

# Chapter 18

## Citizen Science in Support of Digital Earth



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**Abstract** Citizen science can be thought of as a tremendous catalyst for making Digital Earth a participation model of our world. This chapter presents a wide overview of the concept and practice of citizen science in terms of the technologies and social impact. Definitions of citizen science and various existing approaches to citizen involvement are described, from simple contributions to projects proposed by someone else to the design and planning of science as a bottom-up process. To illustrate these concepts, the relevant example of OpenStreetMap is described in detail, and other examples are mentioned and briefly discussed. Social innovation connected with citizen science is focused on to highlight different levels of direct citizen contributions to scientific research and indirect effects on academia, and studies driven by new questions that may support responsible research and innovation (RRI), governments and public administration in making better informed decisions. Despite its growth and success in relatively few years, citizen science has not fully overcome a number of persistent challenges related to quality, equity, inclusion, and governance. These themes and related complex facets are discussed in detail in the last section of the chapter.

**Keywords** Citizen science · Digital earth · OpenStreetMap · Social innovation · Public engagement

### 18.1 Introduction

The Digital Earth vision has evolved from a digital replica of the earth that enables knowledge sharing and simulation (Gore 1999) to a blending of our physical world with digital representations of past, present and possible future realities (Goodchild

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et al. 2012; Craglia et al. 2012; Ehlers et al. 2014). Digital Earth thereby provides innovative ways of interacting with our real and virtual environments. These interactions support different forms of decision-making and enable new approaches of data and knowledge cocreation and facilitate dialogue between conflicting communities (Ehlers et al. 2014). This chapter is dedicated to the possibilities for active contribution that Digital Earth offers citizens, with a special focus on the relationships between Digital Earth and public participation in scientific research (also known as citizen science).

First, central definitions for citizen science, crowdsourcing and volunteered geographic information (VGI) are elaborated. A detailed analysis of a crowdsourcing and VGI application (OpenStreetMap—OSM) provides concrete practical insights on the roles of communities and institutions, technical considerations, and data quality. Following this example, the view is widened to other approaches and categories of citizen science and their relationship to Digital Earth. Additional considerations are taken into account and briefly expanded to wider concepts such as social innovation and public engagement. The chapter concludes with a summary and lists central challenges for future research.

This chapter addresses citizen science broadly, but additional information about citizen science in the European context is presented in Chap. 20. Citizen science addresses the direct and self-conscious participation of people (citizens) in scientific research—which makes it considerably different from passive contributions to research that are carried out by third parties, for example, in the case of social media analysis (see Chap. 12).

## 18.2 Definitions

To fully understand the value and potential impact of citizen science, it is necessary to consider at least three relevant phenomena of the last twenty years. The first is Wikipedia, the free wiki encyclopedia, which was created in 2001 (Kock et al. 2016). Just over a decade later, in 2013, it had become such a successful enterprise that an asteroid was named after it (Workman 2013). Wikipedia currently boasts approximately 79 Million registered users and is probably the most widely known and used encyclopedia. By definition, an encyclopedia is a narrative model of the world that includes all human knowledge, and had always been written by scholars. As a result of new technology and the collaboration of volunteers (who are not necessarily scholars), Wikipedia has become the largest encyclopedia, written in a few short years.

A second example is the Global Biodiversity Information Facility (GBIF), an operational system that is very relevant for the environmental challenges addressed by Digital Earth. The GBIF was founded in 2001 upon the recommendation of the Biodiversity Informatics Subgroup of the Megascience Forum and subsequent endorsement by the Organisation for Economic Co-operation and Development (OECD) science ministers (GBIF 2011). Today, the GBIF has evolved into a renowned data

infrastructure and single access point for biodiversity data (Robertson et al. 2014), much of which originates from volunteer citizen scientists (Chandler et al. 2017). According to its website, the GBIF provides access to almost 45 thousand data sets, including more than 1.3 billion species observation records. This tremendous source of knowledge has led to the publication of more than three-and-a-half thousand peer-reviewed scientific publications.

A third notable example is OpenStreetMap project, which is a free map of the world. Before considering the history and success of this initiative, it must be noted that mapping was a prerogative of governments (mainly for military purposes and land taxation) and that, in some countries both then and now, military forces hold the legislated national monopoly on mapping services. The knowledge of the territory and the science of “where” are a way to monitor and control territory. In this context, OSM represents a complete change of paradigm: everybody contributes to mapping the world; the map is free to everybody for every purpose. Created in 2004, OSM has seen success equivalent to that of Wikipedia and approximately 5 million volunteers have contributed to this project. OSM is the largest existing geospatial database. These examples illustrate the social and technological environment in which the concept and substance of citizen science are situated.

Although public participation in scientific achievements has a long history, recent decades have seen greater attention and an impressive increase in the number of people involved. The term citizen science was used in scientific papers in the mid-1990s (Kerson 1989; Irwin 1995; Bonney 1996). The term was first reported in Wikipedia in 2005 and entered the Oxford English Dictionary in (2014). It describes the scientific work done by laypeople often with the collaboration or under the supervision of scientists. (OED 2014).

However, citizen science is a very diverse practice that encompasses various forms, depths and aims of collaboration between scientists and public researchers in a broad range of scientific disciplines. There are different classifications of citizen science projects based on the degrees of influence and contributions of the public.

Shirk et al. (2012) classified projects into different models based on the degree of participation:

- (1) *contributory projects*, which are mostly data collection;
- (2) *collaborative projects*, involving data collection and project design refinement, data analysis, and disseminating results;
- (3) *cocreated projects*, designed together by scientists and the public, and the public participates in most or all of the steps in a scientific project or process; and
- (4) *collegial projects*, developed by noncredentialed individuals conducting research independently with varying degrees of expected recognition by scientists.

Haklay et al. (2018a, b) distinguish projects in three different classes:

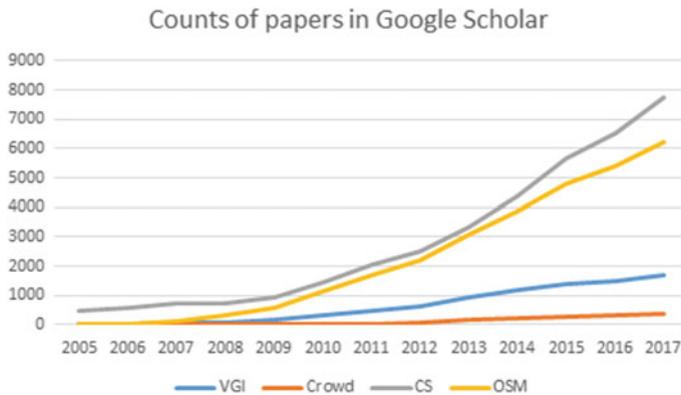
- (5) *long-running citizen science*, which are traditional projects similar to those run in the past (Kobori et al. 2016; Bonney et al. 2009);
- (6) *citizen cyberscience*, strictly connected with the usage of technologies (Grey 2009), which can be subclassified as follows:

- (6.1) *volunteer computing*, where citizens offer the unused computing resources of their computers;
  - (6.2) *volunteer thinking*, where citizens offer their cognitive abilities for performing tasks that are difficult for machines; and
  - (6.3) *passive sensing*, where citizens use sensors integrated into mobile computing devices to carry out automatic sensing tasks.
- (7) community science, involving a greater commitment of citizens in designing and planning project activities in a more egalitarian (if not bottom-up) approach between scientists and citizen scientists (Jepson and Ladle 2015; Figueiredo Nascimento et al. 2014; Breen et al. 2015). This can be divided into the following:
- (7.1) participatory sensing, where citizens use the sensors integrated into mobile computing devices to carry out sensing tasks;
  - (7.2) Do-it-yourself (DIY) science, in which participants create their own scientific tools and methodology to carry out studies; and
  - (7.3) civic science, the science built on the needs and expectations of the community (Haklay et al. 2018a, b).

