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Article

A Systems Perspective on Volunteered Geographic Information

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Abstract: Volunteered geographic information (VGI) is geographic information collected by way of crowdsourcing. However, the distinction between VGI as an information product and the processes that create VGI is blurred. Clearly, the environment that influences the creation of VGI is different than the information product itself, yet most literature treats them as one and the same. Thus, this research is motivated by the need to formalize and standardize the systems that support the creation of VGI. To this end, we propose a conceptual framework for VGI systems, the main components of which—project, participants, and technical infrastructure—form an environment conducive to the creation of VGI. Drawing on examples from OpenStreetMap, Ushahidi, and RinkWatch, we illustrate the pragmatic relevance of these components. Applying a system perspective to VGI allows us to better understand the components and functionality needed to effectively create VGI.

Keywords: volunteered geographic information; Geoweb; GIS; public participation GIS; GIScience; crowdsourcing; systems science

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1. Introduction

The geospatial Web 2.0, or Geoweb for short, is a collection of online location-enabled services and infrastructure that is engaging a wide range of stakeholders in mapping processes. The interactions between individuals and groups and the Geoweb environment is, in some instances, generating volunteered geographic information (VGI). Simply defined, "VGI is crowdsourced geographic information provided by a wide range of participants with varying levels of education, knowledge, and skills" [1]. This type of geographic information, or geo-information, derived from the public through active or passive mechanisms is part of the larger phenomenon of user generated or crowdsourced content [2], and is producing novel, and often valuable, sources of geo-information [3,4]. In the context of the general trend of declining resources for national mapping agencies and the elimination of the Statistics Canada long-form census [5], VGI is becoming especially important where authoritative geographic information is lacking [1].

Adding to the value of a novel source of geographic information, there is mounting evidence that institutions—including government and non-government organizations (NGOs)—can use VGI as a mechanism to build local capacity to support collaboration, supplement traditional data sources, and inform decision-making. Johnson and Sieber [6,7], for example, explored both the motivation driving government adoption of the Geoweb, and strategies for increasing access to and use of the data subsequently produced. Haklay *et al.* [1] studied VGI use in government, providing the most comprehensive guide for VGI implementation to date. Haklay *et al.* [1] further noted that the process by which the data are collected—including organizational practices, regulatory issues (*i.e.*, licence conditions), and technical specifications—is more likely to impede the acceptance of VGI than the early concerns associated with quality, accuracy, and completeness of VGI. This raises the question: what are the organizational practices, regulatory issues, and technical specifications that support the production of VGI? Essentially, what systems support the creation of VGI?

Recent literature has alluded to the fact that there needs to be a formal, standardized framework for the creation of VGI for various reasons, which include increasing the completeness, accuracy, and reliability of the VGI produced. For example, Goodchild and Li [4] highlighted that "the rules in use have been assembled pragmatically and without a conceptual or theoretical framework," suggesting that a framework can help formalize the VGI process and make it "amenable to implementation." Peng and Tsou [8] also encouraged Internet GIS users to understand the mechanisms of system implementation before applying web-based GIS to the range of geographic problems. Finally, Goodchild stated, in a conversation with Turner, "I think the binary between local and professional knowledges is becoming problematic. We need to study the systems that have been used in some VGI projects to measure trust, rather than relying on simple surrogates like professional qualifications or membership in organizations" [9]. Indeed, studying the systems that have been used to generate VGI can tell us more than just about trust. Understanding the systems expands our knowledge of the conditions in which data are acquired; the people, both professionals and citizens, who are involved; and the technical infrastructure that enables the input, management, analysis, and presentation of VGI. As such, this paper proposes a conceptual framework for the systems that support future practical implementations of VGI.

Following this introduction, Section 2 of this paper provides a brief history of VGI, using OpenStreetMap, Ushahidi, and RinkWatch as examples. In Section 3, we look through the lens of systems science and geographic information systems to inform the development of VGI systems. In Section 4, we present both the components (project, participants, and technical infrastructure) and functions (input, management, analysis, and presentation) that are relevant, in varying degrees, to all VGI systems. Section 5 presents a discussion of the potential and limitations of VGI systems as a mechanism for collaboration and participation. We conclude with recommendations for future VGI systems research, development, and application, calling for strategic consideration of the systems that support the production of VGI.

