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Volunteered Geographic Information (VGI) in Spatial Data Infrastructure (SDI) Continuum

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Abstract

Spatial data infrastructure (SDI) is a system that supports the management and use of geospatial data and related resources. It involves the creation and maintenance of a network of organizations, people, and technology that enables the sharing of geospatial data across sectors and stakeholders. In recent years, the growth of geospatial data and the increasing reliance on it by various sectors has led to the emergence of new trends in SDI, such as the use of cloud computing and big data analytics, the integration of geospatial data with other types of data, and the emphasis on open data and data interoperability. Volunteered geographic information (VGI) refers to geospatial data that is collected and contributed by individuals or groups, rather than traditional sources using the application of web 2.0 and location based applications, social media, mobile devices or say citizens as the censors. Crowdsourcing in geospatial data generation concept of VGI has changed the traditional concept of SDI having one way relationship as producers and users to the user driven SDI, where user create diverse, high quality data (spatial, temporal, attribute) and also use the data interoperable, transparently, world widely and free of cost. Various authors have discussed about the application of VGI in the world of the digital data and also point outs the possibility of integration of VGI in SDI as the starting of the new generation of SDI in the form of Global GIS platform, Data Spaces, System of Systems (SoS), Geoverse, Digital Earth, Digital Twin, Virtual Geographic Environment (VGEs). However, there exists multiple VGI challenges such as data quality, data structure, data differentiation, data copyright, and data confidentiality and privacy, but with the proper cooperation and partnerships, policy and legal arrangements, standard developments, financial arrangements, inter/intra communication and added advantages of web 3.0, concept of Global Digital Ecosystem containing Geoverse, SDI and SoS is possible. Hence, VGI is the present and also the future in this SDI continuum.

Keywords: VGI, SDI, GSDI, Open SDI, Future SDI, SDI Continuum.

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1. Introduction

Spatial data infrastructure (SDI) refers to the systems, policies, standards, and technologies that support the management, dissemination, and use of geospatial data and related resources. SDI involves the creation, maintenance, and operation of a network of organizations, people, and technology that enables the sharing of geospatial data and related resources across different sectors and stakeholders [[1]]. So, it's the data hub with the integrated application of information technology and centralize with unified data sources accessible by the users [[2]]. SDI has a long history dating back to the mid-20th century, when national mapping agencies began to establish standardized systems for collecting, storing, and disseminating geospatial data. In the 1980s, the development of geographic information systems (GIS) and the increasing availability of satellite imagery and other geospatial data sources led to the emergence of SDI as a distinct field of study and practice [[3]]. Since then, SDI has undergone significant

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developments and has become an important tool for supporting a wide range of activities, including land use planning, natural resource management, emergency response, and economic development. Some of the key milestones in the evolution of SDI include the development of international standards and frameworks, such as the Open Geospatial Consortium (OGC) and the Global Spatial Data Infrastructure (GSDI), and the increasing adoption of geospatial technologies, such as GIS and remote sensing, by government agencies, businesses, and other organizations [[3]]. In recent years, the growth of geospatial data and the increasing reliance on it by various sectors has led to the emergence of new trends in SDI, such as the use of cloud computing and big data analytics to manage and analyze large volumes of geospatial data, the integration of geospatial data with other types of data, such as social media, public participatory GIS (PPGIS) sensor data and volunteered geographic information(VGI), and the increasing emphasis on open data and data interoperability.

Volunteered Geographic Information (VGI) refers to geospatial data that is collected and contributed by individuals or groups, rather than traditional sources such as government agencies or commercial organizations [[4]]. The concept of VGI can be traced back to the mid-2000s, when the term "crowdsourced mapping" was first coined to describe the process of using online platforms to solicit and collect geographic data from a large number of producers [[5]]. One of the early milestones in the history of VGI was the launch of the Open Street Map project in 2004, which invited users to contribute map data and eventually became one of the largest open geospatial data sources in the world [5].Since then, VGI has grown in scope and complexity, and is now used for a wide range of purposes, including disaster response [[4]], environmental monitoring, and community mapping [5]. One key trend in the field has been the development of increasingly sophisticated tools and platforms for managing and analyzing VGI data, as well as efforts to improve the quality and accuracy of this data through the use of machine learning and other advanced techniques [[6]].