In addition to citizen science, the term crowdsourcing (or geo crowdsourcing or crowdsourcing geographic information) is used. The general term (with no geographic declination) was coined in 2005 to describe the outsourcing and spreading, generally through an open call, of a job previously made by a worker to the crowd, i.e. a large group of people (Safire 2009). When related to the location, it refers to a new source of geographic information that has become available in the form of user-generated content accessible over the Internet.

Citizen science considers the process as a whole, and attention is paid to the community of contributors. Geo-crowdsourcing also considers the contributed data and their condition of usage. In some cases, the contributors (e.g., when they are using Twitter, Instagram, Facebook or Google traffic) are unaware that they are contributing to a project: they simply want to communicate with friends and relatives (in the former cases) or to find directions and traffic conditions (in the latter case). Thus, they are treated more like moving sensors than human beings. The person is an appendix of the sensor and not vice versa. The user-generated data can be provided as open to everybody or (more often) used by the service provider for analytics for diverse purposes. For instance, in the case of Google, one advantage could be to build a powerful database for self-driving cars.

Considering the (re)use potential of citizen science contributions, issues related to fitness for the purpose and data quality should be discussed. Those who are new to the field of citizen science often doubt the quality of the results produced. However, it has been shown on numerous occasions that citizen science can deliver high-quality information (Kelling et al. 2015; Bell et al. 2015; Senaratne et al. 2017), and provide new knowledge that could not be gathered with any other approach (see, for example, Walther and Kampen 2017). Literature on data management, quality assurance, and



**Fig. 18.1** Google Scholar results for papers matching the terms ‘volunteered geographic information’, ‘geo crowdsourced’ and ‘crowdsourced geographic information’ (Crowd); ‘citizen science’ (CS); and ‘openstreetmap’

the provision of accompanying metadata is available for a wide variety of application fields (see, for example, Bastin et al. 2017, 2018; and Williams et al. 2018).

Notably, the term “citizen science” is not uncontested in the sense that the term “citizen” evokes a normative role of what it means to belong to and act as a member of a particular social group, including implications of what it means to participate in public science projects for “noncitizen” residents (e.g., Woolley et al. 2016). These perspectives are not just rhetorical, as labels matter in practical terms if actors such as refugees or resident immigrants participate in contributing. In contrast to the previous terms, volunteered geographic information highlights the active attitude of people when contributing data. VGI was proposed in 2007 and includes examples such as WikiMapia and OSM.

To evaluate the rapid evolution of terms related to user-generated content, Fig. 18.1 shows Google Scholar results for references that match the terms ‘volunteered geographic information’; ‘geo crowdsourced’ and ‘crowdsourced geographic information’; ‘citizen science’; and ‘openstreetmap’ are reported. The growth over time is impressive. Moreover, the success of a single project, OSM, is also relevant and deserves more thorough exploration within this chapter.

### 18.3 Digital Earth Technologies for Citizen Science

The previous definitions allow for specification of the possible roles of Digital Earth as an enabler of citizen engagement—especially for citizen science. Digital Earth technologies provide citizens with advanced sensing devices (see the Chap. 11 on the Internet of Things) and mobile applications that allow for data collection by anyone who possesses a smart device or acquires a sampling tool. In addition, the use

of existing social media platforms helps people collect data about a wide range of phenomena, including natural hazards, crop production and the spread of diseases. Following the Digital Earth vision, these data streams can be interconnected and real-time deliveries can be assimilated with data from complementary sources such as authoritative measurement stations or remote sensing imagery. Accordingly, data contributed by citizen scientists might help improve models about our environment (e.g., for air quality, water quality or extreme events) by ground truthing or validation—or by providing additional data points that are used for improved geographic predictions or forecasting. These possible contributions of citizen science could be considered the Digital Earth Nervous System—DENS (De Longueville et al. 2010).

The concept of VGI fits well into this kind of Digital Earth support for citizen science. VGI platforms can be viewed as a part of the Digital Earth infrastructure, but the uptake and use of VGI in combination with data from other sources are essential. In addition, crowdsourced data directly connects to this view, as data is passively collected before it is used as part of a dynamic and intertwined flow of stimuli and contextual information that is integrated into a gigantic knowledge base that keeps the pulse of our planet. User location information is a direct and obvious example. While protecting privacy, valuable information can be derived that, in combination with other data sources, can provide valuable decision support. For example, real-time locations can help optimize green transport or save lives in a crisis situation by individually guiding evacuees along safe routes or sending rescue teams to locations where they are most needed.

Transitioning from pure data collection, Digital Earth technology can also help other dimensions of citizen science. Once data is collected, Digital Earth could provide access to artificial intelligence that could be used for quality control, which is frequently demanded in citizen science. In this area of citizen science activities, automated algorithms can help assess the probability of a certain measurement or observation. For example, automated image recognition (based on machine learning) could analyze pictures of plants recorded by a participant and suggest the most likely species. This could also take into account when and where a record was made. Similarly, an algorithm might calculate risks based on findings from citizen science. For example, it might calculate the risks associated with a possible new sighting of an invasive alien species in an area where it has not been reported yet. Thus, automated support can help overcome the current difficulties in finding enough expertise to validate species information.

With respect to the next possible area of citizen science activities, Digital Earth technologies—especially visualizations—can help people analyze available data sets and display them in context. Offering multiple visualization techniques and map-based integrations with related information can help explore the latest information available and identify possible correlations or other dependencies. Visual approaches (with maps and graphs) might also help communicate the scientific findings to a particular audience, even audiences with low literacy rates. Interactive story maps can be created to convey core messages in combination with the supporting data.

Through this highly dynamic situation in which data is contributed and can be used for modeling and storytelling in real time, the most advanced possibility of

Digital Earth as an enabler for citizen engagement can be reached. With this fully integrated view, any individual or group could access a Digital Earth representation on their preferred device to experience a certain situation, simulate possible decisions, and immediately assess the possible impacts. Such an advanced functionality can facilitate debates between any physically connected or remote group of people. In such settings, knowledge can be cocreated and experimented with and situations can be reassessed. In such a way, Digital Earth can create a safe space of interaction and cocreation to arrive at group decision-making before taking concrete actions in the real world.

Concerning the use of citizen-contributed knowledge, Digital Earth provides another essential enabler, namely, the possibility to track and trace data through processing chains and its use for decision-making. This traceability is fundamental to provide feedback to citizen scientists about the use of their data.

