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INFORMATION MANAGEMENT

Future Geospatial Information Ecosystem: From SDI to SoS and on to the Geoverse

Making the Step Change Using the Integrated Geospatial Information Framework

July 2022

Discussion Paper

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Foreword

Our world is in a state of continual change - being aided by rapid technological advancements and digital transformation. While it is disruptive, the commercial geospatial industry is at the leading edge of this change. We need to not only be a recipient of that change, we need to be part of directing, at least the policy and governance, aspects of that change.

The United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM) has an important role in ensuring geospatial information is accessible, usable and reusable so it can be used to achieve the sustainable development goals (SDGs) and address other global challenges.

Geospatial information provides a sound basis for understanding what is happening when, where, and why, and how communities are being impacted. With this knowledge we can take action. However, the successful pursuit of knowledge means overcoming many data availability and data integration issues, so we can more easily generate new insights for purposeful decision-making.

A key role of UN-GGIM is to keep abreast of future trends and opportunities in the application and use of geospatial technologies, and to develop the necessary global policy to facilitate change where it will be of most benefit. Through this endeavor, the Committee of Experts has recognized the need to remain both agile and relevant as we move beyond current geospatial management activities, and to take advantage of rapid technological developments and innovations as we consider the future geospatial information ecosystem.

However, obtaining a clear understanding of what the future geospatial information ecosystem will look like remains a challenge. This is not surprising given its 'future looking' and 'aspirational' nature, and with so many technological dependencies and variables. These elements surfaced in more detail as the Integrated Geospatial Information Framework (IGIF) was being developed by UN-GGIM from 2017-2019. Part I of the IGIF, the Overarching Strategic Framework presents a forward-looking approach built on national needs and circumstances, to create an enabling environment where national governments can coordinate, develop, strengthen and promote efficient and effective use and sharing of geospatial information for policy formulation, decision-making and innovation, and to stimulate improved understanding for national development priorities and the SDGs.

Several emerging and complementary initiatives, all connected to the IGIF philosophy, such as the Geospatial Knowledge Infrastructure (GKI) White Paper, the European Union Location Framework (EULF) Blueprint, the UN-GGIM Future Trends reports, and the position paper Towards a Sustainable Geospatial Ecosystem Beyond SDIs, have continued to provide valuable inputs to shaping the future geospatial information ecosystem. In addition, at Geospatial World Forum 2022, geospatial leaders from around the world provided perspectives at a two-hour open discussion session to explore the many dimensions and perspectives of a future ecosystem, including how it might coexist within a larger digital ecosystem.

What has become clear from discussions, is that the geospatial landscape needs to move beyond 'data' as a focal point of activity, to processing and synthesising data into contextualized information, so that it can be readily used to gain new knowledge and insights. With the data revolution, and now with digital transformation disrupting traditional methods of data delivery and dissemination, users have typically not understood or appreciated the value and need for integrated geospatial information as a way to expand and improve the usefulness of their data. Such data has, as its common element, location information. Once location (for example coordinates or a geocode) is included, trends, relationships, geographic comparisons, predictive analytics and other important connections become evident, especially when mapped and visualized.

Having 'knowledge' as the focal point of the future geospatial information ecosystem, is crucial. The socio-economic aspirations of many countries converge around a more sustainable and resilient future where economic prosperity will benefit all of society and support the health and well-being of communities and individuals equitably. These social, economic, and environmental aspirations are predicated on having the necessary knowledge to gain a deep understanding of the local to global challenges faced, in order to tackle problems and implement proactive policy and sustainable solutions.

This discussion paper aims to provide further contextual guidance towards an understanding of the future geospatial information ecosystem, which goes beyond the traditional Spatial Data Infrastructure (SDI) processes, models and architectures. It poses the question "SDIs are known to be delivering valuable access to data for decision-making – so why do we need to change anything?"

The limitations of current SDIs are discussed, and the future ecosystem is described as moving towards a more integrated 'system-of-systems' approach and the 'Geoverse' as major technological innovations that are changing the way we understand, manage, process and use geospatial information.

The paper also describes what we mean by 'knowledge' and how it is created, managed, transmitted and relied upon to address key drivers for change. These drivers are to: (1) enable unified solutions to global challenges; (2) deliver affordable and equitable access to knowledge on-demand; and importantly (3) ensure we continue to bridge the geospatial digital divide.

These three themes shape why we need to do things differently in the future. In this context, technology is the enabler for change; creating opportunities to make a difference that will ultimately bring lasting progress and sweeping transformation to address the challenges we face.

In this paper, the IGIF is used to examine the SDI construct and provide contextual guidance in the form of a step change towards the future geospatial information ecosystem. The discussion considers the needs of countries that are in the early stages of developing their IGIF Country-level Action Plans, as well as those that have already successfully strengthened their SDI capabilities and have started to adopt Fourth Industrial Revolution technologies.

To move beyond the current paradigm to the new ecosystem, the UN-GGIM community is tasked with providing strategic leadership, support and necessary policy decisions to drive change that will deliver the knowledge required to address the world's most pressing problems. Feedback on this important document, from the entire global community, will support this process and contribute to making informed decisions. Please let us know:

- Are we moving in the right direction?
- What do you think the main challenges will be?
- What are we doing now that works well and will contribute to the future?
- What is the best thing we can achieve moving forward?
- What will be the most valuable outcome for you?

Submissions can be made via email to the UN-GGIM Secretariat (ggim@un.org) with the subject 'Determining the future geospatial information ecosystem'. Contributions are welcome from all interested member states, organisations and individuals. The closing date for submissions is 31 October 2022.

We look forward to your contribution.

UN-GGIM Secretariat
July 2022

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Introduction

The UN-GGIM Committee of Experts has an important role in transitioning beyond current Spatial Data Infrastructures (SDIs) to address global challenges using geospatial information.

Part of this transition involves making joint decisions and setting direction on the production and use of geospatial information within national, regional and global policy frameworks. This includes:

- defining what constitutes the future geospatial information ecosystem; and
- guidance on using the IGIF to make the step change required to achieve a paradigm shift.

Leaders in the global geospatial community from government, academia, not-for-profit and the private sector, recognize the need for more enhanced geospatial information management capacities and capabilities. We are also seeing a growing interest for integrated ecosystems thinking and knowledge inferencing within the geospatial community and UN-GGIM. The objective is to enable better informed and ultimately more effective policies to address the Sustainable Development Goals (SDGs) and global agendas (Scott, 2017), and national and local development priorities.

However, there is currently no formal agreement, at a global decision-making level, on what the future geospatial information ecosystem will look like. The complexity of, and thus the need for considering, the future geospatial information ecosystem, has been reiterated by the background paper *Towards a Sustainable Geospatial Ecosystem Beyond SDIs* provided to the eleventh session of UN-GGIM.

In addition, UN-GGIM at its eleventh session, emphasized that the future geospatial information ecosystem will need to be understood, together with the importance of maintaining the impact and continuity of the IGIF, and operationalized through Country-level Action Plans.

Conversations on the future geospatial information ecosystem are well underway, and there is now a growing body of work envisioning a global interconnected geospatial information ecosystem in which everyone can interact to gain knowledge (EUROGI, 2021; GW, 2021; CRCSI, 2017). Several forward-looking vision statements and documents have been developed. These articulate several aspects in common, all of which recognize that:

- Our future digital world will be increasingly interconnected through flows of information, resources, goods and services, people and ideas;
- The 'single' direction supply of data and services is no longer the end point. The future ecosystem must take direction out of the equation to locate, integrate and process disparate and diverse data;
- The Fourth Industrial Revolution (4IR) is bringing unprecedented advances in technologies that are providing the geospatial community with the capabilities to address major challenges and opportunities (GW, 2021);
- The ecosystem must deliver the location-based knowledge, services and automation expected by economies, societies and citizens in the 4IR age (GW, 2021);
- The transition beyond SDIs will be characterized by a shift from data to new insights, knowledge and understanding (CRCSI, 2017);
- The future ecosystem will be self-organized around the demand for geospatial information, technologies and services (EUROGI, 2021) that will deliver solutions to global problems that cannot be addressed on a country-by-country basis;
- The interdependence between the digital (machine) world and human world will be total (EUROGI, 2021) – requiring a new workforce ready, skills development framework;
- Enhanced governance, business models, policies, processes and partnerships are needed to empower users, keep people safe and secure, and break through the participation barrier so that no person is left behind; and
- The future ecosystem provides a momentous opportunity to raise awareness of the importance and significance of geospatial information, unify terminology, cement the geospatial brand globally, and launch geospatial as a career choice. ■

Purpose

This discussion paper aims to provide contextual guidance towards an understanding of the future geospatial information ecosystem, which goes beyond the traditional Spatial Data Infrastructure (SDI) processes, models and architectures.