VGI can be a valuable addition to a spatial data infrastructure because it can provide up-to-date, accurate, and diverse information that may not be available from traditional sources. VGI can also be a cost-effective way to collect and maintain large amounts of geographic data and can help to democratize the process of creating and using geographic data, by giving ordinary people the ability to contribute and access information about their communities and the world around them. In this paper, I will review multiple papers and discuss about the concept of SDI and its developments till now, concept of VGI, importance of VGI in SDI and the possibility or opportunity of integration of VGI with SDI to make the Global Digital Ecosystem.

2. SDI continuum

2.1. SDI

SDI acts as a framework that enables the discovery, access, and sharing of spatial data among various organizations and individuals. It includes both the technical infrastructure (e.g., servers, software, and networks) and the organizational infrastructure (e.g., policies, standards, and governance) required to support the management and use of spatial data [[1]].The concept of SDI originated in the 1990s as a way to address the growing demand for spatial data and the increasing complexity of managing large volumes of data from multiple sources [[7]].Prior to the development of SDI, spatial data was often managed and shared individually by organizations, which led to duplication of effort and difficulty in finding and accessing relevant data [1].

SDI aims to overcome these challenges by providing a centralized system for managing and sharing spatial data. It enables organizations to share their data with others in a standardized format, which facilitates interoperability and enables the data to be used in a variety of applications [[9]]. There are many different implementations of SDI, ranging from small, local systems to large, national or international systems. Some examples of SDI include the National Spatial Data Infrastructure (NSDI) in the United States, the European Spatial Data Infrastructure (ESDI), and the Global Spatial Data Infrastructure (GSDI) [[1]].

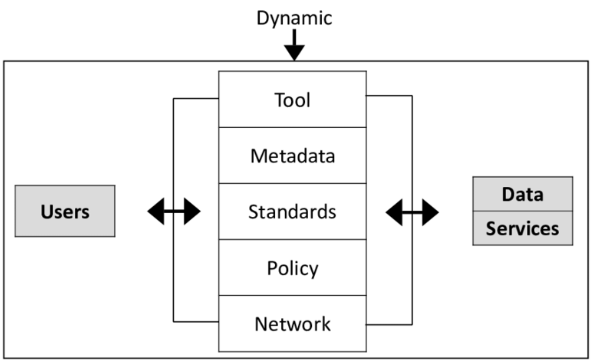

Figure 1. Basic components of SDI (adopted from [7]).

There are three major components in SDI, Producer, Technology and User, according to Rajabifard and Williamson [[7]]. The category Technology connects the users and producers and is made up of the elements Access Network, Policy, and Standards. Metadata and Processing Tools are added to the category Technology by Hjelmager et al. [[8]].

2.2. SDI models and generations

Basically two models in SDI have been used so far; namely, product based and process based models.

Product-based SDI focuses on the development and delivery of specific products, such as maps or spatial data sets, to meet the needs of users [[10]]. It is characterized by a focus on the end product, rather than the processes used to create and maintain it [[1]]. Process-based SDI, on the other hand, focuses on the processes and systems used to create, maintain, and update spatial data [[10]]. It is characterized by a focus on the continuous improvement of processes and the development of flexible systems that can adapt to changing needs and requirements [[1]].

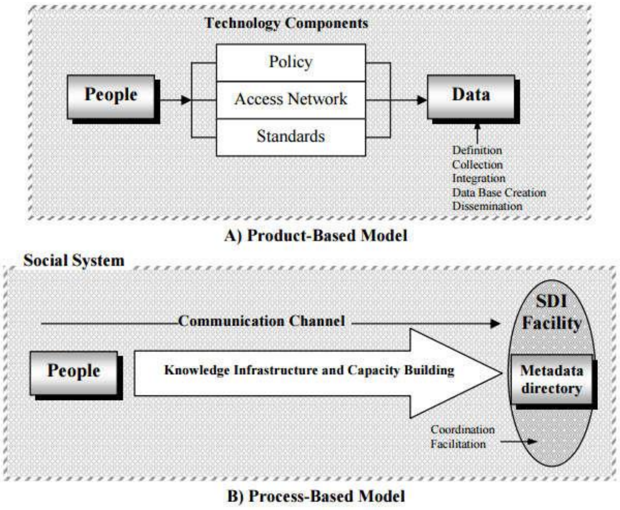

Figure 2. Two models of SDI (adopted from [[7]]).