## 18.4 OpenStreetMap

### 18.4.1 *Social Ecosystem*

OpenStreetMap is one of the most well-known and researched examples of a volunteered geographic project in which data is crowdsourced at a global scale. Many people consider OSM to be an object or to be the free map of the world, which is contributed by volunteers and is available for everyone, being based on an open-content license (OpenStreetMap Wiki Contributors 2017). However, it is also commonly thought of as a data platform where as many as 5 million users contribute, edit, download and assess the data that are shared. As opposed to a map or platform, many others consider it an “online project,” a perspective that refocuses attention on the efforts to create the map instead of the map or database itself. Others, who are often part of the project, speak of “OpenStreetMap” as a community, emphasizing the set of actors responsible for its existence. OSM should be thought of as a community of communities, (Solís 2017) in the sense that this community is increasingly diverse and incorporates the motivations of many different groups with varied approaches to OSM. Together with the technology products and systems, they form a complex sociotechno ecosystem that operates as a multiscalar network (Vespignani 2009). There are fluidities in the kinds of actors that participate in OpenStreetMap, which can be generally categorized and thought of (see Table 18.1) using typical descriptors such as sector-based characteristics: private enterprise, for-profit entities, nonprofit or civil society, and government or public institutions at various scales. It can also be categorized by community through their modality of engagement with OSM: those who directly create map data, locally and/or remotely, entities that add value through map-based services and third-party open source software, algorithms, scripts, or materials, consumers of the data, including individual users exporting for a discrete use, companies that run their navigation or social media platforms live

**Table 18.1** Dimensions of characterizing OpenStreetMap as a community of communities

Sector-based categories	Modality of engagement	Social-based categories
<p>Nonprofit/civil society</p> <ul style="list-style-type: none"> <li>• Humanitarian Sector (e.g., International Federation of Red Cross/Red Crescent)</li> <li>• Local nonprofit entities</li> </ul> <p>Education/Academic Sector</p> <ul style="list-style-type: none"> <li>• K-12 teachers</li> <li>• University students/faculty</li> </ul> <p>Government/Public Sector</p> <ul style="list-style-type: none"> <li>• Local municipalities (e.g., World Bank’s Open Cities)</li> <li>• State /Regional governance (e.g., Transport planning entities)</li> <li>• National agencies</li> <li>• Multinational (e.g., World Bank’s Open Cities)</li> </ul> <p>Private Industry/For-Profit or Commercial Sector<sup>a</sup></p> <ul style="list-style-type: none"> <li>• Information Technology and Services</li> <li>• Computer/GIS Software (e.g., MapBox,</li> <li>• Internet Companies (including Social Media)</li> <li>• Use-Driven (e.g., Restaurants, Construction, Retail, Health Care)</li> </ul>	<p>Data contributors</p> <ul style="list-style-type: none"> <li>• Local mapping (e.g., Craftmappers)</li> <li>• Local and remote (e.g., YouthMappers)</li> <li>• Remote mapping</li> <li>• Dataset uploading (e.g., road networks)</li> </ul> <p>Providers of Map-based Services or Value Added to OSM<sup>b</sup></p> <ul style="list-style-type: none"> <li>• General (e.g., Geofabrik, OpenTopoMap)</li> <li>• Functional Providers                             <ul style="list-style-type: none"> <li>– <i>Edit/Compare</i> (e.g., <i>OSMCompare</i>)</li> <li>– <i>Live/real-time edits</i> (e.g., <i>Show me the way</i>)</li> <li>– <i>Quality Assurance</i> (e.g., <i>Keep Right, Osmose</i>)</li> <li>– <i>Export</i> (e.g., <i>Walking Papers, Field Papers</i>)</li> <li>– <i>3D Rendering</i> (e.g., <i>OSM Buildings</i>)</li> <li>– <i>Routing</i> (e.g., <i>OpenTripPlanner</i>)</li> <li>– <i>Interaction</i> (e.g., <i>Wikipedia overlay</i>)</li> <li>– <i>Services</i> (e.g., <i>OSMNames, OSM Landuse, OpenFireMap</i>)</li> </ul> </li> <li>• Thematic Providers                             <ul style="list-style-type: none"> <li>– <i>Biking, geocaching, hiking, sport</i></li> <li>– <i>Art, history, archaeology, monuments</i></li> <li>– <i>Public Transport</i></li> <li>– <i>Other</i></li> </ul> </li> <li>• Educational (e.g., TeachOSM, LearnOSM)</li> </ul> <p>Consumers<sup>c</sup></p> <ul style="list-style-type: none"> <li>• As Base Maps (e.g., Facebook, Wikipedia, Weather.com, Snapchat)</li> <li>• As Data (e.g., Pokémon Go)</li> <li>• As Media (e.g., films and TV) <sup>d</sup></li> <li>• Internal systems (e.g., Uber)</li> </ul>	<p><b>Purpose-driven</b> (e.g., Humanitarian OpenStreetMap Team)</p> <p><b>Identity-focused</b> (e.g., GeoChicas)</p> <p><b>Place-based</b> (e.g., Tanzania Development Trust)</p>

<sup>a</sup>The OSM Wiki lists 80 entities in this category ([https://wiki.openstreetmap.org/wiki/Commercial\\_OSM\\_Software\\_and\\_Services](https://wiki.openstreetmap.org/wiki/Commercial_OSM_Software_and_Services)); iDataLabs identified 281 <https://idatalabs.com/tech/products/openstreetmap>

<sup>b</sup>Summarized with counts from OSM Wiki ([https://wiki.openstreetmap.org/wiki/List\\_of\\_OSMbased\\_services](https://wiki.openstreetmap.org/wiki/List_of_OSMbased_services))

<sup>c</sup>Adapted from [https://wiki.openstreetmap.org/wiki/Major\\_OpenStreetMap\\_Consumers](https://wiki.openstreetmap.org/wiki/Major_OpenStreetMap_Consumers); see also [https://wiki.openstreetmap.org/wiki/They\\_are\\_using\\_OpenStreetMap](https://wiki.openstreetmap.org/wiki/They_are_using_OpenStreetMap)

<sup>d</sup>More detail at <https://wiki.openstreetmap.org/wiki/Films> and [https://wiki.openstreetmap.org/wiki/TV\\_series](https://wiki.openstreetmap.org/wiki/TV_series)

with underlying OSM data, and governments that download data for comparison in official geodataset validations. These categories are not mutually exclusive, as a single individual or organization often operates in more than one sector and engages in multiple modalities over the course of interaction with OSM, and thus, understanding this social ecosystem is highly complex. Furthermore, in the construction of communities in the OSM community, the way that social bonds formed around purposes (e.g., the Humanitarian OpenStreetMap Team's humanitarian mission), identity (e.g., YouthMappers academic actors and GeoChicas), or place must also be considered as another dimension of connectedness.

For example, one set of these communities that has experienced tremendous growth recently are the communities that engage with the OSM community with an express humanitarian or development purpose. Beginning with the incorporation of the Humanitarian OpenStreetMap Team (HOT) in the international civil society sector, which formed in the immediate aftermath of the 2010 Haiti earthquake, various groups have begun to distinguish and highlight the purposeful creation of volunteered spatial data rather than the creation of open data for its own sake. HOT has since registered as a nonprofit organization and has a structured governance comprising a core group of voting members that support a larger set of global volunteers with specific local and remote mapping campaigns. The Missing Maps project was later founded by HOT, Medecins Sans Frontieres/Doctors Without Borders, and the American and British Red Cross agencies. Similar to other purpose-driven efforts, this project aims to map the world's most vulnerable people. It has since grown to include participation from other organizations, and has developed a presence as a related OSM community in its own right, with close ties to HOT.