The paper develops high-level conceptual guidance using the IGIF as a practical starting point for countries, as they embark on a path towards digital transformation. Using the IGIF means that countries can readily maintain the impact and continuity of change through their IGIF Country-level Action Plans

The paper is structured as follows and is intended to promote thinking and discussion on:

- **Why we need to move 'Beyond SDIs':** SDIs are known to be delivering valuable access to data for decision-making – so why do we need to change anything?
- **The Future Geospatial Information Ecosystem:** Describes the 'system-of-systems' approach and the 'Geoverse' as major technological innovations that are changing the way we understand, manage and use geospatial information.
- **What we mean by 'knowledge':** Clarifies how knowledge is created, managed, transmitted and trusted in a digital context, drawing on theoretical and practical understandings.
- **The drivers for change:** The pressures that are shaping the geospatial sector and the imperatives that help us to understand 'what' type of change we are dealing with.
- **Making the step change:** Discusses the nine strategic pathways of the IGIF and how these overarching concepts provide guidance for making incremental change towards the future geospatial information ecosystem. This includes countries that are in the early stages of developing their SDIs, as well as those that have already successfully implemented SDI capabilities. ■

Why do we need to move beyond SDIs?

There is a vast amount of literature highlighting the value of SDIs in making significant amounts of data accessible for decision-making and policy setting; and social, economic and environmental benefits are accruing on a local to global scale. So why change?

The earliest intent of SDIs has now moved beyond data as the endpoint (UN, 2012; EUROGI, 2021; GW, 2021). SDIs were largely made possible by the creation of the Internet and World Wide Web (Web), which enabled digital content to be shared as html web pages.

As the web evolved, so too did our SDIs. Government data warehouses were developed making it possible for agencies to share their data; data catalogues were created to provide a window for people to search, acquire, use and repurpose data many times over; web portals arose to provide the means to view data layers in an integrated way; and data and software services evolved to support the development of applications and data analytics.

However, while we have seen many developments, we are currently unable to leverage all that advanced 4IR technologies have to offer, particularly the Internet of Things (IoT), which is providing new ways to collect and process data, and create and transmit new knowledge and insights. The main problem is that SDIs are designed as 'human accessible' libraries that are not machine friendly. Search engines find it difficult to locate data within these catalogues, and as a consequence, Artificial Intelligence (AI), Big Data geoanalytics, knowledge inferencing and IoT communication interfaces are not being used to their full potential.

In addition, SDIs are not user friendly. SDIs are designed to 'push' data out with little regard for demand and user requirements, and the many questions users have of data (UN, 2012; Arnold, 2018; EUROGI, 2021). In addition, SDIs are geared towards professional users that have the skills to download, process and analyze geospatial data in order to obtain the knowledge needed to make good decisions. They do not cater for general users and consumers, with limited skills and knowledge to interpret data.

Moreover, the analytical processes required to extract knowledge from data are time consuming. The delay between question and answer is not adequate for a society where access to knowledge on-demand has become the expectation, if not the norm. Easy access to data, is no longer the prime objective of society. Monolithic applications, such as Airbnb, Uber and Spotify have created an on-demand revolution. Even content streaming is now tailored to individuals' preferences by referencing and learning from past choices (Arnold *et al*, 2019).

This level of automation has increased the appetite of consumers for more on-demand functionality that is not achievable with SDIs today (Arnold *et al*, 2019). According to Winton (2019) "Nowadays, people expect the Apps they use each day to just work. And the users who depend on them aren't content to wait minutes, hours, or days until a resolution is found."

The momentum behind the 'beyond SDI' movement is the realization that 'an ever-ready plethora of geospatial data, ready to answer individuals' questions in real time,' is not achievable with the current human-readable SDI paradigm. This is evidenced by the limited number of applications sophisticated enough to allow for processing random, unpredictable, and context dependent queries; where filters on location, culture, environmental conditions, religion, and individual preferences etc., are required to differentiate and personalize answers.

Where do we locate the new hospital?.... Which areas should be declared fire risk zones?.... How likely will flood waters reach my location?.... What are the main concerns of my constituents?... Should we insure this property?... Is this land suitable for a market garden?... and so on. All require geospatial data to be accessed, processed, analyzed and translated 'on the fly' into an individualized setting to answer these types of questions knowledgeably (Arnold, 2018).

It is clear that a paradigm shift from 'human-actionable' SDIs is required if we are to achieve an ecosystem characterized by real time knowledge for 'everyday' decision-making and problem solving (Arnold *et al*, 2019; GW, 2021).

In this new future, access to geospatial data will be essential, but not enough. Our data also needs to be understandable, integratable and actionable by machines using networks, powerful tools, automated geoanalytics (GW, 2021) and multimodal digital network communications. The SDI bi-directional data supply network is not able to deliver the level of sophistication necessary to deliver knowledge on-demand. ■

The Future Geospatial Information Ecosystem

Before describing the future geospatial information ecosystem, it is important to clarify that SDIs are an important first step in the evolutionary process. For those countries working towards establishing their SDI; the work being done continues to be valuable and crucial to strengthening geospatial information management and enabling progress towards the future ecosystem.

In essence, the SDI comes first. This is because, in addition to delivering access to data, SDIs also establish data governance frameworks, enact geospatial policy and laws, and implement technology and standards (Scott, 2022); all of which are the foundation for the step change required to move to an ecosystem centered on delivering knowledge.

Importantly, the evolution of our geospatial information ecosystem is occurring in parallel with advancements to the Internet and its transitionary phase from interactive bi-directional data transactions (circa Web 2.0[1]) to a decentralized multimodal digital environment (Circa Web 3.0 and beyond) that is able to process and curate information in real time.

From a technology perspective, the future geospatial information ecosystem will consist of three concepts - the traditional SDI; a network of systems referred to as a 'system-of-systems'; and a third element, which has until now not been named, and which is referred to here and going forward as the 'Geoverse'. All three concepts co-exist in the future geospatial information ecosystem – potentially manifesting into the Geoverse in the longer term (Figure 3).

For clarification, these concepts, as they pertain to this paper, are explained below, and their relationships illustrated in Figures 1 and 2:

- **SDI:** Recognizing that SDIs have various implementations, this paper describes the SDI as a server-based geoportal for organizing, visualizing and making geospatial data and services available and consumable. SDI geospatial data is accessible via the web, typically using one-to-one communications, similarly to other information, applications and services. These characteristics belong to the realm of Web 2.0 technologies.
- **System-of-systems (SoS):** Are referred to here as a collection of systems that consume geospatial information from SDI data catalogues or from other sources available on the web. Each system is capable of independent operation, but also interoperates with other systems to achieve additional capabilities.

  Smart cities, intelligent transport systems, driverless systems and dashboards that consume data from several databases or registries, are examples of the SoS approach. These systems are constructed and operated by people, but also include connections to machine generated data, such as IoT sensors and other data processed on the edge in real time[2]. SoS participate in a Web 2.0 environment, as well as applying more advanced Web 3.0 technologies.

[1] The line between Web 2.0 and Web 3.0+ is converging as data, systems and applications take on characteristics of both. Web 2.0 (also referred to as the Social Web) is epitomized by dynamic web pages and user generated content; Web 3.0 (also referred to as the Semantic Web) is characterized by a decentralized web of data (global database) and sophisticated interaction between devices and users.

[2] Edge Computing – data that is processed at its source, such as a sensor, without needing to be processed by high-end servers where lag or latency can occur.

- **Geoverse:** Refers to an aspirational globally interconnected geospatial information ecosystem - one that permits intelligent interactions between SDI web portals, systems, sensors, applications, devices and other things; using a broad range of communication interfaces and machine facilitated technologies such as AI, Machine Learning (ML), Natural Language Processing (NLP), data mining, virtual assistants, digital identities, blockchain etc.

  The Geoverse is envisaged as a super-set of the Metaverse[3] that extends the notion of a 3D virtual society to include 4D visualizations, predictive analytics and real time knowledge in all its forms, as well as a wide range of integrated and interoperable data from across various sectors and disciplines.

  Like the web, the Geoverse belongs to everyone; it is non-proprietary and not controlled by a single organization[4]. The name is used to convey the use of geospatial technologies in combination with the web as a medium for positive change. The notion being "to better integrate and understand the complex relationships between people, place and planet" - leading to sustainable development from a position of knowledge, wisdom and insight.

The transition from SDI to the Geoverse will not happen overnight. In the short term, it is anticipated that the future geospatial information ecosystem will include SDIs, SoS and elements of the aspirational Geoverse. This is illustrated in Figure 3, from a digital interaction perspective. In this trajectory of evolution, SDIs will continue to participate in both SoS and the Geoverse, as a persistent source of data supporting new capabilities including new ways to create and deliver knowledge.