Both approaches have their advantages and disadvantages. Product-based SDI can be more efficient and cost-effective in the short term, but it may not be as flexible or adaptable in the long term [1]. Process-based SDI, on the other hand, may be more flexible and adaptable but may require more resources and effort.

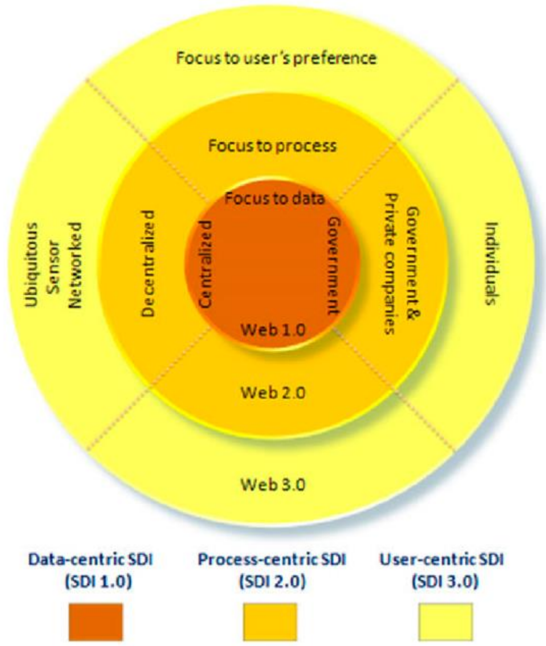

Figure 3. Generations of SDI (adopted from [[11]]).

SDI has evolved through three generations, starting with data-centric SDI (SDI 1.0) which focused on spatial data acquisition and modeling, and moving on to process-centric SDI (SDI 2.0) which emphasized spatial data processing and analysis. When several of the top nations in SDI development revised their policies and updated the conceptual model for SDIs in about 2000, the second generation of SDIs came into being [[9]].The current generation, user-centric SDI (SDI 3.0), prioritizes end user preferences and interests, and emphasizes spatial data visualization, dissemination, access, and utilization. It also allows individuals to input and share spatial data collaboratively and enables ubiquitous access to spatial data/information through Semantic Web applications as part of Web 3.0.

3. VGI

VGI is often associated with the concept of citizen science, which refers to the participation of the general public in scientific research. In the context of VGI, citizen science can involve individuals contributing geographic data to support research or to improve the accuracy and detail of maps and other geospatial data [[12]]. Neo-geography is a term that refers to the use of digital tools and technologies, such as VGI platforms and geospatial software, to create and modify geographic data [[13]]. This can include creating new maps or adding new data to existing maps, as well as analyzing and visualizing geographic data in novel ways. Web 2.0 is a term that refers to the second generation of the World Wide Web, which emphasized user-generated content, collaboration, and the ability for users to interact with and contribute to online platforms and services. VGI platforms and other geospatial tools that enable citizen participation and collaboration are often considered to be a part of the Web 2.0 landscape [[14]].

Several papers have contributed to the development and understanding of VGI. For example, "The role of volunteered geographic information in disaster management" by [[4]] discusses the potential of VGI to support disaster response efforts and highlights the challenges and limitations of using this type of data in this context. "Crowdsourced geographic information and the VGI phenomenon: Origins, evolution, and future challenges" by [[5]] provides a comprehensive overview of the history and evolution of VGI, including a discussion of its key characteristics and applications. "Volunteered geographic information and spatial data infrastructures" by [[6]] explores the relationship between VGI and traditional spatial data infrastructures, and discusses the challenges and opportunities of integrating VGI into these systems.