2. A Brief History of VGI

Recognizing the value of geographic information created by non-experts, Goodchild [2] coined the term volunteered geographic information in 2007 "as a special case of the more general Web phenomenon of user-generated content." Goodchild referred explicitly to the notion of "citizens as sensors", which was introduced previously by Burke, *et al.* [10] as "participatory sensing". VGI has also been described as "user-generated geographic content" [11]. The concept of geographic information that is crowdsourced is not new. Non-experts have been capturing, describing, and recording the spatial nature of their experiences all throughout history—a sort of non-digital VGI. One of the most well-known examples is the Christmas Bird Count; starting in 1900, tens of thousands of participants voluntarily reported bird sightings at Christmas time, which led to an "unparalleled database of migratory and bird population data" [3]. However, VGI was not a prominent topic in geographic research previously because it was difficult to capture these spatial experiences with enough detail to make a significant contribution to the development of spatial data and maps. It is within the VGI paradigm—enabled by the Geoweb, location-aware devices, and citizens acting as sensors—that the tools and resources for collecting and processing geographic information from volunteers are readily available. There are various aims for implementing a VGI system, which include base mapping coverage, emergency reporting, and citizen science. We highlight each of these drivers using OpenStreetMap, Ushahidi, and RinkWatch as examples.

2.1. VGI and Base Mapping Coverage

Arguably, one of the most successful VGI projects is OpenStreetMap (OSM), a global mapping application created by volunteers. Based on Wikipedia's peer production model, OSM provides free, editable, and downloadable coverage for the locations and geometries of topographic features [12]. When compared to traditional mapping projects, the data generated through OSM is, in some areas, more detailed and accurate than the authoritative maps produced by national mapping agencies, such as the UK's Ordnance Survey [13]. Given the efforts of volunteers, these data are more readily updated, especially when there is an immediate need for more detailed data. Prior to the 2010 earthquake in Haiti, OSM data in the area surrounding Port-au-Prince were quite basic: shorelines and rudimentary road coverage. Immediately following the earthquake, the urgent need for detailed topographic data triggered a massive response by the OSM community. Both on the ground (*i.e.*, uploading GPS tracks) and remote (*i.e.*, tracing satellite images) contributions were uploaded, totalling over 10,000 edits in just a few short weeks, which effectively helped thousands of relief workers navigate the disaster area [14]. The utility and open access of OSM is also extending the base mapping coverage to many thematic uses. In fact, in the report on “Crowdsourcing Geographic Information Use in Government”, 10 of the 29 case studies rely on the OSM data, platform, and/or community [1].

2.2. VGI and Emergency Reporting

Similar to the disaster relief efforts enabled by OpenStreetMap, VGI is popular in what has been described as humanitarian aid [1], emergency reporting [15], and crisis mapping [16]. It is within these humanitarian aid efforts where we start to understand the power of the crowd, or what Dodge and Kitchin describe as “the power that can emerge from a mass of individuals converging to tackle a set of tasks” [17]. The motivations to volunteer are diverse; they seem to be imbedded in the social practices associated with VGI [18], which facilitate the ability to “connect socially, communicate meaningfully, and contribute collectively” [17]. Motivations aside, there is a growing response by volunteers to contribute geo-information to emergency response. Haklay *et al.* [1] categorize the use of crowdsourced geographic information in humanitarian efforts as either proactive (natural disaster preparedness) or reactive (crisis management).

As an example, map based emergency reporting was used during the political turmoil that ensued from the 2007 Kenyan presidential election. Striving for a more accurate understanding of what was happening on the ground during the crisis, local activists developed the Ushahidi (meaning “testimony” in Swahili) platform, which enabled citizens to report incidents of violence to the online map using both simple text messages (SMS) and the Web [19]. Since the initial development of Ushahidi, the platform has been packaged and made available to the public, meeting a wide range of crisis mapping (and crowdmapping) needs and supporting thousands of new deployments, including relief efforts following the Haitian earthquake [14]. Interestingly, what initially began as overcoming the weaknesses of traditional media [19] has turned into a supplemental, and sometimes superior, alternative to traditional information channels in times of crisis.

