). As an example, the work of Brovelli et al. (2014) was further improved by replacing ODK Build with the more performing XLSForm (https://opendatakit.org/use/xlsform) for the creation of XForms-compliant forms for data collection.

3.2. Applications for public participation

The described architecture is applied for three projects involving the public into participatory sensing activities. They are presented in the following by outlining the context in which they were born, the main purpose and targeted public as well as the technical details related to the customization of the previous architecture.

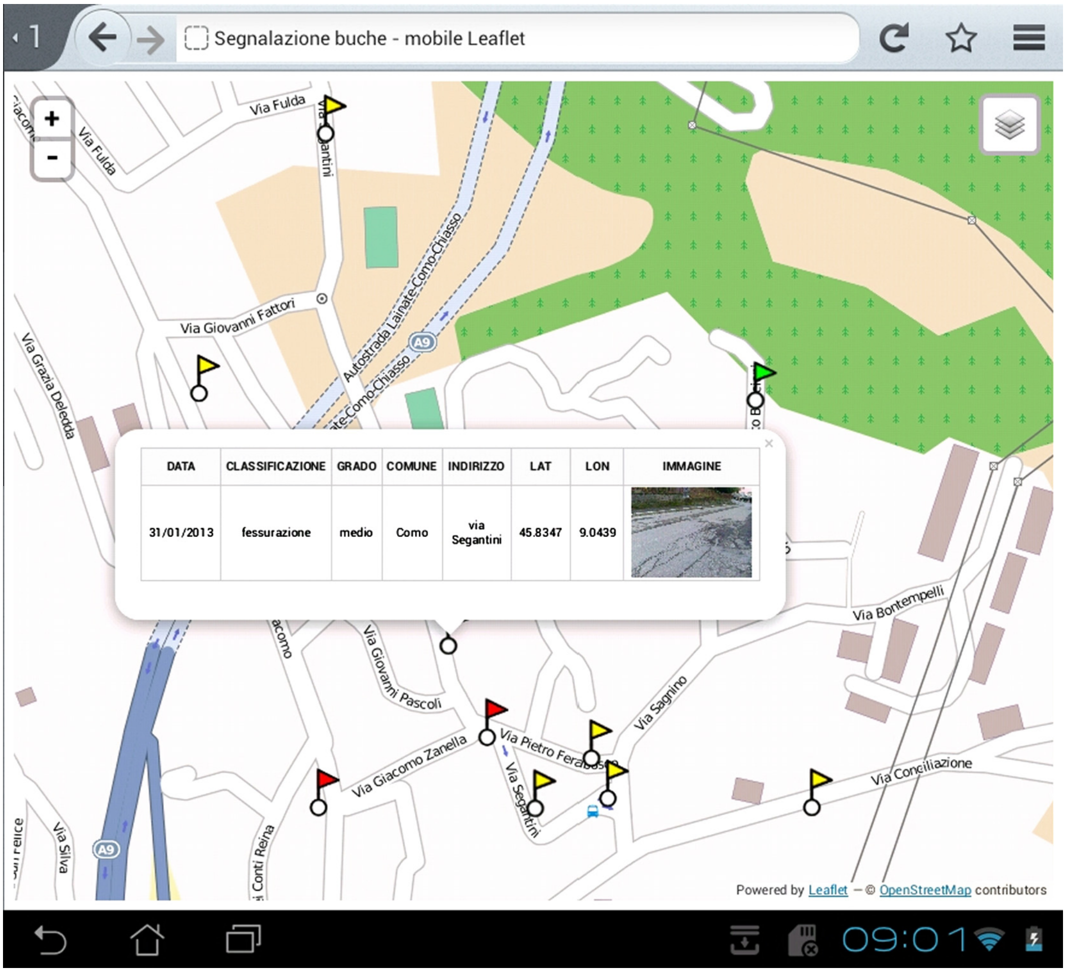

Fig. 2. Web viewer providing interaction with the potholes VGI layer. *Source:* Brovelli et al. (2014)

3.2.1. Citizens' report of potholes

The first project was developed in winter 2013 in response to the generally poor conditions of road pavement in Como city (Northern Italy), which was coupled with the local government's general lack of systematic ways to detect these problems in real-time and to make citizens informed about them. By allowing people to report potholes, the project sought to provide the local government with a new tool to reduce the gap toward the citizens and thus facilitate and speed up the needed interventions.