Importantly, technology will not be the only element that needs to evolve. The governance and people aspects of our geospatial information ecosystem also need to keep pace with, and be an enabler for, change. The IGIF provides the strategic pathway guidance to enable this step change to occur. This is important. If we are to achieve a more advanced ecosystem, the way we govern, manage, structure, develop new skills and integrate geospatial information, must evolve holistically to take advantage of 4IR technologies, including enhancements already available through the IoT.

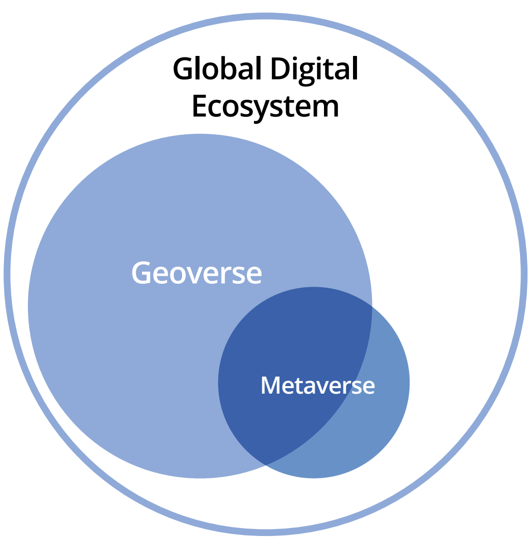


Figure 1. The geoverse is a subset of the global digital ecosystem, and participates in the metaverse.

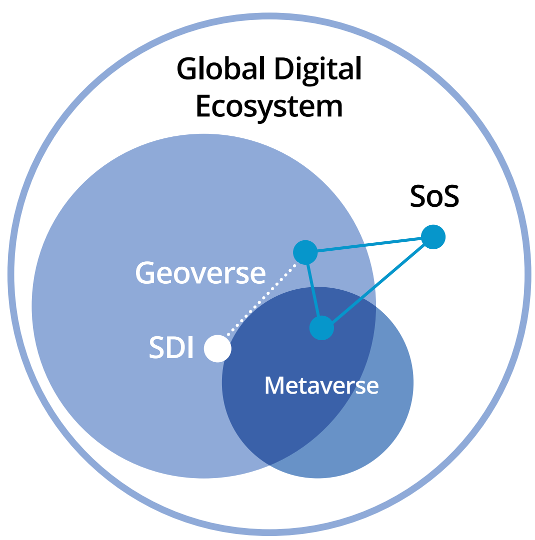


Figure 2. The SDI is a source of data for the geoverse, SoS and metaverse. SoS participate in the global digital ecosystem, geoverse and metaverse.

[3] Metaverse - In its current meaning, the Metaverse refers to integrated virtual 3D worlds (OGC, 2022; Merriam Webster, 2021) where people can socialize, collaborate, learn, and play (Torres, 2022)
[4] This was the intent when Tim Berners-Lee created the World Wide Web (Berners-Lee and Fischetti, 1999).

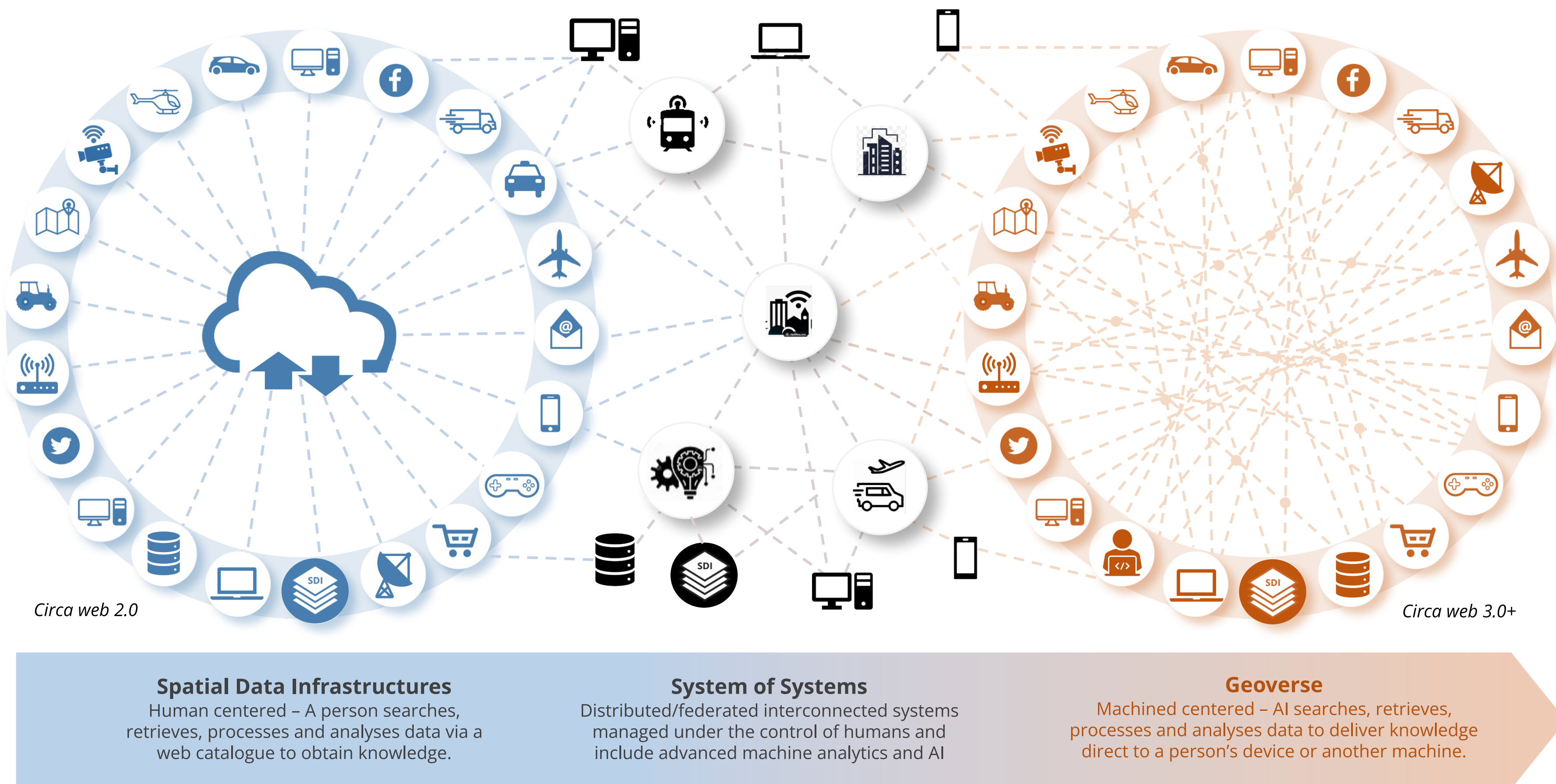


Figure 3. The future geospatial information ecosystem comprising SDIs, SoS and the Geoverse.

What do we mean by Knowledge?

The rationale for the paradigm shift from 'data to knowledge' is at the core of the transition to the future geospatial information ecosystem. But what do we mean by knowledge?

The term 'knowledge' has different connotations, depending on the discipline and philosophy of thought, or simply the way it is used in a sentence. For clarity, knowledge within the context of the geospatial information ecosystem refers to our ability to gain an accurate or deep intuitive understanding of something that leads to insight and wisdom.
Our deep understanding of a subject emerges by passing through four qualitative steps: (1) Data - Facts and figures without context for a specific question; (2) Information - Data that is filtered and analyzed so that it is applicable to a specific question; (3) Knowledge – Information put into context to answer a specific question; and (4) Wisdom – the ability and confidence to act on knowledge (Figure 4).

Two types of knowledge are discussed – tacit and explicit knowledge. People acquire 'tacit' knowledge by asking and receiving answers, or simply through learning experiences – reading (books, graphs, maps, charts, tables etc.), learning to ride a bike (actions), sharing stories (verbal communications) etc. Tacit knowledge often relates to things we know, but don't know how we know. Essentially, it's knowledge that we embed into our memory. On the other hand, explicit knowledge is that which can be imparted to others, as well as codified to guide and control machines.

With geospatial processes, knowledge is embedded into rules and procedures, machines can process and filter data to create synthesized information, which in turn results in the creation of new knowledge, and the cycle repeats. Traditionally, computer algorithms based on pre-determined inputs, rules (algorithms) and outputs, have undertaken this task. However, they are not suited to knowledge on-demand 'question and answer' type scenarios. The system/algorithm knows no more than the coder. Consequently, random, unpredictable and context dependent queries, and those requiring individualized filters, are difficult to code.