The participation of university actors intersecting with this purposefully humanitarian community was present, even if not consolidated, from the outset; in 2014, the academic community developed YouthMappers to explicitly bring together and nurture the community of students and their faculty that operate within and together with the broader set of OSM communities around youth-based identities. Founded by faculty from Texas Tech University, The George Washington University, and West Virginia University, with support from the US Agency for International Development's GeoCenter, and now administered by Arizona State University, YouthMappers organize as chapters on university campuses, run by student leadership under the guidance of university professor mentors. Chapters apply for recognition by the YouthMappers steering committee as existing student organizations that affiliate or as newly formed student-led groups. The network encourages students to participate in global remote campaigns of USAID, HOT and other humanitarian groups, develop and implement local mapping campaigns that create and use geospatial data for needs at the local or national levels, and seek and provide resources for students to expand their volunteerism through internships, leadership development, and research fellowships. Activities center on the concept of not just building maps, but building mappers and promoting exchange and solidarity among student peers across continents. Campaigns create data directly for development programming and seek to promote greater inclusion and participation of students from countries in development as well as female mappers via the #LetGirlsMap campaigns. By late 2018, the

network had grown to 143 campus chapters in 41 countries, linking more than 5,000 OSM volunteers. Although the YouthMappers purpose falls along the humanitarian or development realm, where activities are defined as contributions to global targets such as the UN Sustainable Development Goals (Solís et al. 2018), the community has a strong identity-based composition, as participants are students in universities and learning through the mapping experience carries significant import (Hite et al. 2018; Coetzee et al. 2018). Similarly, consolidating community space for particular actors within the social ecosystem of OSM, GeoChicas formed at the State of the Map Latin America conference in 2016. GeoChicas is a group of women who volunteer map in OSM and work to close the significant gender gap within the OSM community. Their activities promote mapping campaigns that address women's issues such as mapping gender violence and promote female participation by creating more training spaces for women and ensuring harassment-free mapping. They also raise awareness of OSM technical matters such as tagging in support of women and girls in the OSM map and data platform.

An impressive example of a place-based community is Crowd2Map Tanzania, which was established in 2015 to improve the rural maps of Tanzania to fight female genital mutilation and improve development of the region. The community of volunteers creating OSM data in the context of Crowd2Map intersects with all of the above communities (HOT, Missing Maps, YouthMappers chapters in Tanzania, GeoChicas), especially local residents. This demonstrates how the communities of OSM engage and create a multiplicity of volunteer impacts within the social ecosystem of OSM.

End-user communities are important in shaping OSM institutionally and should not be underestimated because they are not actively involved in the construction and constitution of OSM. This community is much more difficult to track and assess, since OSM is free and open for anyone to use. In addition to the user-contributor communities noted above, governmental entities, including at the very small scale such as local civil protection agencies, local disaster response units, and local businesses, are using OSM data in their functions. At the country scale, actors such as national mapping agencies incorporate OSM data with official data sources, especially in times of urgency such as disaster response, e.g., the earthquake in Ecuador in 2016 where OSM data supplemented with official data was used to validate or gap-fill missing data. Multinational organizations such as the World Bank span local to global categories, considering the city-level action that work such as the Open Cities Project supports. The participation of governments and the public sector is significant due to the unique challenges for such actors and communities of actors for adopting crowdsourced geographic data, despite its potential value. The landscape of participation among governments has been highly dynamic in recent years, as the reliability and accuracy of volunteered data has been increasingly seen as appropriate for (to inform or accompany) official use. Obstacles remain; most recently, Haklay et al. (2018a, b) conducted qualitative comparative analysis of multiple use case studies to identify success factors for users with governance missions. The use cases included activities such as base mapping or focus on a particular area of interest, generating updates to authoritative datasets, upgrading public services, policy development or

reporting, and disaster management or response. The authors find that individual champions and change agents are critical, organizational business models are necessary, technical capacity is essential, and conceptual buy-into acceptance of issues such as uncertainty, collaboration, and new ways of serving the public good must accompany this community's involvement in open Digital Earth landscapes.

On a broader scale, the user policies and open license of OSM provide a public good that commercial and for-profit enterprises are keen to leverage or even support in some cases. This is unsurprising in a rapidly growing context where geospatial information is valued as a multibillion dollar industry (Eddy 2014). With an Open Database License, adopted in 2010, OSM is enabled and simultaneously constrained for use in the private sector, and thus, calls for more "business-friendly" approaches are not uncommon (Gale 2015). The range of themes, applications, and industries in this sector are broad and growing and are difficult to comprehensively capture. The inclusion of the OSM layer as a base map in widely used proprietary geospatial software (such as ArcGIS Online) and examples of OSM powering services such as Craigslist and The Weather Channel show that the public may be consuming this volunteer-contributed content base without much awareness. Passive users are less affected by licensing frameworks than actors that seek to build services or add value and comingle data sources and types, who must contend with share-alike clauses. Explicit commercial contributors to the OSM ecosystem include companies that offer commercial OSM software and services that expressly add value to OSM in terms of architecture, analysis, visualization, and/or consulting on a multinational, regional or, very frequently, worldwide scope. Although Google Maps still dominates web mapping, OSM has captured approximately 0.1% of the market share of web mapping, which is impressive for a community that is completely powered by volunteer contributors (iDataLabs 2017). Top industries include IT software and services and Internet companies, with revenues reaching the \$200 M range. Nearly one third of companies have fewer than 10 employees, and Germany, the US, France, and the UK currently account for 40% of estimated formal business activity. However, as OSM grows, its presence in lower-to-middle-income countries (LMICs) is increasing, as the ability to access scarce geospatial data and location-based information is gaining traction as an international economic development strategy in the context of digital development (USAID 2018). Open geospatial data such as OSM powers businesses in real estate, transportation, agriculture, and technology in 177 countries (Bliss 2015), and the corporate sector sees OSM as a priority in the open source community (Moody 2018). The increasing presence and influence of large-scale commercial or for-profit entities within the OSM community of communities is changing the countenance of the social ecosystem in ways that are sometimes contradictory and contested. The OSM Foundation, as the nonprofit entity that exists to protect, promote and support the project (though it does not own the data), continues to navigate this complex array of actors, visions, uses, and contributors in a dynamic landscape of volunteered geographic information.

## 18.4.2 *Technological Ecosystem*

One of the main reasons for the success of OSM is that the technology behind the project allows for everybody to contribute regardless of their level of expertise. More than a simple geospatial crowdsourced database, OSM is an ecosystem of data, software and web-based information stores. The tools and systems developed by different actors in the social ecosystem of OSM are generally characterized as being free and open source, i.e., available for further development by other people in the community. Access to the different applications is often possible using the same personal account as that for the OSM platform.

The geometric OSM data model is easy and simple, based on simple data types such as nodes, ways (polygons and polylines) and relations (logical collections of ways and nodes). The semantic model, i.e., the nonspatial attributes associated with the geometric objects, is more complex but services such as the taginfo (OpenStreetMap Contributors 2018a) help contributors to choose the most appropriate tags (key/value pairs). As an example, the most basic and common representation for a building is by means of a way and the pair: “building = yes”.

After signing up for free access to OSM (OpenStreetMap Contributors 2018b), users can begin contributing by mapping new data in OSM or editing existing data stored in the OSM geospatial database. In December 2018, there were more than 5 million users (OpenStreetMap Stats 2018). There are three ways to contribute:

- (1) by physically surveying an area and inserting the information collected by GPS receivers and paper-based tools into the OSM database;
- (2) by digitizing objects into the OSM platform using available aerial and satellite imagery; and
- (3) by bulk-importing suitably licensed geospatial data.