2.3. VGI and Citizen Science

VGI is increasingly being used in the domain of science and research. Broadly categorized as citizen science, these “projects engage members of the public in working with professional scientists in a diverse range of practices” [20]. Although citizen science predates VGI, Goodchild [2] first introduced the term VGI by relating it to the concept of citizen science because scientific observations are often associated with well-defined geographic features. Haklay [21] describes the integration between citizen science and VGI as “geographical citizen science”. Within the citizen science scope, VGI is being used most frequently in environmental monitoring [22–24]. A notable example of VGI in the realm of citizen science is RinkWatch: a project that gathers VGI from people who have backyard ice rinks in the winter months. Aided by the Geoweb, rink enthusiasts make routine observations regarding the “skatability” of their rinks, which in turn, builds a detailed database about environmental conditions and their change over time. The project is helping researchers study the micro-level impacts of climate change [25]. The growing number of citizen science projects is filling in information gaps between the public, scientists, and decision-makers, by drawing on a range of trained and ad-hoc observers [26]. Moving forward, we draw on OSM, Ushahidi, and RinkWatch examples throughout the paper to demonstrate how the creation of VGI can be conceptualized.

3. Toward Defining VGI Systems

Various authors have already identified a range of components, functions, and subsystems that govern VGI systems. For example, Hardy *et al.* [27] referred to the collection, storage, visualization, analysis, and application of VGI. Turner (by way of Wilson and Graham [9]) discussed the production, consumption, analysis, visualization, and sharing of VGI. Goodchild [11] addressed the collection, compilation, indexing, and distribution of VGI. Brown [28] stated "VGI is the harnessing of tools to create, assemble, and disseminate geographic data provided voluntarily by individuals". Characteristic of more traditional geographic information systems in the realm of Web 2.0 (the interactive Web), Elwood [29] identified new geovisualization technologies "as "not-quite-GIS" assemblages of hardware, software, and functionalities". Common to these different views of VGI is the consideration of multiple system components and their interactions, although this is not explicated by any of the authors. In the following sections, we therefore briefly outline the definition of a system in systems science and explore the parallels between geographic information systems and VGI systems.

3.1. System Definition in Systems Science

According to Kulla [30], systems science emerged from a combination of concepts developed in general systems theory [31] and cybernetics [32]. In an approach to better understand natural phenomena and tackle increasingly complex socio-economic processes, researchers proposed to view the world through a systems perspective. A system is defined as "a set of objects together with relationships between the objects and between their attributes" [33]. The systems perspective provides a holistic view on real-world objects and their relationships, and acknowledges important properties of systems that may otherwise go unnoticed, including: complexity, openness, dynamics, and directedness (finality) [30]. To encompass the many different facets of the systems perspective that have since developed in science, researchers like Klir now define it broadly as "the field of scientific inquiry whose object of study are systems" [34]. Therefore, computer systems, such as GIS, can serve as both the object of study for systems scientists as well as the tool by which to represent, analyze, and visualize complex real-world systems.

3.2. Geographic Information Systems

In addition to the foundations of systems science, the common link of *geographic information* between VGI and GIS warrants the consideration of traditional GIS components before delineating the parts of VGI systems. Relating specifically to spatial analysis tools implemented in GIS, but mimicking a current need in VGI research, Goodchild [11] stated the necessity to "systematize what is otherwise a confusing mass of methods". Tomlinson's [35] GIS implementation framework considered the information products resulting from the components and functions within the system. GIS could be defined based on its primary subsystems, in which geographic information emerges as an information product resulting from the interplay of the hardware, software, data, and people components, and it is shaped by a series of functions for geographic data input, management, analysis, and presentation within GIS [35–38]. This definition identifies stages in the GIS process; however, it does not consider the interaction between those stages or reflect the experience of implementation. Heywood *et al.* [37]