This is where AI has made a huge leap forward and opens significant opportunities for the geospatial sector to move beyond the SDI paradigm. AI has made automating knowledge creation a reality. It still requires an element of explicit knowledge e.g., rules and training data; but now deep learning models (a branch of AI) are able to learn on their own, and we are seeing sophisticated results in image interpretation.

In addition, knowledge graphs are being used to infer relationships and meaning between separate pieces of data, and machine learning is used to improve natural language processors used in virtual assistant technology. For instance, Google uses AI and knowledge graphs to organize information, anticipate needs and define the right context to deliver personalized responses.
These knowledge graphs continually extract meaning from a growing web of 'searched words'[5] and their associations (IBM, 2021).

[5] Here, 'searched' words refers to those sought through search engines and questions posed to virtual assistants.

Wisdom refers to having the confidence to be able to act on knowledge and potentially draw new insights from the experience. The value of knowledge in the context of the user, necessitates an understanding of "*to what degree a person (or business) values the knowledge they receive*". To a large extent, the value of knowledge is dependent on how much a person believes the information to be true, and this requires new ways to communicate the trustworthiness of data and thus the knowledge derived (Arnold, 2018).

Our ability to directly obtain new insights from vast amounts of data, will become a reality when the future geospatial information ecosystem is able to provide real time access to knowledge that has been processed and contextualized for the individual and denoted as trustworthy; be it insights into the relationship between complex phenomena, the likelihood of an event, or simply navigating to a location.

New knowledge-based services will evolve to operate via a range of commands (voice, touch, keyboard) and devices; and be delivered through an array of machine-accessible, integrated and multi-dimensional geospatial data, and conveyed virtually and in real time through a combination of visualizations, audio and haptic technologies.

This is a paradigm shift from single direction, supplier driven SDI data networks and traditional data analytics and services created for a general market. In contrast, the knowledge on-demand paradigm focuses on specific knowledge, created by machine-actionable data and automated analytics driven by, and in response to, the questions of individuals. Importantly, the accuracy of answers, and therefore the trustworthiness of knowledge services, will have an interdependency with the accuracy and timeliness of the source data.

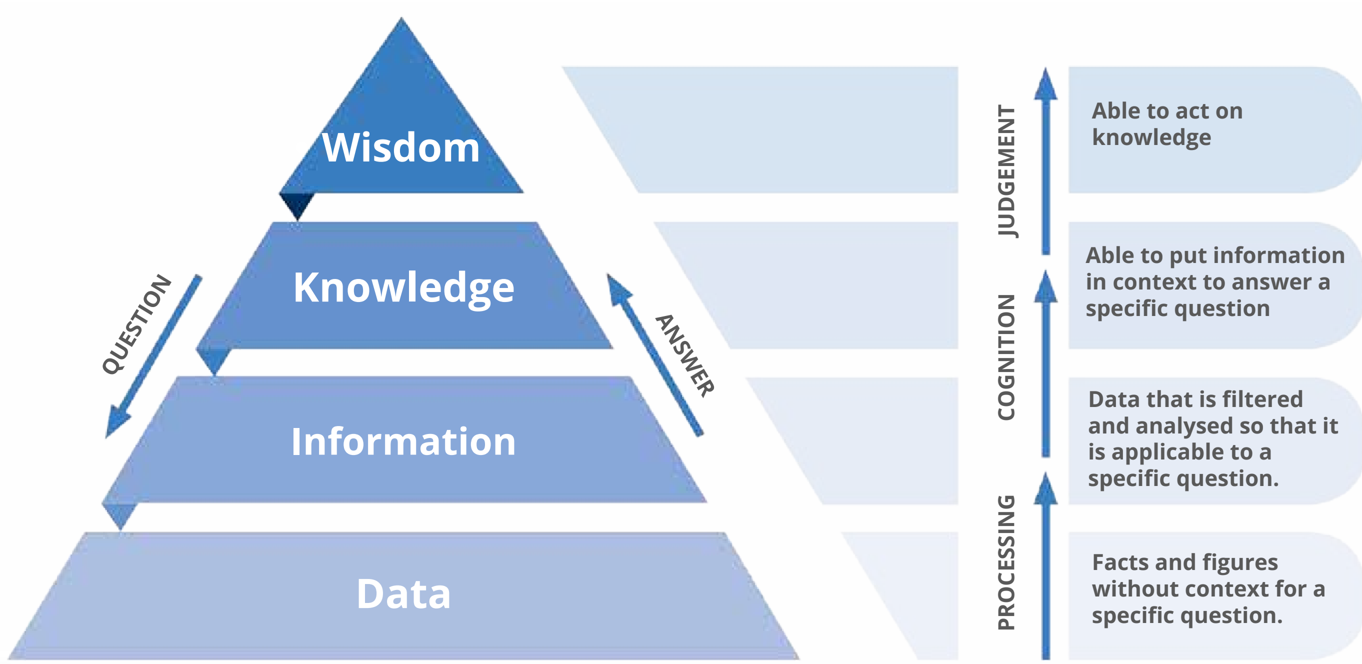


Figure 4. From data to information, knowledge and wisdom. Adapted from DIKW Model for knowledge management and data value extraction.

What are the Drivers for Change?

There are multiple reasons why countries need to enhance the way geospatial information is managed and used. Much of the discussion in recent literature focuses on delivering knowledge value with technology serving as an enabler for change; creating opportunities to make a difference that will ultimately bring lasting progress and sweeping transformation to address the challenges faced.

Understanding our challenges provides us with context to know what needs to change. From a national and global perspective, the drivers for change are recognized under three main themes that (Figure 5):

a. deliver unified solutions to global challenges;

b. meet society's growing demand for equitable and affordable access to knowledge on-demand; and importantly,

c. bridge the ever-widening geospatial digital divide between developed and developing countries.

These three themes shape why we need to do things differently in the future. Each theme requires a new technical capability, supported by good governance and policy, beyond the constructs of current SDIs.

Driver 1: Unified Solutions to Global Challenges

There is an urgent need to use geospatial information to tackle the world's most complex humanitarian and sustainable development challenges, address climate change, respond promptly to global pandemics, and reduce the consequences of natural disasters and their impacts on our land and oceans (EUROGI, 2021). Solutions to these challenges[6] have significant benefits to all countries. What occurs in one part of the world has a ripple effect to others.

Geospatial innovation is needed to better connect the world and enable positive change to happen. Everything around us is interconnected in some way, and local decisions can have an impact on humankind at a global level. If we are to better understand interrelated social, economic and environment issues, we need to be able to harness geospatial intelligence on a local to global scale.

Global issues cannot be solved by one country or a few countries in isolation, nor can they be solved by government alone. No single government agency or country has all the answers to global challenges; nor the knowledge to address emerging issues before they become a problem.

Often, it is not until information from across many countries, and in some cases all countries, is integrated that new patterns, trends, and insights come to light. Being able to visualize this new knowledge in the 'geospatial sense', and model multiple future scenarios, will help us to find new ways to address what are often long-term and interconnected development challenges.

However, current SDI data production and consumption systems, make it difficult to address challenges in common. Geospatial solutions have become fragmented and slow to implement because national SDIs are typically disconnected from the global context. Our future geospatial information ecosystem must be able to respond in a timelier and more integrated manner and ▶

[6] Global Challenges – poverty alleviation, climate change, sea level rise, food security, gender equality, resource depletion, overconsumption, biodiversity loss, renewable energy production, and mass migration etc.

be able to make use of global data resources in a safe and secure way – so that all countries benefit.

Driver 2: Affordable and Equitable Access to Knowledge On-demand

Society's perception of 'easy access to data' has changed and the bar has been raised significantly (EUROGI, 2021). The emphasis has shifted to knowledge-based products and services (GW, 2021).

While, SDIs have played an important role in creating and sharing geospatial data; this is a far cry from democratized access to knowledge, where end users want answers to complex and urgent questions in real time. Data is no longer the end point. Rather it is the start point. Societal expectations have changed and our user community is now seeking knowledge in the form of processed information. We have entered the 'on-demand era' where people want personalized, reliable and real time answers, and not simply links to information that they need to sort through (CRCSI, 2017).

The fixed line technologies, organized around the demand for geospatial information, that characterize current SDIs, are not able to deliver this 'on-demand' future. SDIs prevail as the domain of 'professional users' (Mongus, 2020) and the privileged few that can afford to pay for exclusive services. However, SDIs have failed to deliver knowledge uniformly to the wider population.

Driver 3: Bridge the Geospatial Digital Divide

Addressing the widening wealth and digital divide between developed and developing countries, men and women, and ocean-bordering and landlocked countries, is a priority driver for change (UN, 2017). This comes with the need for some serious policy changes.