As no specific constraints (e.g. age, education and cultural background) for participating to the project were identified, all citizens of Como city were recognized as potential users of the system. An advertisement campaign was accordingly performed over a couple of months through the local press and TV channels. Recommendation was done to visit the project website which provided instructions on how to create an account and use the app.

User form compilation (also available offline) basically consisted in describing the type of pothole, classifying it according to the severity degree, recording its position and taking a picture of it. The technical details related to form design, compilation and submission can be found in Brovelli et al. (2014). Finally the Web viewers allow to interact with the WMS layer of the potholes reported by volunteers, which are automatically styled in different colors (green[3], yellow, and red) according to the severity degree of the damage declared by the users (see Fig. 2).

3.2.2. Mapping and evaluation of architectural barriers

The second project focused instead on the issue of architectural barriers, which include both physical obstacles being a source of frustration for the mobility of anybody, particularly those with a limited or prevented mobility; and the lack of indicators that would allow anyone, but particularly blind, partially-sighted, and deaf people, to orient and recognize impending sources of danger (Italian Ministry of Public Works, 1989). The Italian legislation, issued by the Ministry of Public Works, provides technical specifications to enable building accessibility, visitability, and adaptability in relation to three main types of architectural barriers, i.e. stairs, ramps, and pathways (Italian Ministry of Public Works, 1989). In detail, the compliance of each barrier is defined through a number of variables which are both qualitative (e.g. presence of signage) and quantitative (e.g. length, width, and slope).

Taking this document as reference, a participatory sensing campaign was launched during summer 2013 with the purpose of mapping the architectural barriers of Como city center and check their compliance. A radically different choice (compared to the potholes project) was made regarding the targeted users. Instead of requesting participation by the broad public, this project took a different tack: we recruited a team of six students from a local high school through a school-work initiative in partnership with the authors' university.

The educational nature of the initiative was thus crucial, as students were first instructed on the social importance of architectural barriers and their compliance. They were further instructed on the practical use of the ODK Collect app, which, besides taking

[3] For interpretation of color in Figs. 2 and 4, the reader is referred to the web version of this article.

a picture and recording the position of the barrier, required them to express its compliance to the set of measurable variables issued by the legislation, whose official text is also included in the mobile form (see Fig. 3, which shows a subset of form compilation steps).

Students were encouraged to cover the whole city center of Como but no time limit was fixed for completing the survey. As a result, the reports were performed in almost a week and they acceptably covered the target area. They are again published as a WMS layer which styles stairs, ramps and pathways according to their overall compliance, i.e. in green if they comply to all the examined parameters, and in red if they do not comply to at least one parameter (see Fig. 4). We should comment on one striking component of the data in this figure: the large percentage (69%) of non-compliant barriers is mostly due to the lack of signage, particularly for stairs.

3.2.3. Mapping of tourism points of interest

A third implementation of the architecture described in Section 3.1 addressed the field of tourism valorisation within an Interreg project named "The Paths of Regina – Cross-border paths linked to Via Regina". Central to the project is Via Regina, i.e. the road overlooking the West coast of Lake Como and defining a dense system of soft mobility paths across the mountainous, cross-border area between Italy and Switzerland. Together with these paths located in a beautiful naturalistic region, Via Regina possesses a unique value in that it has been a historically fundamental trade and pilgrim route throughout Europe since the ancient Roman times (Brovelli et al., 2013). Born from the synergy between local communities and experts in GIS, landscape design, history and cultural heritage, the project seeks to rediscover and enhance the richness of the territory by valorising slow and sustainable tourism (Dickinson et al., 2011) even through the new participative technologies of GeoWeb 2.0.