3.1. VGI Dynamics

Geospatial framework data, gazetteer data, and thematic data are three categories into which VGI can be broadly divided. The production of data on transportation and road networks, one of the issues of geographic framework data, is significantly aided by VGI. By uploading GPS tracks or tracing and digitizing geographic features from high resolution satellite images, Open Street Map (OSM) (www.openstreetmap.org(link is external)) is an excellent VGI platform where volunteer contributors assemble detailed streets, roads, and other features for much of the world [[15]].A VGI technique is particularly suited for gazetteers, which are expensive to build and maintain using standard approaches yet are concerned with connecting place names to specific locations. In order to create gazetteers, Wikimapia (wikimapia.org(link is external)) compiles data about locations all over the world. Volunteers create polygons to represent the locations. Other VGI offers a variety of thematic information on geographical occurrences, such as geo-tagged tweets that capture wildfire scenes and geo-referenced postings that describe bird sightings. A variety of application disciplines are very interested in this type of VGI because it produces rich geographic information that reveals the spatiotemporal dynamics of the underlying events. For example, geo-tagged social media is utilized as a novel method of "social sensing" to comprehend socioeconomic contexts [[16]]; daily records submitted by birdwatchers to eBird (ebird.org (link is external)) are used to research the distribution and migration of birds [17].

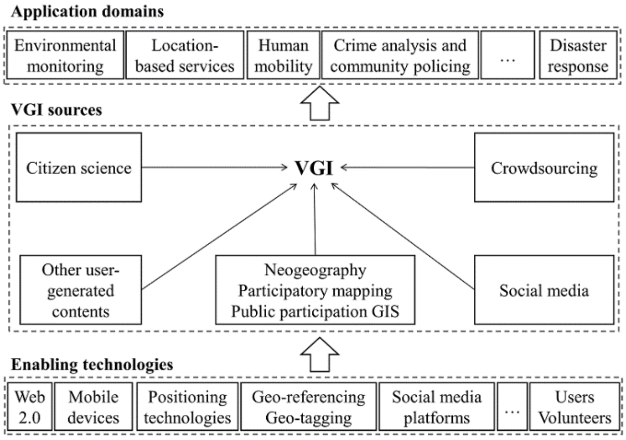

Figure 4. VGI system architecture (adopted from [[18]]).

3.2. Data quality aspects

The quality of VGI data is often under scrutiny due to the fact that it is collected by volunteers who may not be well-trained professionals and whose data collection efforts may be constrained by their own internal commitment. To ensure the quality of VGI, various approaches have been proposed, including "crowdsourcing" (using a group to validate and correct errors made by an individual contributor), "social" (trusted individuals acting as gatekeepers to maintain and control the quality of contributions), "geographic" (using geographic knowledge to assess data quality), "domain" (using domain-specific knowledge to assess data quality), data mining (discovering patterns by learning purely from data to assess data quality), "instrumental observation" (removing some aspects of human subjectivity in data collection by relying on accurate equipment to improve data quality), and "process-oriented" (participants going through training before data collection to ensure data quality).

Representativeness is another important aspect of VGI data quality that is relevant when using VGI for modeling and inference. Representativeness refers to the degree to which a sample of VGI observations can represent the underlying population of a geographic phenomenon. Demographic biases among contributors can impair the representativeness of VGI, as not all citizens have equal opportunities to contribute due to factors such as the digital divide and spatial bias. To address these issues, some studies have proposed methods such as stratified sampling and weighting to improve the representativeness of VGI.

3.3. Privacy and security

Privacy and security are major concerns associated with VGI as volunteers may expose their locations, willingly or unwillingly, when contributing data to a VGI platform or database. This can potentially allow for the tracking of individual users and pose privacy and security risks. To mitigate these risks, VGI contributors should be aware of the intended use of the data they contribute and be cautious about sharing their locations or disclosing sensitive information. There should also be regulations in place to protect the privacy of VGI data, similar to any other user data. For example, the use of Open Street Map data is governed by data protection regulations in the European Union due to the presence of some European contributors.