The first two modalities are more generally used whereas the third must be coordinated with the OSM community.

Many guides and tutorials on how to map with OSM are available; excellent examples include those made available by the company Mapbox (Mapbox 2018) and the Humanitarian OpenStreetMap Team (HOT 2018).

Editing and visualization are the two basic functionalities for interacting with the OSM geospatial database. The choices are very broad for both and depend on the exigencies and skill of the user. As the OSM platform has an editing API, many editors have been developed, some with a simplified subset of functionality and others that operate on specific platforms such as mobile technology (OpenStreetMap Wiki Contributors 2018a). The three main editors are iD, which is the default editor for the user when accessing the OSM platform and is meant for beginners; MAPS.ME, which is an app for iOS, Android and BlackBerry designed mainly for travelers, with more than 50,000,000 installations, that provides offline maps and a straightforward editor (Maps.me 2018); and JOSM (Java OpenStreetMap Editor), which is a desktop application popular among expert editors because of its more advanced performance (JOSM 2018).

In addition to enabling individual contributions, the OSM technical ecosystem is designed to elicit and simplify collaboration among contributors. One fundamental tool for this purpose is the Tasking Manager developed by HOT (HOTOSM Community 2018).

The main purpose of this tool is the subdivision of a large area into smaller areas, which require less time and effort to map. Individual contributors work on smaller areas to avoid problems of overlap and confusion. Moreover, the Tasking Manager allows for a second level of contribution: validation of the mapping of other users. Validation is generally done by expert OSM users and consists of verifying the geometric and semantic accuracy of the mapped objects and reviewing the mapping for completeness.

The Tasking Manager has a graphical interface that shows the main characteristics for every project (status, project creator, last updates, difficulty, priority, types of mapping, organization, campaign, and contribution level required) and the map with activity and stats. Figure 18.2 shows the example of Typhoon Ompong: Cagayan and Batanes Structures (task: #5236) as published on 6 October 2018. The map helps contributors know where to edit or validate, depending on their role.

TeachOSM is another site eliciting collaboration that is useful, but not limited, to educators (TeachOSM 2018). It is another instance of the HOT Tasking Manager and is used mostly by the academic and educational community. It provides training documentation and resources that help instructors identify, assign, manage and grade mapping assignments.

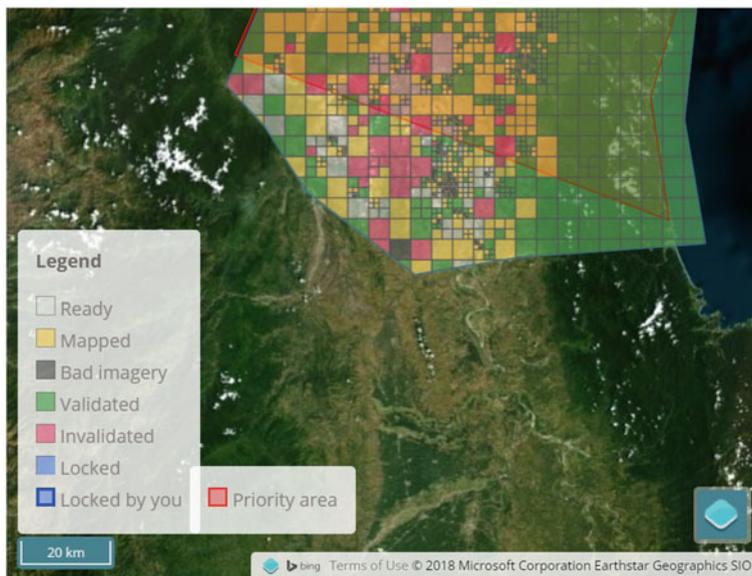


Fig. 18.2 Example of activity and status on the HOT tasking manager

The OSM ecosystem provides many opportunities for collaborating, and the possibilities of using these data are many and various. The license of the project, Open Database License (ODbL), permits free copying, distribution, transmission and adaptation of part or the whole dataset as long as credit is provided to OSM and its contributors. If someone alters or builds upon OSM data, the results must be distributed under the same license.

As noted above, this free and viral license has been pivotal in the development of communities, research, and business around the project. Moreover, it has led to the creation of a very wide range of applications.

Many visualization tools have been created with different sensitivities and needs: rendering for cyclists, transportation maps, rendering for humanitarian purposes, maps of specific collections (hydrants, fire stations, etc.), 3D maps and artistic maps such as those provided by the US company Stamen (see Fig. 18.3).

Data can be downloaded in several ways. The first option is to download in .osm format directly from the OSM geportal by selecting the area of interest and using the “export” button. As an alternative, the Planet.osm (OpenStreetMap Wiki Contributors 2018b) file is released weekly and contains the entire global dataset. It is a big file, almost 40 GB compressed. For the complete time-varying dataset, a full history planet dump is made available at irregular intervals.

For selected downloads, Geofabrik (Geofabrik GmbH Karlsruhe 2018) provides access to continental, national and regional data extracts as OSM raw data or in shapefile format and most of these files are updated daily. The same service is offered by OSMaax (HSR Hochschule für Technik Rapperswil 2018), through which OSM data are downloadable in the most common GIS formats. The HOT Export Tool (HOT

**Fig. 18.3** Stamen watercolor rendering of OSM data (Tiber River in Rome)



2018) creates customized extracts of up-to-date OSM data in various file formats, with the limitation of at most 10 Million nodes.

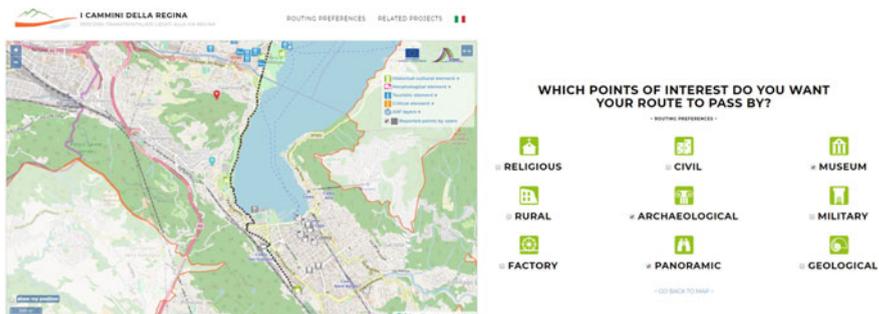
Additionally, there are API calls to directly create, read, update and delete map data for OSM (OpenStreetMap Wiki Contributors 2018c), and this provides software developers and applications with the most up-to-date data available. The Overpass API service (OpenStreetMap Wiki Contributors 2018d) allows clients to send queries using a special API query language or a graphical interface and obtain the requested data (which can be huge). The ecosystem also includes free and open source GIS packages, for instance, QGIS. In this case, a plugin, QuickOSM, allows users to extract customized OSM data.

The availability of the data and this rich technological ecosystem has created opportunities to invent services and applications suited for different aims. In addition to “traditional” routing services (for cars, bikes and pedestrians), there are customizable ones. Among the many examples, Via Regina is a project related to “slow” tourism (Brovelli et al. 2015), i.e., tourism based on environmentally friendly forms of transportation, the appreciation of nature and the rediscovery of local history and cultural identity. Using OSM as a database, customized routes according to the user’s preferred points of interest (religious, civil, museums, rural, archaeological, military, factory, panoramic, or geological) can be shown on the interactive map, as shown in Fig. 18.4 (I Cammini della Regina 2018). Before departure, the user can create a personalized itinerary according to her/his own choices, supported by other information such as the slope of the route and the presence of suitable tourist services (restaurants, hotels) in the area.