In this context, mapping parties represented a valuable way to attract people toward slow tourism activities and in turn raise awareness about the project. A number of mapping parties were organized during spring and summer 2014 in different areas along Via Regina. They consisted of one-day nature walks in which, thanks to the cultural experts and associations involved, focus was placed on tracing the history of the territory and rediscovering its local traditions (e.g. customs and food). Mapping parties were advertised through the official channels (mainly websites and social network profiles) of the project and those of its partners. The public was thus quite heterogeneous, being formed by university staff, people from the associations and communities involved and also citizens interested in the activity.

Instructions on how to setup and use the ODK Collect app were printed and distributed to all the participants before the mapping parties started. The designed data collection form allowed users to map a variety of points of interest including historical/cultural elements, morphological elements, and tourism facilities. Particularly useful – compared to the previous applications that were strongly based on field survey – was the ODK Aggregate integration with Enketo. As a matter of fact, this made it also possible to upload – after the mapping parties – the reports of the same points of interest as well as new contents, e.g. photos taken and drawings made during the events. Besides pictures, participants exploited ODK Collect or Enketo to also upload videos and audios related to the points of interest. Data contributed to each mapping party are accessible as WFS layers from ad hoc Web viewers (see e.g. Fig. 5). This customization of the general architecture can represent a valuable tool for tourism communities and – more generally – cultural associations, whose activities can be focused e.g. on documenting or restoring natural paths and thus can highly benefit from a participative approach in the form of mapping parties.

3.3. Characteristics of public participation

The outcomes of the three projects described above allow to also make some considerations about the factors influencing user participation in collecting VGI, which in turn represent a key element organizations should consider when programming such kinds of data collection campaigns. This is discussed in the following by only addressing the level of participation, i.e. the quantity of user contributions and not their quality (which, as mentioned in Section 1, is another fundamental issue related to VGI but is not addressed in this work).

As can be inferred from our application descriptions, no gamification strategy was applied to foster user participation. The main reason was that, being these the first participatory sensing activities the research group managed, the authors considered important – at least as a starting point – to evaluate the results in the most basic approach where users voluntarily contribute data – perhaps in response to a call, but without any incentive or prize derived from a game-driven approach. With this premise, results show that user participation in VGI projects similar to those described is highly dependent on the number and the kind of their expected users as well as their duration.

The importance of the number of users is evident by comparing the results for the projects on potholes and architectural barriers. In the former, where all Como citizens were invited to participate, 77 reports from only seven users were collected; in the latter, the sole six students involved collected 96 reports. It is thus clear that the campaign for collecting potholes was largely unsuccessful, because it did not reach a significant subset of Como citizens. More than 50% of the data were collected by only two users, while the activity of three other users stopped after the report of just one pothole. Curiously, approximately ten citizens created an ODK account but they never used it. As a result, the spatial distribution of the potholes reports was largely biased by the contributions of the most active users. Although achieved into a much smaller-scale application, our results reflect those found for OSM (Mooney and Corcoran, 2012; Neis and Zipf, 2012) and are in an almost perfect agreement with Nielsen's (2006) 90:9:1 rule for participation inequality.

Specifically concerning the project on potholes, the reasons of this negative outcome can be found in a number of factors. First, people did not perceive the importance of the contributions they could give to the community, or they thought – even without experimenting the application – that its use should only pertain to people having some technical knowledge of the potholes and/or people able to play an active role in decision-making processes related to the city. The fact that the initiative was not launched by the local government (with a clearly-stated purpose of improving road condition) but rather by a university – which has no voice in decision-making processes – may have influenced people in this sense. In addition, the absence of any incentive to use the app may have discouraged people to try it at least once, or to use it again after the first time.

