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EDITORIAL

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Recent advances in Volunteered Geographic Information (VGI) and citizen sensing

1. Introduction

The contribution of data by citizens has a very long history, whether one goes back centuries to amateur scientists or to one of the early cited examples of citizen science in the form of the Christmas Bird Count, organised each year by the Audubon Society since 1900 (Bergerot 2022). In addition to citizen science, there has been a proliferation of terminology to capture this phenomenon (Eitzel et al. 2017; See et al. 2016) but the term Volunteered Geographic information (VGI) has become firmly established as a core concept in the geospatial sciences and geography, outlined originally by Goodchild (2007).

Enabled by technology, VGI emerged at a time when the adoption of smartphones was already on the ascent, and OpenStreetMap (OSM) was developed as a way of moving digital mapping from traditional producers such as national mapping agencies (NMAs) to the citizen (Figure 1). This was followed by more than a decade of research on key topics starting with data quality and assessment, as researchers began comparing OSM data with authoritative data from NMAs. Early examples include the papers by Muki Haklay and colleagues (Haklay 2010; Haklay et al. 2010) followed by many others as reviewed by Senaratne et al. (2017) and Medeiros and Holanda (2019).

Two networking COST Actions on VGI were funded by the European Commission, which produced a considerable body of research on a range of VGI topics (Capineri et al. 2016; Foody et al. 2017). The COST Action TD1202 on Mapping and the Citizen Sensor had a particular focus on VGI and NMAs, which brought together NMAs across Europe for the first time to exchange perspectives and approaches (Olteanu-Raimond et al. 2017). Citizens were becoming producers of data and not just consumers (Coleman, Georgiadou, and Labonte 2009), which could be used to help NMAs update or enrich their authoritative databases.

A recent survey run by EuroSDR in 2024 on the evolution of VGI in NMAs (Cantat 2024) showed that 18 NMAs among the 23 replying to the survey used or have used VGI, whereas they were only 12 in 2016 (Olteanu-Raimond et al. 2017). Most of the NMAs engaged with VGI initially through pilot projects, representing the first level of maturity. It is important to note that some NMAs have undertaken various pilot projects over the years. This is reflected in the paper published by Rönneberg and Kettunen (2023) as part of this Collection, which describes a border marker data Collection pilot, which is one of several pilots that has been proposed by the Finnish NMA over the years. Some of the pilots proposed by NMAs have evolved into programme phases or even become institutionalised, as indicated by 10 of the survey respondents. Surprisingly, however, despite their success and positive outcomes, some programmes have been discontinued for various internal reasons, such as the lack of resources or the availability of more efficient alternatives, as indicated by five respondents.

Another prominent area of VGI research has been in the development and validation of land cover and land use maps (Fonte et al. 2015; Schultz et al. 2017). In these applications, VGI is particularly useful for obtaining land use information, which is harder to detect from satellite imagery than land cover (e.g., Fonte et al. 2018). However, VGI quality is a critical factor in these types of

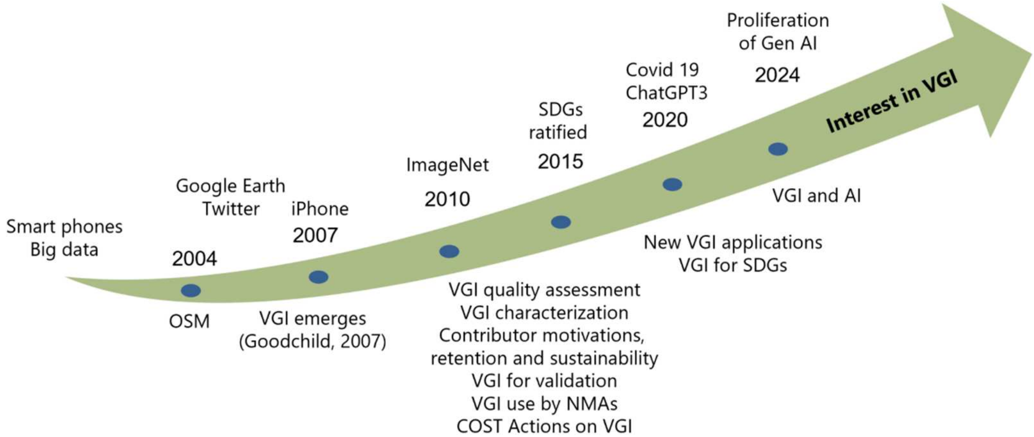

Figure 1. Key milestones in the evolution of research in VGI.

applications, so methodologies have been proposed to filter and/or validate the land use and land cover data extracted from VGI (e.g., Fonte et al. 2020; Schott et al. 2024). Another popular area of VGI research has been in understanding the motivations of the volunteers, with attempts to classify them (Budhathoki and Haythornthwaite 2012; Gómez-Barrón, Manso-Callejo, and Alcarria 2019; Heipke 2010) in order to better understand how to design VGI applications and sustain participation in the longer term.