There is a broad and almost universal view that people's relationship with technology will deepen and their reliance on digital connections for work, education, health care, commercial transactions and social interaction will grow (Anderson *et al*, 2021). However, there are also those who currently have limited access to digital tools and training, and any advancement will widen the gap between the 'haves and have-nots'.

As we move beyond SDIs, it will be important to ensure the future geospatial information ecosystem is able to evolve with a priority on 'putting' developing countries at the center of everything we do. This means exploiting new technologies and incentivizing partnerships in a way that fosters the sharing of new capabilities and increasing digital literacy and innovation, so that everyone benefits.

Now is the time to reconfigure and enhance our geospatial information ecosystem, in all areas of the nine strategic pathways of the IGIF, so that outcomes lead to improved quality of life for all. One way to achieve this is for the ecosystem to deliver 'access to knowledge' in a way that is available to everyone – a strength being its universality in access and use.

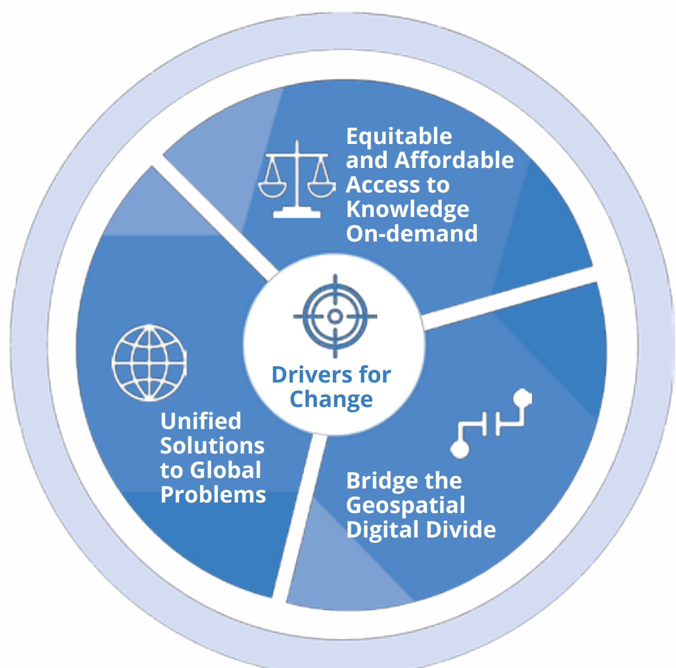


Figure 5: Drivers for Change

Making the Step Change

The IGIF was designed to provide guidance for countries to strengthen their national geospatial information management arrangements. We are now seeing many countries adopting the IGIF into their geospatial transformation strategies, and in doing so, they are making a change for the better.

As we transition towards a future geospatial information ecosystem, we will need a plan to guide the step change needed – so all countries can participate equally in the transition. The IGIF can be used to develop this evolutionary plan, and the advancements needed in all of the nine strategic pathways.

The IGIF was designed with constancy and flexibility in mind. In terms of constancy, the IGIF provides a consistent basis for strategizing, analyzing and creating action plans for strengthening geospatial information management. In terms of flexibility, the IGIF recognizes that countries have unique starting points, and as such, action plans can be designed for different circumstances. Indeed, at its eleventh session in August 2021, UN-GGIM emphasized the importance of maintaining the impact and continuity of the IGIF, as well as acknowledging the need to maintain flexibility to cater for variability in national circumstances and conditions, particularly between developed and developing countries.

In the following sections, each strategic pathway of the IGIF is discussed in terms of its four key elements, the three 'drivers for change' and the step change needed to transform geospatial information management arrangements to realize an ecosystem that meets future needs.

The IGIF strategic pathways provide a 360-degree view of the capacities and capabilities needed to strengthen geospatial information management to participate in the new future. The nine strategic pathways are organized in response to three principle areas of influence: governance, technology, and people, and are: (1) Governance and Institutions; (2) Policy and Legal; (3) Financial; (4) Data; (5) Innovation; (6) Standards; (7) Partnerships; (8) Capacity and Education; (9) Communication and Engagement (Figure 6).

Planning for change, is a significant milestone in the evolving use of the IGIF. While it is impossible to know how the future will unfold; we can map out the future geospatial information ecosystem as it appears at the present, and adjust using the IGIF strategic pathways, as new possibilities arise. ■

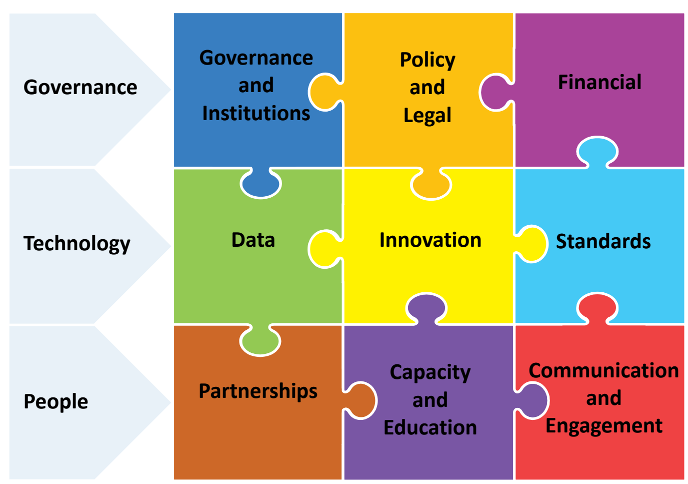


Figure 6: The nine strategic pathways of the IGIF influenced by governance, technology and people

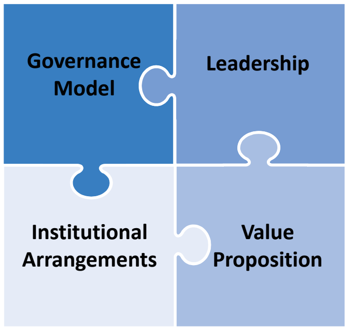
Governance and Institutions

This strategic pathway guides the leadership, governance model, institutional arrangements and future value proposition needed to strengthen multi-disciplinary and multi-sectoral participation to address the drivers for change

Addressing sustainable development challenges and societal demands for knowledge on-demand, calls for new leadership styles, governance models and institutional arrangements; and the recognition that we need to deliver a new value proposition so we can solve our most pressing social, economic and environmental challenges - leaving no one behind.

As geospatial leaders, we have an excellent starting platform to grow national digital economies and open doors for new partnerships. The web, global SoS, mass social media, IoT and global 'commercial' geospatial platforms have given rise to more information being accessible to more countries and citizens, than ever before.

However, these same technologies have also created corresponding leadership challenges, particularly around "how to make sense of multimodal data flows in a globally interconnected geospatial information ecosystem, and manage the plethora of diverse data and ensure its ethical use."



New data governance and digital knowledge management strategies will be required (GW, 2021) if the future geospatial information ecosystem is to evolve, thrive and remain sustainable and equitable. The question is, "how will these new governance tools be brought to bear in such a complex collaboration environment?"

It is becoming clearer that a common 'Global Geospatial Knowledge Governance Framework' is required to guide how data is to be created, managed and processed to democratize knowledge in the interest of individuals' needs, good governance, developmental interests, and humanitarian and global crisis management.

Strong and informed leadership will be crucial. As is the case with an 'ecosystem' itself, complex problems require the integration of diverse information (physical, social, economic and biological) drawn from local to global sources and from across a multitude of government, business, open source and academic contributors.

In a globally interconnected ecosystem, the international geospatial community will need to work cooperatively towards a shared vision. Overcoming sustainable development challenges will require global leadership in contributing to the digital commons, setting universal data governance, policy frameworks and clear digital knowledge management strategies. A failure to find some level of consensus may serve to speed up the widening digital divide between wealthy and developing countries.

Global geospatial strategies and initiatives are the vehicle to lead collective action on priority sustainable development challenges. They also provide guidance to formulate the delivery of national strategies and plans, and promote the creation of knowledge to solve national sustainable development challenges.

SDI governance models are typically nationally focused, hierarchical and government led. Future governance models will need to be more inclusive of the broader stakeholder group (private sector, academia, open-source community, policy makers, community groups and beneficiaries) - to open doors to partnerships and broaden the scope of policy solutions, increase capacities for information sharing and learning, and to advance policy changes.

The rapidly evolving technological landscape means that future global data governance needs to be an agile non-hierarchical array of organizations; encompassing not just the public sector, but also the, private, non-profit, academic and community sectors. These multi-actor governance configurations will need to be able to coalesce with traditional hierarchical SDI governance models, and expand participation and diversity of views by including a broader spectrum of stakeholders.