The success of the project on architectural barriers could instead be explained by the opposite reasons: students understood the importance of the reporting activity; instructions were given to them during a real meeting and not through a website (i.e. their involvement was much more stimulated); and, in a sense, they "had to do" the activity to complete their school-work initiative (i.e. they had a strong incentive to undertake the work). In any event, as mentioned in Section 3.2.2, the Como city center was satisfactorily covered with reports even if students were not given constraints neither on the number of architectural barriers to report nor on the time to be spent on the activity. It is thus clear that the mainly social value of this project, which in this sense is comparable with traditional PPGIS practices, played a key role for determining its success in terms of user engagement.

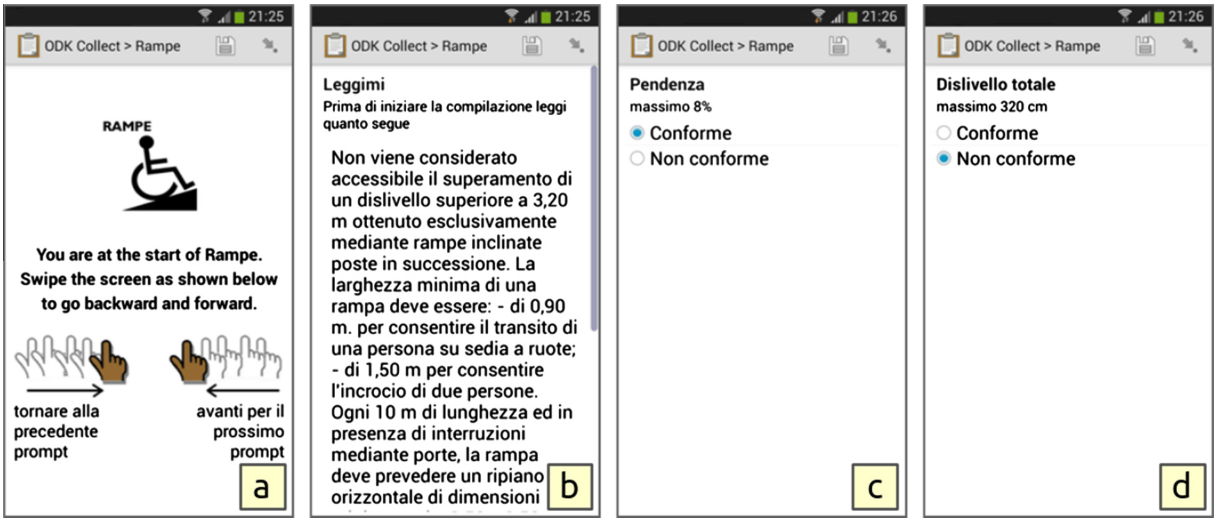

Fig. 3. ODK Collect screenshots showing some steps of form compilation for reporting a ramp and checking its compliance: (a) starting page of the form; (b) official text of the legislation; (c) selection of the ramp compliance according to its slope (which must not exceed 8%); (d) selection of the ramp compliance according to its total drop (which must not exceed 320 cm).