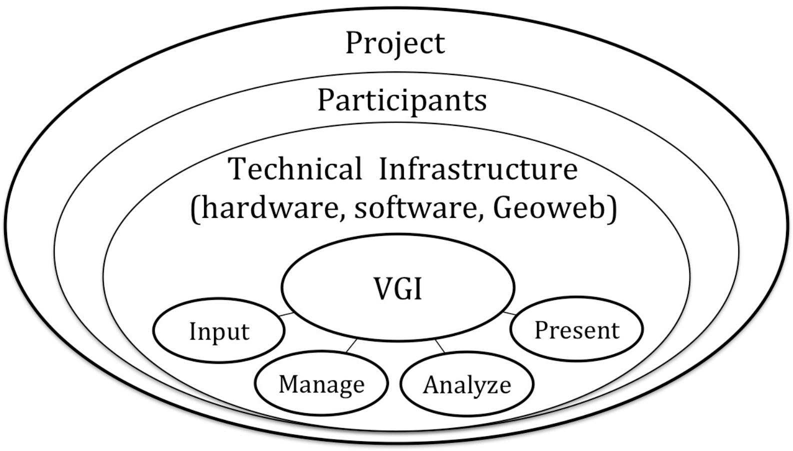
extended the traditional system perspective when defining the components of GIS by taking the position that "GIS cannot operate in isolation from an application area".

To overcome the limitations of a linear systems approach, Chrisman [39] proposed a view of GIS as a set of nested components with interactions that encompass the technical components as well as the larger context and institutional arrangements. The nested rings in Chrisman's conceptual framework are, from the simplest to the most complex level: measurements, representations, operations, transformations, institutional context, and social and cultural context. Each ring depends on components addressed on a simpler level, while embedding the considerations that are involved in operating the entire GIS. It is Chrisman's definition of the subsystems that shape GIS, which most influences how we understand VGI systems.

4. VGI System Components

VGI systems can be regarded as an environment for the production of VGI as an information product. The components, which serve as the building blocks for the system, are a complex arrangement between the project and its initiators, the participants who volunteer their geographic information, and the technical infrastructure (hardware, software, and/or the Geoweb); together, these components lead to the creation of a crowdsourced information product, or VGI (see Figure 1). Within the technical infrastructure, the functions allow for the input, management, analysis, and presentation of VGI. Mimicking Chrisman's [39] nested rings used to understand how GIS operates, VGI systems consist of interdependent components with interactions that address technical, contextual, and organizational considerations. Further, the considerations within each component have a substantial impact on the entire VGI system, and subsequently, on the VGI produced. Although the framework needs to be tailored to fit specific projects, we illustrate each component using OpenStreetMap, Ushahidi, and RinkWatch as examples.

Figure 1. The components of volunteered geographic information (VGI) systems.



4.1. Project

VGI systems are often initiated around a problem or a purpose, and are executed through a project. Projects can be triggered by an event, such as a political crisis or natural disaster. Ushahidi, for example, was first initiated in response to the political upheaval following Kenya's 2007 presidential election [19].

Alternatively, there is the less urgent (but arguably equally important) need to gather and share topographic or thematic geo-information, such as in the cases of OpenStreetMap and RinkWatch. Regardless of the initiating motivations, the goal and strategy of all VGI systems need to be clearly defined at the onset of a project. Otherwise, a project might suffer a similar fate as the thousands of Ushahidi maps that have ended up in the "Ushahidi graveyard"; a collection of purposeless crowd maps [40]. Although some now-defunct maps did serve as learning and training tools for those experimenting with crowdmapping, the graveyard is an important reminder to consider the purpose and plan for sustainability within a project.

The project is often closely related to the domain of the initiator, and in the early stages of VGI system development, the initiators have the greatest control over the design. As individuals or groups, they make important methodological decisions that influence the VGI produced. Key considerations include the study location (e.g., global, Kenya, or Canada), and the timeframe of the project (e.g., ongoing, immediate emergency response, or duration of a funded research project). In traditional GIS, the people component typically refers to professionals (*i.e.*, researchers, consultants, or technicians) and applications are tied to institutions (*i.e.*, academic, business, or government) [38]. In VGI systems, on the other hand, the people initiating the application still plan, implement, and operate the system but may not have formal training in GIS or institutional ties, and often present a unique arrangement between subject, producer, communicator, and consumer [41].