Strategic Pathway Elements	Spatial Data Infrastructures	Future Geospatial Information Ecosystem
Leadership	Strategies and plans on geospatial data management	Global interconnectivity to leverage knowledge creation opportunities
Institutional Arrangements	Traditional hierarchical SDI governance arrangements	Agile non-hierarchical inclusive multi-actor governance configurations
Value Proposition	Access to fundamental data	Affordable and equitable access to knowledge
Governance Model	SDI data governance models	Global Geospatial Knowledge Governance Framework

Figure 7. Governance and Institutions Strategic Pathway – the Step Change

This will require governance mechanisms that:

- **Operate and draw expertise from all levels of governance** – local, state, transnational, international and private sector governance - to engage in discourse and form collaborative efforts to achieve the expected outcomes of the SDGs (and other agreed agendas).
- **Support engagement with multidisciplinary professions** and end users across all sectors (health, transport, agriculture, planning and so on) to promote the creation of more integrative data to support state-of-the-art geoanalytics to deliver knowledge on-demand.
- **Achieve innovation diversity** by reaching out to the underrepresented (race, ethnicity, gender, age, socio-economic status, religious belief, political views, disabilities or other end points) for their unique perspectives and skills.

A focus on the democratization of knowledge, as opposed to focusing on data access, is the new value proposition. Equitable and affordable access to accurate knowledge, and solutions to the most complex of world problems, can only be delivered through a new approach to geospatial data governance and knowledge management. This will require systematic change and new thinking, attitudes and behaviors, particularly if we are to leverage local to global insights to better understand what was, what is and what could be.

In summary, as we move beyond SDIs to a new geospatial information ecosystem, governance arrangements will need to shift in focus (Figure 7):

- **Leadership:** *From* strategies and plans on geospatial data management; *to* global interconnectivity to leverage knowledge creation opportunities.
- **Institutional Arrangements:** *From* traditional hierarchical SDI governance structures; *to* agile non-hierarchical inclusive multi-actor governance configurations.
- **Value Proposition:** *From* access to fundamental data; *to* affordable and equitable access to knowledge.
- **Governance Model:** *From* SDI data governance models; *to* align with the Global Geospatial Knowledge Governance Framework.

Policy and legal

This strategic pathway guides the development of a policy and legal framework that will deliver the necessary data and geoanalytics to achieve a knowledge-focused geospatial information ecosystem to address the drivers for change.

As we move to a globally interconnected geospatial information ecosystem where accurate and unbiased knowledge is the end point; the basis of our geospatial policies will need to shift towards knowledge creation, governance, security, ownership, responsible use and trustworthiness. These concepts contrast with conventional SDI policy and legal frameworks that focus on geospatial data – its creation, management, and accessibility.

In addition to 'Open Data' polices and data sharing, we will need increased focus on sharing geoanalytics and knowledge inferencing capabilities. In this way, new levels of machine-generated content will be realized as part of the burgeoning knowledge economy stimulated by the new ecosystem. As a consequence, existing SDI policies and laws will be pressure-tested, potentially creating new legal, regulatory and technical issues that need to be addressed, as the new ecosystem evolves and scales.

The overriding issue will be how to protect people and safeguard fair markets in a globally connected world, while also enabling innovation to prosper and businesses to thrive. Today, everything can be wirelessly interconnected and customized by simply adding lines of software code. While this is heading in the right direction, in terms of the democratization of knowledge, it can be dangerous when new applications are relied on in critical settings and do not meet the necessary standards of guaranteeing respected rights, privacy, security and the protection of the vulnerable.

Technological advancements are putting pressure on governments to be more effective in protecting individuals' privacy, intellectual property and sensitive

[7] Integrity – communicating data provenance, quality, and any potential bias in geoanalytics.

information. Policy development typically lags behind technological innovation. We have seen this with emergent ubiquitous sensors, remote-controlled drones, self-driving vehicles, artificial intelligence (AI), biometric monitoring, surveillance technology and facial-recognition software. These mass accumulation devices can cause cybersecurity or privacy risks and more policy problems than they solve.

Nonetheless, we now have the opportunity and potential to overcome these same issues by looking for solutions within these technologies themselves. This requires a shift in thinking. Most SDI policies and laws are currently geared towards data that is human-accessible, readable and reusable, such as data sharing, end user licenses, copyright and intellectual property – all of which are managed and administrated by people.

In the future, data creation and geoanalytics will be performed automatically by machines without the need for human intervention. We therefore need machines to be able to simplify, execute and enforce policy accountability in areas such as privacy, cybersecurity, information bias, and the ethical use of data, information and knowledge. This means developing on-the-fly methods, such as to de-identify data and prevent re-identification.

Automation is already occurring. Blockchain technology is now providing a secure ledger to resolve issues of security, scalability and privacy in the healthcare and land sectors; Digital Rights Management (DRM) allows publishers to control what users can do with their works through encryption; application code is used to deliver role-based access control; and digital identity programs are enabling people to simply and securely establish a digital identity and safely reuse that identity to transact with government and the private sector – with their privacy assured (Wyatt *et al*, nd).

However, work is still required to provide accountability for how data is reused. For instance, DRM needs to be integrated into geospatial concepts. Data itself will need to be self-describing so that machines know what they can and cannot do. Columns and rows of sensitive data need to be encrypted so they are only accessible to machines with the right access code, and fail safes are needed to prevent re-identification when

Strategic Pathway Elements	Spatial Data Infrastructures	Future Geospatial Information Ecosystem
Legislation	National policy and legal frameworks for the democratization of data	Global guidance for national policy and legal frameworks for the democratization of knowledge
Policies, Norms and Guides	Standalone geospatial policies and laws for data management, access and use.	Geospatial policies and laws interoperable with wider government digital policy and global knowledge management agendas
Governance and Accountability	A reliance on humans to comply with geospatial data policies and laws	Use of technology to enforce geospatial knowledge management and use, as well as internet compliance
Data Protection, Licensing and Sharing	Open data policy balanced with protection of sensitive material and respected rights	Knowledge creation and the ethical challenges of information bias, digital identities, usage and cybersafety

Figure 8. Policy and Legal Strategic Pathway – the Step Change

data is reconstituted, integrated and/or linked to other publicly available data, such as social data, where it may impinge on privacy. Standards for self-describing interrelations of data will be needed to complement new policy requirements. Whilst, data protection legislation is growing, particularly relating to privacy; policy initiatives are nationally-based implementations and inconsistencies in approach will have a detrimental impact on global interconnectivity. This calls for a global geospatial policy and legal framework to provide guidance and promote uniformity in policy application across all countries.

Importantly, global policy guidance means that all countries have access to the same information – leaving no one behind. This includes human readable policy, and importantly, machine-actionable policy implementations.

The challenge of a Global Geospatial Policy and Legal Framework is that it will need to deliver quadruple impact to:

a. stimulate technical innovation including growing the range of analytics, IoT devices and automation of use cases;

b. achieve democratization of knowledge (openness);

c. provide public confidence in how information is used and protected; and

d. communicate 'knowledge' reliability and integrity[7] to end users.

In addition, a Global Geospatial Policy and Legal Framework will need to be horizontally and vertically scalable to accommodate regional, national and local needs, as well as wider government digital policy. It will also need to be adoptable by the private sector, open-source community and not-for-profits, academia and other suppliers and end users, in addition to government.

In summary, as we move beyond SDIs to a new geospatial information ecosystem, national policy and legal frameworks will see a shift in focus (Figure 8):

- **Legislation:** *From* national policy and legal frameworks that typically focus on the democratization of data; *to* establishing global guidance for national policy and legal frameworks for the democratization of knowledge.
- **Policy, Norms and Guides:** *From* standalone geospatial policies and laws for data management, access and use; *to* establishing geospatial policies and laws that are interoperable with wider government digital policy and global knowledge management agendas.
- **Governance and Accountability:** *From* a reliance on humans to comply with geospatial data policies and laws; *to* using technology to enforce geospatial knowledge management and use, as well as internet compliance.
- **Data Protection, Licensing and Sharing:** *From* open data policy balanced with the protection of sensitive material and respected rights; *to* additionally include knowledge creation, and the ethical challenges of information bias, digital identities, usage and cybersafety.

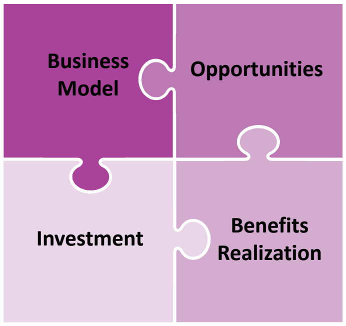
Financial

This strategic pathway provides guidance on the business models and financial partnerships that will characterize the future geospatial information ecosystem and address the change drivers for change.