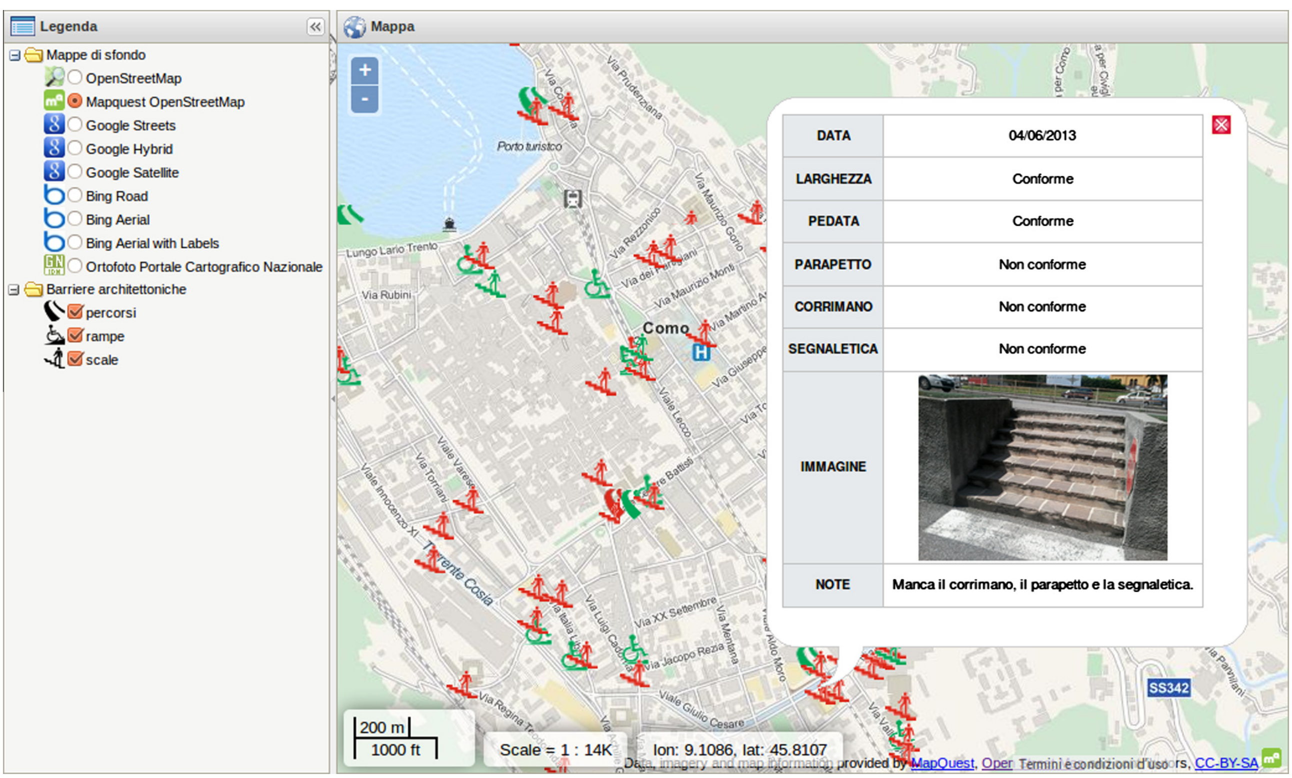

Fig. 4. Web viewer providing interaction with the architectural barriers VGI layer.

The kind (particularly the age) of the targeted public – which is somehow a proxy for the second kind of digital divide (see Section 1) – proved to be another crucial factor for the outcome of the projects. As a matter of fact, a high percentage of the citizens who did join the pothole campaign, and the tourism mapping parties as well, and all the students reporting architectural barriers were less than 30 years old. With the premise that the submission of contents through ODK Collect did only require Internet access and familiarity with an Android device, a reason for that should be found in the higher "technology-orientation" of younger people, which corresponds to Van Dijk's (2006) educational inequality of digital divide. In other words, the practical effects of this second-level digital divide were to largely exclude adults and seniors from the range of potential users.

This was specially clear during the mapping parties along Via Regina, when the usage of the app was explained to all participants both orally and through printed instructions, but almost only young people decided (or were able) to make full use of the potential of their devices to map the points of interest. Clearly this may further explain the poor level of participation to the pothole campaign, for which instructions – while exhaustive and accompanied by illustrative screenshots – were only provided through a website.

Fig. 5. Web viewer for the VGI collected during a mapping party for the valorisation of slow tourism.

A third factor influencing the project results was the duration of the participatory sensing campaigns. While potholes VGI was collected (with scarce results, see above) during almost three months, architectural barriers were reported in a week and the mapping parties, by nature, lasted for one day. It is thus clear that, with all the assumptions made, longer campaigns do not necessarily lead to the collection of more data. On the contrary, for VGI projects targeting local people in small areas, short data collection campaigns have to be preferred because they allow to directly involve the public and, in turn, get more data.