Furthermore, many other services unrelated to routing have been created. A detailed list of services is available on the wiki section of OSM (OpenStreetMap Wiki Contributors 2018e).

In conclusion, OSM is a very vital collaborative project with a flourishing and vibrant social ecosystem and a strong technologic support.

One of the main criticisms of this dataset is that, as a collaborative product created mainly by citizens without formal qualifications, its quality has not been assessed



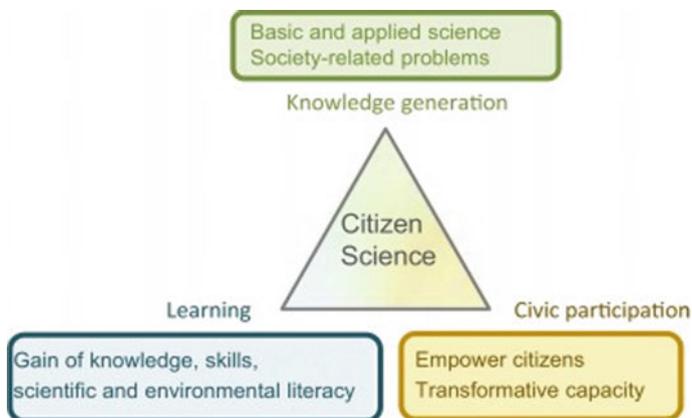
**Fig. 18.4** Routing according to preferred points of interest (via Regina geoportal <http://viaregina3.como.polimi.it/ViaRegina/index-en.html>)

and therefore its usage can be detrimental for some applications. The assessment of OSM is a hot research topic and the majority of scholars have compared the database against authoritative ones. Whereas significant attention has been paid to OSM positional accuracy assessment and completeness, fewer authors have investigated its semantic, temporal and thematic accuracy and consistency (Antoniou and Skopeliti 2015) and none, to the best of our knowledge, have assessed all the elements of data quality. Some scholars have sought alternative quality metrics through “fitness of purpose” tests (Wentz and Shimizu 2018; Solís et al. 2018) in ways that prioritize how the data are used over abstract technical attributes of fidelity. The purpose for mapping has been suggested to influence productivity and quality in surprising ways: humanitarian mappers knowledgeable of the end use of the data may be on par with respect to productivity and error rates relative to mappers who operate without regard to purpose; however, they tend to make more and different *kinds of* errors, although they are more confident in the quality of their work. The implications of this so-called “do good effect”, where new volunteers may think they are doing well just because they are doing good, holds significant implications for tailoring the training and quality control of new mappers motivated by humanitarian mapping purposes (Solís and DeLucia 2019).

It is impossible to draw a unique conclusion about the spatial accuracy and completeness, although recent case studies of OSM have indicated that they are comparable to those of regional-scale official datasets (Brovelli and Zamboni 2018). In other cases, for instance, in some developing countries, OSM is the only available dataset and therefore comparisons are not possible. The activism of the communities and attention paid to validation of the collected data (for brevity, many available tools are not mentioned) gives hope for continuous improvement of this product, as has occurred for other collaborative projects such as Wikipedia. As a practical reinforcement of our idea of “communities of communities” contributing in the scale-up of this resource, the OpenStreetMap community recently issued guidelines (OpenStreetMap Contributors 2019) for groups who are contributing collectively to the resource, making the ethic that quality matters to OSM creators and users more explicit and transparent.

### ***18.4.3 Other Citizen Science Projects: Social Innovation and Public Engagement***

OSM is a flagship example of citizen science. As noted above, although the primary purpose is to collect up-to-date topographic and other spatial data, it has additional benefits such as community building and active citizenship. Turrini et al. (2018) recently described the multiple benefits of citizen science more formally (Fig. 18.5). Their research examined how citizen science contributes to knowledge generation, learning and civic participation. The contributions can be clearly identified for the knowledge dimension, e.g., by the contributed data and quality control of OSM.



**Fig. 18.5** The threefold potential of citizen science (Source Turrini et al. 2018)

With respect to learning, citizen science contributes to scientific literacy and to the improvement of topically related skills, e.g., those related to mapping. In addition, self-organized learning and education networks such as Geo4All (OSGeo 2015) for open geospatial software comprise this dimension. Lastly, civic participation is stimulated and facilitated. The YouthMappers community is an excellent example of this aspect of citizen science, as well as GeoChicas. The latter group adds different perspectives and experiences about conceptions of gender and ways of participation within the OSM community and analyze the roles, representation and participation of women in OSM to find a path of dialogue and close the gender gap. Improved gender inclusion also promises to impact the map and data and, ultimately, the knowledge products and decisions made with it (e.g., Holder 2018).

In addition to these multifold dimensions that materialize with different intensities in all citizen science initiatives, the concept of citizen science covers a much wider set of possibilities for (i) the public to understand and contribute to scientific research; (ii) academia to research new questions and carry out Responsible Research and Innovation (RRI); and (iii) governments and public administration to make better-informed decisions.

The different forms of contributions of citizens to science is likely the most debated and researched topic of citizen science. There are many different categorizations (see, for example, Shirk and Bonney (2015) for an overview), within specific contexts and justifications for existence. The framing introduced by Pocock and others (2017) is the most self-explanatory to describe the relationship to the research process, see also Fig. 18.6.

In addition, the relationship between academia and citizen science has been widely discussed; see, for example, the report of the League of European Universities (LERU 2016) or Mitchell et al. (2017). The form and shape of these discussions clearly depend on the way that citizen science is seen and embraced in different countries around the globe. There is great diversity across cultural regions and between more-

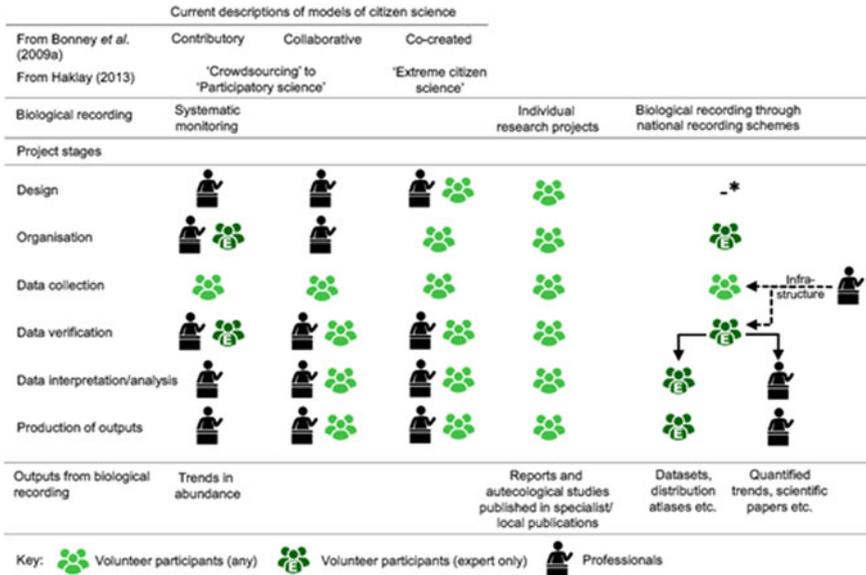


Fig. 18.6 Roy’s categories of citizen science (Source Pocock et al. 2017)

and less-developed countries. It is also closely related to where the funding for citizen science comes from. For example, in Europe, the overarching topics of responsible research and innovation (RRI) and the open science agenda are strong promoters of citizen science—as is the funding of citizens’ observatories in the context of innovative Earth Observation. In the US, citizen science is more often linked to open innovation (Congress.gov 2016).