3.4. Data license and copyright

Most VGI data is open and free for non-commercial use, but users may or may not be allowed to distribute the data depending on the specific data license. For example, users are allowed to copy, distribute, transmit, and adapt Open Street Map (OSM) data under the same license as long as credit is given to OSM and its contributors. However, users are prohibited from sharing eBird data with others, even though they are able to download the publicly available data directly from the site. VGI contributors often hold the copyright of the creative materials they contribute, such as photos, audio recordings, and videos, although the hosting VGI platform may have the right to use or sublicense these materials for non-commercial purposes.

3.5. Challenges and outlook

Assessing the quality of VGI data is important for its use in various domains. While evaluating the basic dimensions of spatial data quality (e.g., positional accuracy, attribute accuracy) may be sufficient for evaluating the suitability of the first two types of VGI (geographic framework data and gazetteer data), it does not provide insights into the representativeness of VGI observations. This is particularly important for using the third type of VGI (thematic data) in modeling and inference, where the underlying phenomena of interest are inferred from a sample of VGI observations. While various biases in VGI have been identified, there are limited methods for addressing these biases and current research tends to focus on issues at the data collection stage rather than on the impact of these issues on VGI applications. Addressing representativeness and biases in VGI is important to fully realize the potential of VGI, which has been used in a wide range of domains, including modeling avian distribution and population trends and generating traffic network databases for autonomous driving. Future research is needed to better understand the operation, implications, assumptions, limitations, and affordances of VGI across its applications.

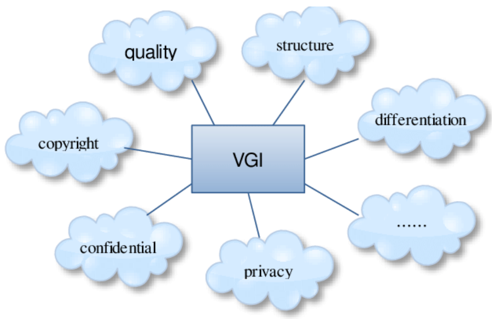

Figure 5 Challenges of VGI (adopted from [[19]]).

Data quality, data structure, data differentiation, data copyright, and data confidentiality and privacy are some of these issues. Data quality is a concern because VGI frequently lacks the attribute standardization seen in expert surveying and mapping data, and because VGI frequently uses mobile phones or GPS devices to collect data, which may not be as precise as professional equipment. Data structure can also be a concern because different users may change the same features in VGI, creating geometry objects with numerous points that can be challenging to acquire and query. Because VGI tends to be more detailed in heavily populated places and less detailed in more rural areas, data differentiation can also be a problem. Data security, privacy and data copyright are additional difficulties. There are several challenges in using VGI to support the updating of SDI [19].

4. VGI in SDI continuum: Paper reviews

4.1. Highlighting current trends in VGI

This paper, [[20]], examines the role of volunteered geographic information (VGI) in the field of geography and GIScience. VGI refers to geographically-referenced information that is collected, shared, and used by individuals or groups, rather than by traditional organizations or institutions. Examples of VGI include user-generated content on social media, crowdsourced data from citizen science projects, and participatory mapping initiatives. The authors argue that VGI is a valuable source of information that can complement and enhance traditional sources of geographic data. It can provide timely, fine-grained, and locally relevant data that may not be available through other sources. Additionally, VGI can be an effective means of engaging the public in the collection and use of geographic data and promoting greater transparency and accountability in the field. However, the authors also highlight several challenges and limitations of VGI. One challenge is the issue of data quality and accuracy, as VGI is often generated by individuals rather than trained professionals. VGI may also be biased or incomplete, as it may only represent the experiences and perspectives of certain groups. Another challenge is the issue of sustainability and maintenance, as VGI projects may be short-term and lack the resources to ensure the long-term availability and maintenance of the data. Despite these challenges, the authors argue that VGI has the potential to transform the way geographic information is collected and used. They recommend that researchers and practitioners in the field carefully consider the strengths and limitations of VGI and work towards developing best practices for its use.

Overall, "Highlighting Current Trends in Volunteered Geographic Information" provides an overview of the current state of VGI in geography and GIScience and highlights the opportunities and challenges it presents.