Investments in SDIs are typically framed in terms of a business case for a project or program of work that targets a specific problem. The implementation of a solution, bought at a cost, subsequently delivers financial and social benefits – both tangible and intangible. This is the traditional provider/purchaser business model.

SDIs were built during the wave of web 2.0 business models and support private sector revenue generation; where online content (e.g., digitization of newspapers), marketplaces (Amazon and eBay), Software as a Service (SaaS) (e.g., B2B businesses), sharing (gig) economy (e.g., Uber, Airbnb), and advertising (e.g., Google and Facebook) have launched the world's most valuable companies and showcased their innovative use of geospatial information.

Business models are constantly evolving. With advanced Internet technologies, such as blockchain, we are starting to see secure trusted decentralized networks based on the exchange of tokens as a safe way to collaborate with Internet strangers and commit funds (Kremenova and Gajdos, 2019). To illustrate, imagine government (an actor) releasing content, such as demographic statistics, to a company(s) in exchange for tokens to access different content, such as imagery. No money is exchanged as such, each actor has something that the other values. For government to participate in these new business models, data needs to be of value to business (i.e., machine friendly and easily consumed) to support on-selling value added commercial services as cheaply as possible in return for tokens.



By and large, organizations find it difficult to attract geospatial investment, and trying to explain a new 'knowledge' value proposition to policy makers will be an additional hurdle, particularly for lower income countries. There are however, new business model opportunities in the future ecosystem that provide a systematic structured and end-to-end process that are suited to developing economies.

These models require a new approach to financing through partnerships, and the ability to exploit online technologies that focus on knowledge and people and the creation of new value propositions. For this to occur, the future ecosystem needs to be formed in a way that leverages existing business models, as well as exploiting advancing technologies to create new business models; ones that favor developing countries where funds, resources, skills and knowledge are transactable.

The private sector is key to driving this change, particularly companies that provide global data services. However, the challenge for many developing countries will be the lack of funds to get a foothold into 4IR technologies, knowledge services, and Earth Observation (EO) data vaults. New innovative private sector business models are now spawning new ideas, disrupting the market, and helping to transition capability and capacity to capitalize on new opportunities. These include (Yee, 2020):

- **Crowd economy business model**, where people participate in a shared platform typically towards innovation and problem-solving. This is sometimes referred to as staff-on-demand, which is a break from traditional organizational structures, and offers a new way to attract and retain skillsets. These business models are particularly suited to geospatial content providers. They offer new ways for consumers to become part of a company's 'content tribe', by providing mechanisms to incentivize 'content' contributions. Essentially, this turns consumption into a two-way street.
- **Data/free economy business models** where companies offer free maps/data and services e.g., navigation and search tools, in exchange for being able to monetize users' information and preferences. This is essentially a 'bait and hook' model that is not for everyone, but the advantages often outweigh the negatives.

Strategic Pathway Elements	Spatial Data Infrastructures	Future Geospatial Information Ecosystem
Business Model	Traditional bi-directional Purchaser/Provider Models	Decentralized autonomous business models enabled by advanced internet technologies
Opportunities	Creation of geospatial data to support the delivery of new products and services	Creation of geospatial analytics to support knowledge on-demand
Investment	Investment in geospatial data and interfaces for SDI programs and projects	Investment in machine-readable data, AI, blockchain etc. enabling participation in global digital connectivity
Benefits Realization	Economic development and societal benefits derived from geospatial products and services	New revenue and cost savings from tokenized multimodal business opportunities

Figure 9. Financial Strategic Pathway – the Step Change

- **The smart economy business models** that utilize artificial intelligence (AI), blockchain, 5G, Big Data, and IoT to create newer and smarter products from data, which form a new addition to revenue streams.
- **Freemium models** where users have free access to data, software and limited services, with the option to pay for high quality/unlimited data access, software upgrades, value-added services and Apps.
- **The closed-loop business models**, often referred to as the circular economy, are inherently suited to the geospatial adage 'create once – use many times', which gives rise to environmentally-conscious consumers. Traffic Apps use density and road incident data from anonymized data from people using the Apps and crowdsourced data from motorized and other transport users. This information is sent to other App users. With 'knowledge on-demand' services, there is potential for more reuse and repurposing of data, generating production efficiency and positive society-wide benefits.
- **Decentralized autonomous business models**, refers to tokenized networks in which a financial or non-financial transaction record and self-enforcing program rules are maintained on a blockchain. This approach eliminates having to involve third-party entities in a transaction, which in turn, decreases cost and simplifies bureaucracy.
- **Geopolitical asset sharing**, in contrast to traditional donor funding models, focuses on sharing specific knowledge and knowhow typically as a way to strengthen relationships between countries, but more often as part of a program of international collaboration. As an example, the Australian Geoscience Data Cube was intentionally developed using open-source technology and is now a global analysis platform freely available to other governments to adapt and implement their own versions (GW, 2017). ■

In summary, as we move beyond SDIs to a new geospatial information ecosystem, financial arrangements will see a shift in focus (Figure 9):

- **Business Model:** *From* traditional bi-directional purchaser/provider models; *to* decentralized autonomous business models enabled by advanced Internet technologies.
- **Opportunities:** *From* the creation of geospatial data to support the delivery of new products and services; *to* the creation of geospatial analytics to support knowledge on-demand.
- **Investment:** *From* investment in geospatial data and interfaces for SDI programs and projects; *to* investment in machine-readable data, AI, blockchain and other advanced technologies enabling participation in global digital connectivity.
- **Benefits Realization:** *From* economic development and societal benefits derived from geospatial products and services; *to* new revenue and cost savings from tokenized multimodal business opportunities.

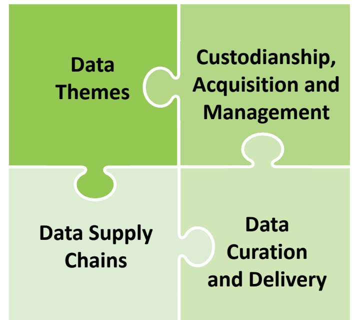
Data

This strategic pathway establishes a geospatial data framework and custodianship guidelines for best practice collection and management of integrated geospatial information that is appropriate to ensure cross sector and multidisciplinary collaboration.

SDIs have characteristically given priority to providing access to fundamental data themes that underpin and provide a common reference for a wide-range of applications. Establishing this data framework is a logical first step. Fundamental data has significant reuse value, and being able to repurpose this information many times, makes sound economic sense.

As we move from data to knowledge, the urgent questions we have of data have become the priority. National and global sustainable development agendas identify these important questions, but not necessarily the quality of data (completeness, coverage, accuracy, and currency) and the geoprocesses needed to solve these challenges. The future calls for 'use case frameworks'[8], which list the steps for how a use case is carried out.

National use case frameworks identify, prioritize and specify data collection, quality improvements, geoanalytics, and the policies and standards needed to transform data inputs into knowledge outputs. Targeted use cases allow us to develop road maps that consider digitalization[9] priorities in relation to the most important questions we need answered.



These 'use case' road maps will often lead to the development of integrated SoS to deliver a specific function/service, such as Smart Cities to manage city assets, resources and services. They will also be used to address societal problems from a local to global level within the Geoverse through communication interfaces. For instance, understanding sea level rise at a national level requires local tide gauge information,

[8] Use Case Frameworks – refer to a specification that describes how a goal is to be accomplished.
[9] Digitalization – referring to the adaption of systems, data and processes to enable operation by computers and the Internet.

dam capacities, ocean currents, glacial melt and water temperature etc., as well as the processes that integrate, analyze and provide visualizations of interpreted information. Processes are repeatable, and local information can be scaled and pieced together to give a better understanding of global sea level rise (Cassidy, 2020); its interrelationship with global climate change, and inferred future impacts e.g., risk to infrastructure, livelihoods and biodiversity.

A global use case framework is needed to provide guidance to countries establishing their national use case frameworks. The SDGs Geospatial Road Map (UN-GGIM, 2022) provides excellent support for road map development, particularly from the perspective of 'data readiness'. Further direction on specific use case designs from a 'knowledge on-demand' perspective, are required. These use case designs specify data quality, step-by-step geoprocessing and rules to support automation, policies needed to provide protections[10], and interoperability standards that enable participation in an ecosystem that uses mainstream web approaches to interconnect data in real time.

Digitalization is intrinsic to 4IR technologies; generating huge amounts of data to address the critical challenges we face. Big Data includes concentrations of data generated by mobile phone users, social media and IoT sensors. These sources of data characterize the web of data today, but they are not easily integrated and analyzed with fundamental geospatial data held in an SDI catalog. This will change once SDI data catalogues are exposed to the web; to become one of many 'multimodal' communication interfaces.