In regard to the uptake of citizen science by governmental organizations, there are many different approaches (Schade et al. 2017). A possible overall model is summarized in Fig. 18.7. In this framing, the typical elements of citizen science (data gathering, quality control and analysis) are connected to the policy-making process. This imposes a need to provide feedback about the influence on political decisions, and creates an opportunity to consider citizen science to monitor the impacts of those decisions. Such an “accountability cycle” could be imagined at any administrative level, municipalities, regions, nations, macroregions or the entire earth. It can be distinguished by whether the contributing citizen science initiatives are initiated from the top down (i.e., on request by governmental institutions) or bottom-up (i.e., by an active citizenry that wants to raise an issue or challenge a governmental decision). Both approaches have success stories, and they face different challenges. Top-down approaches often have issues about acceptance or community uptake or buy-in. Bottom-up approaches often face difficulty in reaching the relevant decision makers or being taken seriously.

Given the multifaceted nature of citizen science, its relationships to the notion of Digital Earth are manifold. As set forth in the visionary work on the European



**Fig. 18.7** Cyclic value chain of citizen science for policy (Source Schade et al. 2017)

Perspective to Digital Earth (Annoni et al. 2011), the Digital Earth Nervous System (De Longueville et al. 2010), the Digital Earth Living Lab—DELI (Schade and Granell 2014) and views beyond the next-generation Digital Earth (Ehlers et al. 2014), a clear direction of Digital Earth and related research concentrates on the possible contributions of and interrelationships with citizens—and citizen science is a very promising way to progress in this direction on local and global levels.

Digital Earth can be seen as an enabler of citizen science. With its enabling geospatial information infrastructures (see also Chap. 5) and Digital Earth platforms (see also Chap. 2), it offers citizen scientists a rich set of content and functionalities that can help develop and prepare citizen science initiatives. For example, technical solutions, recommendations and training material for geospatial data management could be offered by parts of the Digital Earth community (Chap. 5). Digital Earth technology can provide mapping tools and others forms of visualization, and can help any group of people explore, analyze, and model data collected by citizen scientists in combination with data from other sources. It can also provide access to machine learning algorithms and other forms of artificial intelligence (see also Chap. 10) that can help in quality control and quality assurance of citizen science data. With this capacity, Digital Earth technology can help address the continuing challenge of data processing scalability. With the potentially very high volume of citizen science data, it is impossible to rely on skilled community members and scientists alone to meet the need for quality-assured results. In addition, Digital Earth capabilities can help communicate core messages underpinned by research results. The story map of

the European Year of Cultural Heritage is one example of many (Cultural Heritage 2018).

Digital Earth and Digital Earth research are also a beneficiary of citizen science. Citizen scientists can provide valuable input on priority items for research agendas and in terms of data provisioning, for example, from mobile apps or lower-cost sensors systems. Citizen scientists can also provide valuable contributions to field validation (e.g., to validate land use types that have been extracted from satellite imagery) or training of artificial intelligence algorithms (e.g., by crowdsourced applications that combine human reasoning with machine learning to extract damaged buildings in remotely sensed images). Concrete cases can be found on the GEO-Wiki platform (Geo-Wiki 2018).

The above examples only scratch the surface of the possibilities to advance Digital Earth research. Projecting these capabilities into the not too distant future, it can be imagined that new technologies will enable citizens to contribute to individual data and to our reasoning capabilities and interpretations via a global Digital Earth infrastructure for dedicated use. Possible uses might include new scientific discoveries in the earth and environmental sciences or in areas such as astronomy, social science and economics. Whereas most cases of citizen science apply to the former fields, possible applications might address more holistic approaches to overcoming challenges including energy, food and water. It has been illustrated that citizen science can contribute to all of the United Nations Sustainable Development Goals (European Commission, Directorate-General for Environment et al. 2018).

In exploring these new possibilities of citizen science within the context of Digital Earth, it cannot be forgotten that the indicated approaches must adhere to ethical and legal considerations. When operating on a global scale, the values and standards of the communities involved vary largely, as well as the cultures and habits of participants. Any realistic future scenario should adhere to local circumstances and define the possible contributions to (geographically) larger scale initiatives. The example of Let's do it World (Let's do it 2018) underlines some of the difficulties and Global Mosquito Alert (European Citizen Science Association 2018) confirms and, to some extent, complements these issues. Both initiatives aim at data collection and actions around our planet. However, they also allow for diversities, for example, in the data collection approach and additional community activities. By doing so, they provide a global framework and initiate movements while remaining open to the emerging (unpredictable) dynamics of those that react to the call for action. This openness and readiness to adapt to and accommodate specific needs is a key success criterion when dealing with local communities and stakeholder groups, and becomes even more important when the activity is spread across the globe.

## 18.5 Forms of Citizen Engagement and Distribution of Participation

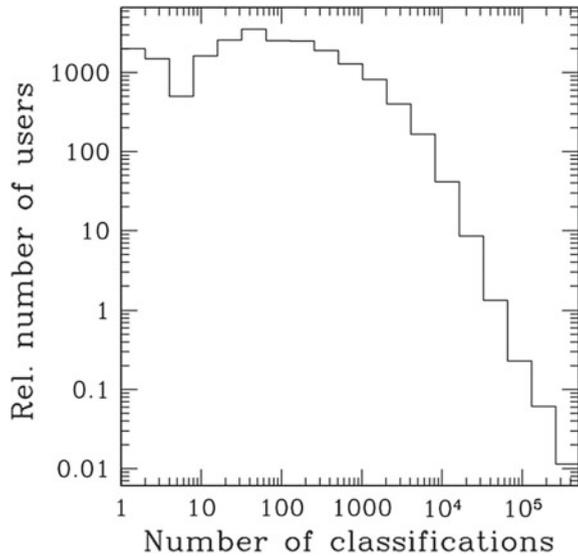
Citizen science can be considered one form of citizen engagement, which is a broader concept encompassing other practices such as civic engagement, public participation and do-it-yourself (DIY) science (Figueiredo Nascimento et al. 2016). These practices involve different forms of contributions from citizens and collaboration with actors other than the academic community. A common feature of citizen science is the collaboration between the public and professional scientists in civic engagement rather than collaboration with academics, and the primary aim is to develop the knowledge, skills and values that can make a difference in the civic life of communities (Ehrlich 2000). DIY Science (Figueiredo Nascimento et al. 2014) includes nonspecialists, hobbyists and amateurs who do research outside institutional research centers in settings such as Makerspaces, FabLabs, and Hackerspaces, where people meet and work together to develop new projects and devices (Figueiredo Nascimento et al. 2016). Technically savvy people can carry out their own DIY science efforts using low-cost sensors and other devices including easy-to-program control boards, miniaturized computers (such as Arduino or Raspberry Pi) and 3D printers, and share information over collaborative websites (Haklay et al. 2018a, b).

Regardless of the differences in contributions, actors, and settings, these forms of citizen engagement provide opportunities for citizens to engage in science and innovation and, more generally, in the challenges that affect our society (Figueiredo Nascimento et al. 2016). As argued by previous authors, better use and integration of the inputs from citizens can expand the evidence used for policy-making and science, turning citizens into generators of innovation (Figueiredo Nascimento et al. 2016).