4.2. Big Data – A step change for SDI?

This paper, [[21]], discusses the potential impact of big data on spatial data infrastructure (SDI), which is a framework for collecting, storing, and distributing spatial data that can be used to support a range of applications and services. The paper begins by defining big data and discussing its key characteristics, including its large volume, high velocity, and variety. It then goes on to examine the potential benefits of big data for SDI, including the ability to improve the accuracy and timeliness of spatial data, and to support new and innovative applications and services. However, the paper also notes that there are several challenges to overcome in order to fully realize the potential of big data for SDI. These include issues related to data quality and accuracy, data interoperability, and data security and privacy. The paper suggests that addressing these challenges will require a combination of technical and policy-based solutions, as well as a focus on building the necessary infrastructure and capacity to support the use of big data in SDI.

Overall, the paper concludes that big data has the potential to be a step change for SDI, but only if these challenges are effectively addressed. It suggests that there is a need for further research and development in this area, and for collaboration between different stakeholders, in order to fully realize the potential of big data for SDI.

4.3. From SDI to Data Spaces – A techno-logical perspective on the evolution of European SDIs.

This paper, [[22]], begins by providing an overview of the history of SDIs in Europe, including the development of early SDIs in the 1990s and the growth and evolution of these systems over time. It then goes on to discuss the current state of SDIs in Europe, including the challenges they face and the opportunities they present. The paper argues that the current generation of SDIs, which are based on centralized systems and technologies, are limited in their ability to support the growing demand for spatial data and the increasing complexity of the data itself. As a result, the paper suggests that there is a need for a new generation of SDIs, which it refers to as "data spaces," that are more flexible, interoperable, and scalable. Data spaces are characterized by a decentralized architecture, in which data is distributed across a network of nodes rather than being stored in a central repository. This approach allows for greater flexibility and scalability, as well as improved data interoperability and security.

Overall, the paper suggests that the evolution from traditional SDIs to data spaces represents a significant shift in the way spatial data is managed and used, and has the potential to support a wide range of applications and services. It concludes by calling for further research and development in this area, in order to fully realize the potential of data spaces for supporting the use of spatial data in Europe.

4.4. Integrating SDIs with VGI for creating a Global GIS platform

In this paper, [[23]], author explains that spatial data infrastructures (SDIs) and volunteered geographic information (VGI) are two types of systems that allow for the collection and dissemination of geographic data. SDIs are typically developed and maintained by governments or other organizations, while VGI is contributed by individuals or groups on a voluntary basis. Both types of systems have their own strengths and limitations. The paper discusses the potential benefits of integrating these two types of systems to create a global geographic information system (GIS) platform. The authors argue that such a platform would allow for the efficient collection, management, and dissemination of geographic data on a global scale, and could be used to support a wide range of applications and services, including disaster management, environmental monitoring, and urban planning. To create this platform, the authors propose a framework that combines the strengths of both SDIs and VGI, including the use of standard protocols, interoperability, and open data principles. They also discuss the challenges and potential solutions for integrating these two types of systems, including issues related to data quality, privacy, and security.

Overall, the paper suggests that the integration of SDIs and VGI has the potential to create a powerful tool for managing and using geographic data on a global scale.

4.5. Future Geospatial Information Ecosystem: From SDI to SoS and on to the Geo-verse

The report, [[24]], published in 2022, discusses the evolution of the geospatial information ecosystem, starting with the concept of a Spatial Data Infrastructure (SDI) and moving on to the idea of a System of Systems (SoS) and ultimately the concept of a Geoverse. A Spatial Data Infrastructure (SDI) is a framework for the collection, management, and dissemination of geospatial data and related information. It typically includes a range of components, such as data servers, data portals, metadata catalogs, and geographic information systems (GIS). The goal of an SDI is to improve the accessibility and interoperability of geospatial data, enabling different organizations and individuals to share and use this information in a coordinated and effective manner. However, the report notes that the traditional SDI model has certain limitations, particularly in terms of its ability to accommodate the growing volume and complexity of geospatial data. As a result, the report suggests that the next generation of geospatial information systems will need to move beyond the SDI model and adopt a System of Systems (SoS) approach. A SoS is a network of interacting systems that work together to achieve a common goal or set of objectives. In the context of geospatial information, a SoS would involve the integration of multiple data sources, systems, and services, enabling users to access and use geospatial information in a seamless and integrated manner. The report argues that the adoption of a SoS approach will be essential for enabling the geospatial information ecosystem to keep pace with the rapid advances in technology and the growing demand for geospatial data. Finally, the report introduces the concept of the Geoverse, which is a vision of the future geospatial information ecosystem in which the boundaries between virtual and physical space are blurred and all geospatial information is seamlessly integrated and available in real-time. The Geoverse would enable a wide range of applications and services, such as location-based services, virtual and augmented reality, and intelligent transportation systems.