Interest in VGI has continued to grow since its emergence (Figure 1), as social media in multiple forms has become a popular source of information for research as well as for practical and humanitarian purposes (Feng, Huang, and Sester 2022; Tavra et al. 2024). With the adoption of the United Nations Sustainable Development Goals (SDGs) in 2015, research on how VGI can support SDG monitoring has also emerged, particularly as the SDGs continue to be hampered by a lack of data (Antoniou 2023).

The Covid-19 pandemic was a significant global event that stimulated bottom-up activities and citizen participation. Mobile apps were developed to share VGI on health related data (Allam 2020) while Suzuki (2022) has reviewed the Covid-19 related VGI research that emerged in the first two years after the start of the pandemic, including a classification of the VGI actors based on the role they played in collective action.

Finally, Artificial Intelligence (AI) is an area of considerable global interest, driven by advances in generative AI and large language models (LLMs), although machine learning approaches have been used in the geospatial sciences for decades. Advances in computer vision with the release of pre-trained networks such as ImageNet and the proliferation of geotagged photographs from social media sites have resulted in new types of VGI applications, for example, in areas such as tourism, mobility and land cover classification (Cuenca-Jara et al. 2020; Cui et al. 2021; Zhu, Deng, and Newsam 2019).

Reflecting on changes in this field, this Article Collection was compiled to capture the latest trends in VGI research. The next section provides an overview of the papers in this Collection, divided into three main areas of research. The first is VGI applications that involve the active participation of volunteers, including a paper that is driven by an NMA, the second is applications of passive VGI data, continuing the interest in social media, while the final set of papers represent new and innovative areas of research for VGI.

2. Overview of papers featured in this Article Collection

2.1. Applications involving active participation

Three papers in the Article Collection are focused on the development of VGI applications that involve the active participation of volunteers. The first two are applications for data collection of relevance to NMAs and urban planning departments while the third application collects data from satellites for the purpose of weather forecasting related applications.

In the paper by Rönneberg and Kettunen (2023), the Finnish NMA developed a gaming application for improving the accuracy of the border marker locations in the digital cadastre. Containing over 13 million markers, many of them are of low quality and can result in border-related disputes. As it would not be possible to professionally resurvey all the border markers, it was decided to involve citizens in the data collection process. The gaming application was developed with stakeholder involvement and then evaluated over a 4.5-month period. In total, 22,166 contributions were made from 2,741 volunteers, with the top 10% providing 59% of the data. Similar results were found in a VGI application run by the French NMA IGN with 10% of contributors providing 65% of the data (Jolivet and Olteanu-Raimond 2017), following a typical type of contribution pattern (Fritz, See, and Brovelli 2017). A questionnaire on motivation was sent to participants, with 423 responses, which can help to improve the future design of the app, but it also confirmed that the volunteers found the experience pleasant. Overall, the paper showed that the active involvement of citizens in updating an authoritative database from an NMA can be successful.

Public Participation in Planning (PPGIS) emerged as an area of interest in the mid-nineties (Sieber 2006), which involves citizens in providing their inputs to planned developments. PPGIS is essentially an early form of VGI. With advances in 3D mapping and digital twins, the paper by Hasanzadeh et al. (2023) specifically considers the extension of PPGIS to a 3D environment. Using a small area from the city of Turku in Finland, which is undergoing urban renewal, the authors developed a 3D mapping interface, inviting citizens to indicate their preferences regarding future developments. In total, 135 citizens took part, marking up 368 locations with development preferences. Using a series of micro-scale metrics, some of which were extensions of 2D PPGIS mapping approaches, they showed that participants made suggestions in eight different categories, where culture and sports/leisure were the most frequent, but comments were also made regarding new housing types, working spaces and city greenness. Such a 3D approach, including the framework for the analysis of the 3D PPGIS data, holds considerable potential for the involvement of citizens in the planning process, but due to its realistic and detailed representation, it also has the advantage of increasing the awareness of a city and its significant buildings, spaces and developments.