Despite the changing roles between producers and users, or "produsers" [15], the initiators leading the development of VGI systems have typically been associated with grass-roots movements, and encompass individuals, community groups, and organizations. Such is the case with Ushahidi, which was initiated by a group of Kenyan activists led by Okolloh, a prominent Kenyan blogger [19]. However, the increasing institutional interest in VGI and crowdmapping, especially by government, represents a more traditional top-down approach and introduces a new set of incentives for initiating VGI systems. In the report on crowdsourcing geographic information by Haklay *et al.* [1], each of the 29 case studies presented include various levels of government involvement. The interactions, or information flows, were broadly categorized as: public-government, government-public-government, or, public-government-public. Regardless of the domain of the initiators, they ultimately make critical decisions about the participation strategy and technical infrastructure used, as discussed next.

4.2. Participants

Within the application area, project initiators need to identify from whom they wish to collect the VGI. This participation strategy varies substantially between projects. Related to geographical citizen science specifically, Haklay [21] identifies that the role of the volunteer can be "active" or "passive". We believe this concept extends to VGI, where participants can contribute VGI both actively and passively. With projects aimed at collecting active contributions, the participants are often drawn from an engaged group of stakeholders such as a purposely selected community group, a pre-selected segment of the population, a set of authorized and trusted contributors, or unknown contributors motivated via a media or outreach campaign. In the case of RinkWatch, initiators identify those who maintain backyard ice rinks as their primary participants, while OpenStreetMap relies on a broad range of participants to contribute information on their local community [12,25]. In all cases of VGI systems aimed at collecting active content, the participant "is expected to consciously contribute to the observation or the analysis" [21].

Conversely, in projects that aim to gather passive contributions, "the contributor is acting more as an observation platform and the data are gathered without active engagement" [21]. In these types of projects, the participants use technology, such as GPS transmitting a signal from a smart phone or other hand-held device. Although the participant may not be actively volunteering content, such as logging into a Geoweb environment and adding a contribution to a map, they are volunteering to contribute their geo-information. A well-known case of passive contribution is Google Maps application that employs user-authorized GPS information to crowdsource traffic information [42]. It is important to note that active and passive content is not mutually exclusive. OpenStreetMap, for example, relies on passive contributions when a participant uses GPS tracking to map a road, and relies on active contributions to clean the GPS recordings and add relevant attribute data [12].

In many projects, a well-defined methodology for generating participation increases the likelihood of volunteer contributions. Thus, a major consideration related to participants is the media or promotional strategy employed. In addition to social media as an obvious avenue for promotion, combining web outreach with more traditional media, including radio and newspapers, has proven to increase the reach of a project. For example, RinkWatch organizers observed spikes in participation on their website during promotional campaigns and most notably, when the project was picked up by the local newspaper and national radio [43]. Because of the variability within VGI systems, suitable media strategies are contingent upon the project at hand. Although there is not yet an established methodology for generating participation in VGI systems, purposefully devising a participation strategy could lead to a greater understanding of the type of VGI created.

4.3. Technical Infrastructure: Hardware, Software, and the Geoweb

A technical infrastructure supports the creation of VGI, and each system depends on a unique array of hardware and software components. The combination of technical infrastructure deployed ultimately depends on the type of VGI desired, and varies greatly across projects. VGI systems hardware can include server and client computers, and location-enabled devices, such as GPS units and smart phones. The software component can include proprietary and open-source platforms, such as ArcGIS Online (e.g., RinkWatch) or Ushahidi, respectively. There are also two sides to the technical infrastructure: the user interfaces or client-side architecture, and the developer or server-side architecture. OpenStreetMap, for example, relies on navigation (e.g., GPS), desktop computer, and server hardware, and dozens (if not hundreds) of software options (for more, see the OSM wiki [44]).

The compilation of hardware and software that enable web mapping is more commonly understood as the Geoweb, a collection of online location-enabled services and infrastructure. Initially limited to a one-way flow of information from producers to users, the Geoweb evolved to be participatory, enabling a two-way flow of information and thus facilitating the production of VGI [7]. The Geoweb can provide the user interface for the collection of VGI. However, not all Geoweb infrastructures are capable of collecting VGI; similarly, not all VGI is collected by way of the Geoweb. One notable advantage of the Geoweb is the layers of geo-information that support the mapping interface, which provide geographic context and allow contributors to identify the relevant geographic area (*i.e.*, seed content).