In conclusion, report identifies the key trends and challenges facing the geospatial information ecosystem and discusses the evolving concepts of SDI, SoS, and the Geoverse as potential solutions to these challenges. It suggests that the adoption of a SoS approach and the development of the Geoverse will be critical for enabling the geospatial information ecosystem to keep pace with the changing needs of users and the rapid advances in technology.

5. Conclusion

Spatial data production, due to the development of navigational systems, mobiles, location based applications, internet connectivity and web 2.0, has now become a robust ecosystem of tools and technology, making it simpler than ever to produce data. Additionally, the time, expense, and effort required for gathering new data are all steadily declining and the phenomenon is VGI. As a result, the creation of GI has undergone a significant transition, effectively becoming more democratic. Therefore, it is not unexpected that, there are lots of research in different aspects of VGI and also its role in the SDI.

Because one technology may complement the other, the importance of VGI in SDI offer significant benefits for all parties involved, including public and commercial organizations, professionals, and individuals. Benefits for specific professional groups dealing with spatial issues, planning and decision-making, and the general public may all be possible, allowing for the dissemination and uptake of real-time updated information about routine activities or emergency situations, natural disasters, or unknown threats. Although some initial steps have been taken toward this integration, there are still a number of institutional and technical challenges that need to be handled.

A global integrated GIS platform with a general framework that incorporates aspirations and ideas similar to Digital Earth would be ideal if the integration were to be furthered. In order to achieve successful examples of integration and, ideally, an integrated GIS platform, research needs to be concentrated on the establishment of a larger network of involved stakeholders, including academia, industry, public authorities, citizens, and NGOs, within the context of a well-defined project and could result in the creation of Global GIS platform providing SDI as the cloud based service incorporating

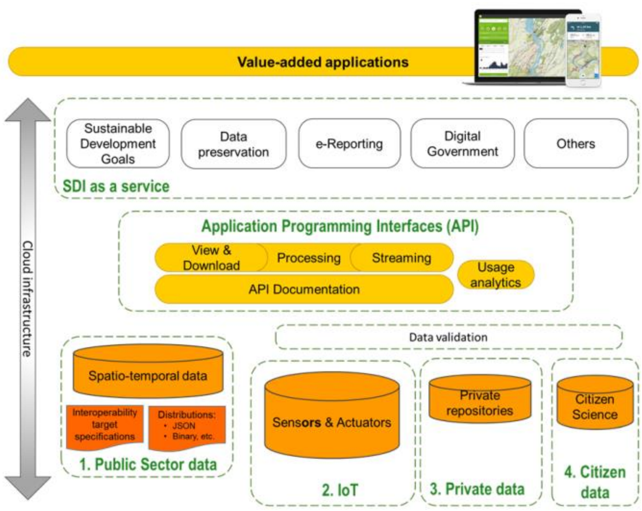

Figure 6. Modern architecture of SDI as service with integration of VGI (adopted from [[25]]) and key terms

-public, private, IoT and VGI data (Figure 6). Moreover it's the major component of the future of SDI towards the concept of data space, SOS or Geoverse. Whatever the terms and concept, it will lead us towards the abundance, ubiquity, interoperability, high resolution (spatial, temporal, attribute) and highly accurate spatial data and service for modeling the geographical phenomenon for digital twins using machine learning and artificial intelligence.

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