Finally, in See et al. (2023), the authors present the CAMALIOT mobile app for collecting raw data from the Global Navigation Satellite System (GNSS). With two new advancements in mobile technology, i.e., access to raw GNSS data in Android phones through an Application Programming Interface (API) made available by Google and the emergence of mobile phones with dual frequency receivers, new applications of GNSS data have become possible. Since the GNSS signal is modified by water vapour in the atmosphere, raw GNSS data could be used in precipitation and weather forecasting. For this reason, the CAMALIOT mobile app was developed, and similar to the cadastral application described above, the CAMALIOT app also utilised gamification to motivate participants. From data collection campaigns that ran over 6.5 months, 116.3 billion GNSS observations were collected from 11,828 volunteers. A questionnaire was also distributed to volunteers to determine the underlying motivations to participate, with most choosing the desire to help science.

2.2. Applications involving passive VGI data analysis

The next three papers in the Collection are focused on applications involving passive VGI analysis. The authors of these papers used existing data produced by citizens in a passive way and proposed new approaches to manage and analyse these types of data.

The first paper in this section by Hartmann and Purves (2023) presents a workflow to detect individual transportation modes for pedestrians, cyclists and vehicles using videos from the YouTube platform to develop a soft mobility indicator in urban areas. This novel data source, called City Walking Tour Videos (CWTV), falls under the category of Volunteered Geographic Videos (VGV) as defined by Lewis and Park (2018). CWTV consists of videos shared by individuals, primarily in touristic urban areas, capturing views of pedestrians, streets and cars. The proposed workflow includes several steps from object detection to geo-location at the street level and employed deep learning and geocoding techniques. The approach was applied to CWTV in Paris, and an analysis was conducted to show the evolution of three different transportation modes between 2017 and 2021. A change in behaviour was observed before and during the COVID-19 pandemic. Ultimately, this research demonstrates the potential of deriving a mobility indicator from videos by aggregating travel modes across space and time.

In the paper of Deng et al. (2023), daily electric vehicle trajectories are used to gain a deeper understanding of passenger vehicle usage characteristics and patterns. In this study, trajectories from 6,600 volunteered passenger cars that generated over 21 million trajectories during one week in Shanghai were used. A new rule-based algorithm was developed to detect the locations and the types of vehicle stopping points for both residential and working places. This algorithm was validated by comparing the results with census data, providing additional insights into travel behaviour and enabling the determination of relevant spatio-temporal indicators. Based on this newly generated knowledge and the employment of a Gaussian mixture model, a new approach was proposed to classify electric vehicles into four categories: family-used commuting, family-used non-commuting, commercially used and semi-commercially used. These categories allow for a better characterisation of electric vehicle use for commuting or for other mobility activities, revealing particular behaviours such as elevated road use being higher for family-used commuting vehicles compared to semi-commercial vehicles.

Finally, the paper by Senaratne et al. (2023) investigates the use of passive VGI from the X social media platform (formerly Twitter) to detect crisis events. To achieve this goal, state of the art methods and techniques for natural language processing were employed and adapted for a crisis event vocabulary. Thus, a keyword-based approach was used, involving the definition of a dictionary of relevant terms extracted from the data and characterising two events: floods and earthquakes. To add contextual information, part-of-speech tagging was applied, based on the assumption that X messages are similar if they share the same definition and context. In crisis events, even when X messages have a geographical location, this location cannot be directly used because the message might be posted by users located far from the crisis area. Thus, accurately georeferencing crisis events is challenging. This issue is addressed by combining geocoding and geoparsing, the latter assigning a location to a place name mentioned in the text using a gazetteer. The approach was tested on two types of crisis events: floods and earthquakes occurring in 2022 in various parts of the world, including Poland, Indonesia, Ukraine and Bangladesh, which demonstrated the feasibility of this approach for detecting and locating these events.

2.3. Emerging areas of research in VGI

The final three papers grouped into this subsection address research that is advancing the research agenda of VGI in directions that are moving beyond topics more commonly researched over the last decade.