The technical infrastructure employed also dictates the functions available to create and manage VGI. Although there are a host of functionalities within the spectrum of VGI systems, we define the main functional groups (in analogy to GIS) as input, management, analysis, and presentation. An example of the technical infrastructure supporting the collection of VGI is the Ushahidi platform; an open-source self-contained Geoweb tool with customizable crowdmapping options. Initially designed to facilitate the sharing of information during the Kenyan election crisis, it has been repurposed thousands of times to gather a diversity of spatial information from the crowd [19].

Zook *et al.* [14] profiled Ushahidi and three other web-based mapping services (CrisisCamp Haiti, OpenStreetMap, and GeoCommons) that were deployed to crowdsource disaster relief during the 2010 Haitian earthquake. The Ushahidi platform demonstrates the unique data input options, including text messaging (short message service, SMS) and Twitter, which allow project initiators to gather local, on-the-ground knowledge [14]. Beyond the input functions, the Ushahidi platform also offers functionality for management (e.g., administrator approval of participant contributions), analysis (e.g., contributor statistics), and presentation (e.g., interactive web map) of the VGI within the technical environment. With an abundance of hardware, software, and Geoweb considerations and combinations available for VGI systems, coupled with an array of functional options, the technical infrastructure needs to be evaluated on a system-by-system basis.

5. Discussion

Through this research, we have come to understand VGI systems as a set of components that help tackle the increasingly complex task of creating VGI. In addition to providing a novel source of geographic information, the system that drives the creation of VGI is, in itself, collaborative. Crowdsourcing "is about creating fluidity in data sharing and collaboration by breaking down barriers in access to technology and participation through the web, open standards, and simplified interfaces" [14]. Thus, beyond another mechanism for generating (geo-) information, akin to a survey, there is the added benefit of fostering collaboration and participation. The following sections explore the collaboration and participation enabled by VGI systems, as well as provide a critical assessment of issues associated with the implementation of VGI systems.

5.1. VGI Systems as a Mechanism for Collaboration and Participation

There is a long history of government and decision-makers relying on a broader public to participate in and provide valuable information to aid decision-making. Arnstein [45] identified a ladder of citizen participation to typify the extent of citizen power within the participation process associated with federal social programs back in 1969. Later, in geographic information studies, Public Participation GIS (PPGIS) responded to the need to develop a collaborative and partnered approach to GIS [46]. Furthering the goals of PPGIS, participation on the Geoweb is bringing together diverse stakeholders, both professionals and the public alike, representing the convergence of spatial information and technologies with digital media [47]. The participatory Geoweb, in some instances, seems to be achieving a higher rung on Arnstein's [45] ladder of citizen participation than PPGIS because the public can achieve greater control over the system.

Expanding on the participation enabled by the Geoweb, VGI represents a social transformation in the way data can be collected and shared. Web-based participation and the production of VGI are supporting novel types of collaboration [48]. The participatory nature of VGI is demonstrated through the plethora of VGI projects that employ Geoweb tools to collect data from actively engaged citizens and groups [49]. For example, the MapChat tool [50] was "developed to facilitate Web-based interaction between individual citizens and groups interested in discussing issues of local spatial relevance." Similarly, Rinner and Bird [51] and Cinnamon and Schuurman [52] used a participatory approach to collect and map observations and opinions related to sustainable neighbourhood planning and public health, respectively.

However, it is important to note that not all VGI systems are participatory. While active contributions can be considered participatory, passive contributions do not require the same level of engagement from volunteers. Rather, content is volunteered by consent, rather than active participation. Given this distinction between active and passive contributions, we are more confident stating that VGI systems are collaborative but not necessarily participatory. VGI systems support a distributed process, where tasks are outsourced to a diverse network of individuals and institutions, enabling a wider group to collaborate in information creation and knowledge sharing [53].