### 18.5.1 *The “Power Law” Distribution of Participation*

Digital technologies such as smartphones and tablets enable many people to engage but participation in online communities plots along a solid core/periphery model—provided that social software supports both low threshold participation and high engagement. Although the number of citizen science initiatives has grown, many projects fail to attract and retain enough participants. Participants tend to engage with projects for short periods of time, and successful projects rely on a small number of contributors who do most of the work (Dickinson and Bonney 2012; Curtis 2014; Sauermann and Franzoni 2015). For example, in GalaxyZoo, a very successful crowdsourced astronomy project, Lintott et al. (2008) show that a small number of participants complete a high number of classifications and that there is a tendency of participant withdrawal over time (Fig. 18.8). In their study of individual-level activity in seven different citizen science projects, Franzoni and Sauermann (2014) found that most participants contributed only once and with little effort, and the top 10% of contributors were responsible for almost 80% of classifications. This pattern

**Fig. 18.8** The distribution of classifications among users. A small number completed more than 100,000 classifications each and the peak of the distribution is at approximately 30 classifications per user (Source Lintott et al. 2008)



of participation is known as a ‘power law’ distribution, or the ‘Pareto Principle’, and has been observed in several online communities such as Wikipedia, where most content is generated by a minority of users. Therefore, this phenomenon is not specific to citizen science projects. Franzoni and Sauermann note that the reasons for this uneven distribution of contributions are unclear. In their opinion, one reason could be that, as soon as the volunteers start contributing to the project, they realize that the match does not fit their expectation or is not suitable for their skills. One can argue that the specific demographics in citizen science may influence this distribution of participation.

### ***18.5.2 Citizen Scientists Are a Minority and Have Specific Demographics***

Digital technologies enable mass participation and increase the potential for considerable diversity among citizens in terms of age, gender, experience, race, and education, but participation in most citizen science projects is biased towards white men aged 20–65 from well-to-do socioeconomic backgrounds (Haklay 2015). For example, a study found that 87% of participants in a volunteer computing project were men, and a similar bias was identified in ecological observations of birds (Krebs 2010). A report by the Stockholm Environment Institute for the UK Government (DEFRA 2015) showed that the percentage of the UK population that had participated in environmental volunteering was biased towards white, male, middle-aged, higher income people. Low-income people, those with disabilities, and those of black and minority

ethnic origin are traditionally underrepresented in citizen science, for example, in environmental volunteering (Ockenden 2007). Identity-based communities such as YouthMappers and GeoChicas can achieve higher inclusion rates among specific demographics but may not achieve other goals such as racial and ethnic or economic diversity.

At the international level, citizen science is concentrated in advanced economies, especially the US and northern Europe. Access to connectivity represents a barrier to wider participation, with a level of access of 87% in the UK, 81% in the US, and 65% in European countries such as Poland and Portugal (Haklay 2015). Haklay noted that many software applications developed for citizen science projects require continuous connectivity, but 3G and 4G coverage is partial even in highly urbanized environments such as London or New York City and less in remote nature reserves. Another barrier to broad participation is language. English is the main language in science, and many tools and technologies that support citizen science projects presuppose knowledge of English and are not available in local languages (Haklay 2015).

### ***18.5.3 Not Only Science: Citizen Science for Digital Social Innovation and the Role of Local Authorities and Governments***

It can be argued that citizen science should extend beyond the framing of citizen engagement in scientific research. The European Commission stated this need in relation to responsible research and innovation (RRI), which is an element of the EU Horizon 2020 program. RRI calls for researchers, companies, NGOs, and members of the public to collaborate during the research and innovation process to align both the process and its outcomes with the values, needs, and expectations of the European society (European Commission 2018). This view reflects the aspiration to cocreate the future with citizens and include diverse stakeholders to address social challenges.

Digital technologies such as social media and online platforms, open data, and open and standardized APIs have led to opportunities for different modes of citizen engagement and new forms of interaction among different stakeholders. Therefore, digital technologies and the Internet have the potential to enable forms of digital social innovation, that is, social and collaborative innovations in which different actors use these technologies to cocreate knowledge and solutions for issues of social concern (Bria 2015). In a study commissioned by the European Commission, Bria illustrated examples of digital social innovation involving citizen science, including the Globe at Night project in which citizens used a camera and geo-tagging functions on their smartphones to help the research project measure global levels of light pollution, effectively coupling open data and citizen science.

The growth of data generated by citizens can benefit scientists as well as other social actors. For example, the public sector could use data volunteered by citizens

to address critical socioeconomic and environmental issues and inform policies. Two projects are worth mentioning: CuriousNoses (Curieuze Neuzen 2018), a citizen science project in which 20,000 citizens measured the air quality near their homes in Antwerp, Belgium in May 2018, and the Decentralised Network for Odour Sensing, Empowerment and Sustainability (D-Noses 2018), a large project in which citizens in 7 European and 3 non-European countries use innovative mapping tools to detect odor issues and cocreate specific solutions with several stakeholders including local authorities. Local authorities and governments can play a leading role in championing citizen science and social innovation projects. As noted by the Earthwatch Institute (n.d.), local authorities can champion citizen science to raise awareness of the surrounding environment and support environmental protection and education programs. Furthermore, local authorities and governments can enlist citizen scientists to participate in efforts to study social problems and cocreate actionable solutions. To this end, open data platforms can provide powerful tools for sharing information and developing collaborations to apply knowledge in the real world.

## 18.6 Conclusions

The rapid and profound nature of the technological innovations related to Digital Earth resources are matched, and even outpaced, by the social innovations unfolding in relation to creating and using them for citizen science. These dynamic configurations bring together new arrays of actors and diverse communities of interest to contribute to and apply the data and knowledge in ways that are only made possible by the massive participation of individuals and institutions.

In this chapter, we deliberately took a positive stance towards citizen science but some important operational challenges should not be overlooked. In the previous section, we addressed one of challenge, which is the difficulty of attracting and retaining a diverse base of contributors. Another main issue faced by citizen science is ensuring quality, especially the intrinsic quality of data, that is, the accuracy and believability of data provided by citizens (Prestopnik et al. 2014). Quality concerns are a large barrier to wider use of citizen science approaches by professional scientists and policy makers and the diffusion of citizen science project findings (Burgess et al. 2017; West and Pateman 2017). The reasons for this concern include participants' lack of formal scientific training and limited scientific knowledge, uneven levels of expertise and anonymity, as well as nonstandardized and poorly designed methods of data collection (Hunter et al. 2012). Research findings and data are sometimes not published because the ownership and property rights were not clarified during project initiation, leading to disagreements or misunderstandings among diverse participants with different norms and interests (Guerrini et al. 2018; Resnik et al. 2015). Therefore, it is important to understand how citizen scientists produce data, how accurate these data can be, and the factors that influence data quality. The literature suggests a number of approaches that can help projects ensure high-quality processes and results (Wiggins et al. 2011). Among others, reviews by experts can help establish scientific

standards, and training of new participants can improve the consistency of research processes and results.

Despite these challenges, the current state of progress is encouraging given the results of humanitarian, environmental, and economic efforts but it has not fully overcome complex challenges related to quality, equity, inclusion, and governance. Outcomes unfolding in present contexts will determine the future extent to which Digital Earth created with and for citizen science is accountable to the needs of the planet and its inhabitants.

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