The first paper in this section by Lush et al. (2024) focuses on the European Commission's aim to generate a Green Deal Data Space (GDDS), and how the success of such an achievement is dependent upon data compliance with the FAIR (findable, accessible, interoperable, and reusable) principles (Wilkinson et al. 2016), which also applies to data provided by citizen science platforms. This review paper investigates the platforms, tools and standards currently used by the citizen science community and their projects. The authors analyse how the projects comply or will be able to comply with the FAIR principles and then they try to identify gaps that may help to support FAIR compliance in citizen science. The analysis concluded that the major citizen science initiatives already promote FAIR procedures and principles and that there is even recent research focusing on the FAIRification of citizen science. However, smaller scale projects still either lack awareness of the FAIR principles, have limitations on the selection and use of tools that enable the use of such principles, or still do not acknowledge the advantages of FAIR to society. Work is still required to bring together the commercial, private and public sectors to agree on procedures that may be acceptable by all. Other limitations related to citizen science and FAIR are the use of different semantics in different projects, the project lifetime and the capability to maintain data repositories after a project ends. These aspects may limit the usability of some valuable data provided by citizens in the GDDS, and therefore efforts should be made to further promote the use of FAIR in citizen science (and VGI) projects.

The paper by Zhang, Gong and Zhu (2024) addresses aspects related to the social interactions between contributors of VGI, illustrated using iNaturalist. The authors analysed the relationships between the contributors, the characteristics of the observed species, and the location and date of the observations. The land cover type at each location was also obtained from the MODIS land cover data set. From this, a network of social interaction was built. The results of the analysis showed that proximity, species similarity and land cover similarity play a significant role in the establishment of interactions between contributors. These results reflect the presence of homophily between contributors, as they have preferences for certain species and/or environments. Another identified driving force was prestige, as page ranks tend to be associated with expert species identifiers. Although these findings cannot be extrapolated to all types of VGI platforms, they may be relevant for some types of platforms where inter-contributor collaboration is important.

The sustainability of OSM, one of the most successful VGI projects, is discussed in the final paper by Zhang et al. (2024). Two new tools are used, one to track the evolution of the editing behaviour of the contributing volunteers and the second to assess what may be more relevant to the sustainability of such a project, i.e., if it depends upon many contributors that make just a few contributions or on a core group of very active contributors. The study analysed the historical evolution of OSM and then concluded that OSM does show signs of self-sustainability and stability. However, the authors raise some doubts about the role of professional editors in these contributions and what their overall impact might be. The other main conclusion is that the critical mass theory applied in the paper shows that it is more important to have more editors that might make only very small edits than relying only on a core group of power contributors for sustainability.

3. Conclusions and the future of VGI

VGI has been an area of active research with increasing interest since it emerged as a named concept in 2007. This has been driven largely by technological advances, the open availability of many new types of data, and entering into the big data era, whether from traditional producers such as space agencies or by citizens through social media and other forms of VGI. This Article Collection demonstrates that NMAs still see the potential of VGI for updating their authoritative databases while social media and other applications that collect data about citizen movements can provide a wealth of information for research purposes.

One notable change that has occurred during the lifetime of VGI as a concept has been the increasing recognition that data from citizens is becoming a valid source of information. For example, according to the latest EuroSDR survey, most NMAs show good acceptance of VGI and recognise its significant role in data collection. Although authoritative geographic data are not predominantly based on extensive use of VGI, which is understandable given the sovereignty of topographic data, two notable shifts can be observed: first, NMAs have adopted the mechanisms and tools developed around collaborative projects and established partnerships with local, regional or national stakeholders to exchange and co-produce data such as community-sourcing. Secondly, NMAs consider VGI as relevant for enhancing citizen engagement and improving relations between them and citizens, leading to the implementation of various citizen-oriented programmes, such as the Panoramax programme, which is a collaboration between IGN-France and OSM to share geolocated photos across France. Both citizens and stakeholders are involved in this programme, and the data collected are used by stakeholders in their mapping processes.

While we see continued advances in VGI applications building on areas already researched, we also see clear evidence of new types of research emerging on open data, social interactions within VGI applications and new approaches to measuring sustainability, as illustrated by the papers summarised in section 2.3. This shows that there is clearly an interest in making the use of VGI more sustainable and widespread while considering new aspects of VGI.

Finally, a significant advance that will undoubtedly influence the direction of VGI research is the emergence of generative AI. Although not yet evident in this Article Collection, studies are already emerging that consider the use of LLMs in the geospatial sciences (Wang et al. 2024), so we expect to see a rise in research on VGI and generative AI in the future. What is certain, however, is that VGI is here to stay, and its role in providing a valid and valuable source of data for a range of applications will only continue to increase in the future.

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