4. Discussion

The way geospatial information is produced and disseminated has faced a tremendous change over the last decade, characterized by the rise of VGI as the new, crowd-centric paradigm for GIS-based applications. This study focused on the related issue of public participation by investigating the VGI – and specially citizen science – subset of participatory sensing, which is centered on the use of mobile device sensors as key tools to perform scientific measurements. The methodology adopted reflects also some distinctive features of Public Participation GIS (PPGIS) practices.

An open source architecture for civic engagement activities was developed, which allows the user to manage data collection campaigns using sensor-enabled mobile phones. Designing ad hoc forms for entering data (including images, audios and videos) and arranging specific Web viewers to visualize the results, the architecture could serve as a useful tool for a number of organizations (including public-sector bodies) wishing to involve citizens in multi-purpose spatial data collection projects. Three case studies were presented where users were engaged in urban monitoring (report of potholes and architectural barriers) and tourism valorisation (mapping of tourism points of interest).

From the technical perspective, the developed architecture has a number of features that have utility and could be a reference for readers wishing to develop similar applications. First, the use of open standards (particularly W3C XForms and OGC WMS/WFS) makes the modular components of the system prone to be either integrated with other software tools or seamlessly substituted with new ones, in case of need. In addition, the use of interoperable standards allows the VGI collected to be publicly available for reuse. Being fully built on open source software, the system can be easily extended or customized according to the specific needs. Two other implemented features are worth mentioning which can simplify data collection and, in turn, widen participation: the availability of an interactive map to manually select the position if the one provided by the mobile device (e.g. through the GPS) is not satisfactory; and the extension of data collection clients to desktop applications.

Some possible improvements related to the data collection phase concern positioning quality. For instance, future work should focus on adding the chance (on the mobile interactive map or at least on the Enketo client) to exploit custom data (e.g. WMS layers) within the reference map used to select point positions. This would enable the use of accurate maps of known (and potentially very high) accuracy. Nevertheless, research should continue on investigating the accuracy of mobile device positioning (see e.g. Minghini, 2014) as it will be very much likely to be improved over the next few years along with the related technological advancements.

Outcomes of the case studies in which the architecture was tested resulted in a number of lessons learned which can be used as guidelines for projects with comparable characteristics (in terms of purpose and scale). The level of participation was found to vary with the number and the kind of the targeted users as well as the foreseen duration of the campaign.

Even if occasionally advertised, initiatives involving large and undefined publics (e.g. the citizens of an entire city) for an undefined duration (i.e. without an a priori definition of the end of the campaign) have little chance of succeeding in engaging and stimulating people. This might be overcome by switching to a gamification approach, which was deliberately discarded in this study but is under experimentation in similar projects (e.g. Garcia-Martí et al., 2013). Alternatively, shorter campaigns involving small and selected user groups (e.g. the technicians of an administration) are more likely to be successful. People's "technological orientation", which reflects a secondary but essential aspect of digital divide (i.e. the inability of making full use of the available technology), has also an important role in shaping participation patterns. In other words, even though using the system's mobile application is relatively easy, a further simplification and refinement of its UI (resulting in turn in an increase of usability) might not be sufficient to recruit a wide range of users.

A final remark must be made about the way users can interact with the mobile-collected data. This is presently bounded to the traditional 2D visualization but could be possibly extended to the third dimension by means of virtual globe technology. As a matter of fact, 3D visualization can represent a crucial improvement for projects such as the one on slow tourism valorization, which is focused on a mountainous region and can thus highly benefit from a more realistic globe-based visualization. Moreover, a new solution is under current development to complement the simple 3D data access with a pool of other functions, aimed at enhancing user participation after data collection process. Examples are data filtering in time (which would result in a 4D visualization), the upload of new multimedia contents related to the field-collected data, the addition of any external layer (e.g. from other ODK Aggregate and WMS-compliant servers), and the subsequent creation of customized 3D projects.

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