Owing to the distinction between active and passive contributions, how VGI systems fit into the PPGIS paradigm is still to be fully understood. PPGIS emerged from critiques of GIS in the 1990s, calling for more inclusive use of GIS that engages and empowers the public while developing more sustainable community-driven GIS practices [28,46]. Tulloch [54] explored the extent to which VGI and PPGIS demonstrate overlapping boundaries, and Hall *et al.* [50] later concluded that it is more constructive to view those boundaries as an intersection, rather than a division. Although it seems to follow that VGI and PPGIS are not synonymous, Elwood [55] emphasized that PPGIS can offer a productive framework to motivate VGI research.

5.2. Critical Assessment of Collaboration and Participation within VGI Systems

Since VGI systems can engage the public in collaborative and sometimes participatory ways, it is important to step back to look at the fundamental issues raised by their implementation. The creation of VGI lies at the intersection of technology and society [18,56]. Thus, VGI systems have not only technical, but also social and political ramifications [50]. Discussions surrounding the implications of VGI are already in progress, with a growing body of literature related to credibility [3], uncertainty [57], privacy [58], the data-divide [52], and contributor motivations [17]. In response to the critical appraisal of the inherent issues that come with an evolving system, Mooney and Corcoran [59] counter that the risk of obtaining a fragmented dataset is trumped by the collaboration it can generate.

The capacity of VGI to democratize the creation, use, or dissemination of geographic information is also an important consideration. Haklay [60] affirmed that, "a concerted effort is required to integrate new groups in society in the design and development of technological objects and systems and an ongoing effort to reach out to those who are under-represented". Although there are inherent issues in the democratization of VGI, or what Haklay [60] referred to as the delusion of democracy, Hardy *et al.* [27] stressed the importance of working collaboratively, which can act as a process of empowerment. Poore and Chrisman [61] explored a social theory for the production and use of GIS; similarly, we need to continue to critically consider the production of VGI systems, while addressing the fundamental issues instigated by their use.

6. Conclusions and Future Research Directions

This paper presented an investigation into the creation of VGI from a systems perspective. VGI itself is understood as a crowdsourced geographic information product, while VGI systems enable the creation of VGI. The VGI system framework breaks down the process of creating VGI into three connected components: the underlying project, the participants, and the technical infrastructure. By identifying these primary components, and the considerations within each one, those initiating VGI systems are better able to make informed decisions on the system design, which will ultimately influence the outcomes, whether the desired outcome is to generate new geographic information or promote greater collaboration. Overall, VGI has the potential to add to our collection of maps and spatial data and serve as an information source that can enrich our research programs. VGI systems, then, should be viewed as a method to harness the crowd and connect us to the phenomena we are most interested in studying.

There is more to add to this conversation. As concluded by Hardy *et al.* [27], "research on VGI production is a nascent area with many unexplored avenues." To date, VGI remains largely untapped as a resource for exploratory and analytical research [13]. Now that we have established a conceptual framework for the many moving parts that make up VGI systems, we need to evaluate how existing projects apply the components and functions within the framework. Adding to Beaudreau, Johnson, and Sieber's [16] research on strategic choices made when developing Geoweb applications, we need to evaluate the strategic choices made during VGI system development, and the impact those choices have on the resulting VGI.

Next, within the VGI systems framework, we did not address temporal considerations. Recent research by Resch [62] emphasized the importance of incorporating (near) real-time collection of observations and measurements from both people as sensors (or what we describe as active) and collective sensing (passive) networks. Future work could explore incorporating sensor networks into VGI systems to enable real-time monitoring. Finally, it is necessary to explore Geoweb environments that are capable of supporting the collection of VGI. While Ushahidi and OpenStreetMap are good examples of Geoweb platforms that support VGI systems, the increasing interest in crowdmapping from public, private, and non-profit sectors necessitate a more strategic review of the tools readily available to support VGI systems. It is only once the system is understood that we can better implement VGI as a viable approach to address the host of geographic problems that may arise in the future.

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Author Contributions

Victoria Fast and Claus Rinner conceived the concept of VGI systems, and Victoria Fast developed the framework and wrote the manuscript with input from Claus Rinner.

Conflicts of Interest

The authors declare no conflict of interest.

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