To enable this capability, human readable SDI catalogues, will need to be augmented by machine discoverable interfaces, potentially using a broker and a machine-readable metadata catalog (Ivanova *et al*, 2020) to manage interactions between a user application, from within the Geoverse, and the geospatial resources available in the SDI catalog.

Strategic Pathway Elements	Spatial Data Infrastructures	Future Geospatial Information Ecosystem
Data Themes	National data frameworks focusing on fundamental geospatial data themes	National use case frameworks contributing to priority challenges on a local to global scale
Custodianship, Acquisition and Management	Geospatial data to support the delivery of new products and services	Linked data and geoanalytics that enable knowledge on-demand
Data Curation and Delivery	Manual value-added data delivered via data catalogues	Automated real time knowledge delivered via AI and machine accessible data registries
Data Supply Chains	Centralised bi-directional supply chains	Decentralised multimodal communication interfaces

Figure 10. Data Strategic Pathway – the Step Change

[10] Protection is used here in an all-encompassing way - individual privacy, cybersecurity, safety, ethical use, misleading bias etc.

Machine-actionable data and geoprocesses for specific use cases are an enabler for 'knowledge on-demand', as well as for knowledge inferencing to better understand and solve sustainable development challenges. Increasingly machines are autonomously undertaking geospatial data processing and applying sophisticated geoanalytics, leading to an increasing number of cases where algorithms make final action-orientated decisions (EUROGI, 2021).

This digitalization approach supports developing countries, as process automation and machine-readable data and methodologies are inherently shareable. The all important first step, is for custodians to transition data to a machine-readable format and according to FAIR[11] data principles. Access to machine-readable data will stimulate innovation and creativity. The conversion process requires little technical overhead; with mainstream web Application Programming Interfaces (APIs) able to be converted to machine-readable Linked Data[12] using JavaScript Object Notation for Linked Data (JSON-LD)[13], schema.org, OpenAPI, etc., (Atkinson, 2020). Ordnance Survey UK and Ireland have pioneered the process - exposing large geospatial resources via machine accessible data registries and a Linked Open Data interface (Ivanova *et al*, 2019). The second step is to ensure machine-readable data is findable. This requires each resource, ideally down to the feature level, to have a globally persistent identifier[14] (Parsons, 2020).

The globalization of 'knowledge on-demand' will require semantic data models and data vocabularies that provide relationships between objects to enable the integration of data about people, business and the environment. These semantic data models are key to supporting and empowering decision making – be they a model of a fundamental data theme or a more complex digital twin. Semantic models provide the meaningful interoperability needed to enable a sophisticated chain of geoprocesses to be coded for particular use cases; and once encoded, they can be shared, reused and repurposed.

In summary, as we move beyond SDIs to a new geospatial information ecosystem, data management will see a shift in focus (Figure 10):

- **Data Themes:** *From* National data frameworks focusing on fundamental geospatial data themes; *to* National use case frameworks contributing to priority challenges on a local to global scale.
- **Custodianship, Acquisition and Management:** *From* geospatial data to support the delivery of products and services; *to* Linked data and geoanalytics that enable knowledge on-demand.
- **Data Creation and Delivery:** *From* manual value-added data delivered via data catalogues; *to* automated real time knowledge delivered via AI and machine accessible data registries.
- **Data Supply Chains:** *From* centralized bi-directional supply chains; *to* decentralized multimodal communication interfaces.

[11] FAIR data principles – Findable, Accessible, Interoperable, Reusable https://www.go-fair.org/fair-principles/
[12] Linked Data – structured data that is interlinked with other data, such that it can be read by semantic queries.
[13] JSON-LD JavaScript Object Notation for Linked Data https://json-ld.org/
[14] Identifiers – data is structured and tagged in a way that it can be read directly by machines.

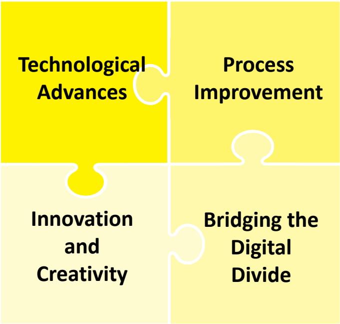
Innovation

This strategic pathway recognizes that innovation has the potential to stimulate, trigger and respond to rapid change, leapfrog outdated technologies and processes, and bridge the geospatial digital divide.

As we move toward a future geospatial information ecosystem, the challenge will be "how to inspire productivity improvement and innovation, and deliver change without exacerbating the already growing geospatial digital divide".

A pre-requisite to establishing an SDI is to digitally transform hardcopy geospatial assets and modernize data sharing processes – an aspirational objective for many developing countries, and the tipping point for leapfrogging to a future ecosystem.

Data digitization[15] leapfrog opportunities exist. We have progressed beyond flatbed scanning, line scanning and heads-up digitizing. Machine learning is enabling powerful feature extraction capabilities that are cutting data acquisition times[16]; drones are providing 'just-in-time' aerial coverage, street view imagery is enabling desktop verification of road assets etc., (Biljecki and Ito, 2021); vehicle GPS are used to rapidly capture road centerlines (Arman and Tampere, 2020); and mobile Apps are being used to digitize fit-for-purpose land boundaries (GIM, 2015).



Having appropriately formatted data will be crucial to participating in the Geoverse. It is touted that artificial intelligence will provide a major leap in knowledge and capability for mankind to progress in ways that were once only imaginable (Thomas, 2022). However, the difficulty for developing countries is that AI is a learning

[15] Digitization here refers to the process of converting graphical information into a digital format.
[16] A wide range of geospatial machine learning research papers are available at https://www.microsoft.com/en-us/research/project/geospatial-machine-learning/publications/

technology and needs digital data from the past and present to predict the future, and all its variables.

Leapfrog opportunities to 'knowledge on-demand' is difficult to predict, as we are not there yet. However, it is clear that 4IR technologies, Internet communication interfaces, process automation, semantic web tools, AI and global digital connectivity will all be a part of our future.

As in the past, the most advanced countries will likely provide the knowledge, support and lessons learned so that others can follow. We can already see this process happening with the growing number and nature of geospatial digital twins in urban planning, livestock monitoring (Geopard, nd), crop growth (Pylianidis, 2020), manufacturing, healthcare, construction and retail etc., (Dilmegani, 2022). These digital twins are increasingly employing sophisticated models, often incorporating AI and machine learning for 'what if' queries that test real world scenarios in a virtual environment. Similarly, the number and nature of SoS is expected to grow; with systems progressively moving from fixed line communication interfaces to interconnect with the web of data and ecosystem of geoanalytics.

As we seek to narrow the geospatial digital divide moving forward, it is time to go a step further and start sharing workflows, algorithms and codes that enable the vast quantities of SDI data to be converted into purpose-driven information (Belgui, 2020). Sharing geoanalytics capabilities will grow the potential for 'knowledge creation' globally, and in doing so, deliver digital equity to communities that would not otherwise have access to this knowledge. Simply put, the availability of automated workflows will enable us to leverage current SDIs by transforming them from merely data pools to participate in a data analysis ecosystem serving various societal needs (Belgui, 2020).

Automation of knowledge will be a major disruptor over the next 10 years. Higher levels of spatio-temporal resolution and massively increased processing power, and machine-readable data are expected to play an increasingly dominant role in knowledge creation. However, without suitable geoanalytics, data cannot be put to good use (EUROGI, 2021). There is now growing pressure to automate domain knowledge activities, such as the creation of knowledge representation models and rule formulation to enable user queries to be processed meaningfully.

Strategic Pathway Elements	Spatial Data Infrastructures	Future Geospatial Information Ecosystem
Technological Advances	Digitization and diversification of data sources, and cloud computing	4IR technologies, Internet, geoanalytics, semantic tools, sensor networks, AI and edge computing
Innovation and Creativity	Business innovation: data, products and services	Social innovation: knowledge on-demand and ethical human-centered design.
Process Improvement	Digital transformation, increased productivity and improved data quality	Enriched knowledge economies, responsive communications and enhanced reliability of knowledge
Bridging the Digital Divide	G2G relationships that deliver hardware, software and knowhow	Knowledge sharing that delivers inclusivity and digital equity for communities

Figure 11. Innovation Strategic Pathway – the Step Change

Geoanalytics need to evolve to enable a shift in focus from data to services that enable knowledge creation – the new value proposition. These geoanalytics are expected to embrace fully matured semantic and AI reasoning technologies to become autonomous, proactive, content-exploring, self-learning, collaborative and content-generating. Understanding the meaning of what people (end users) are doing and need, and not just providing links to web pages, will require developers, singularly or in collaboration, to use self-descriptions, digital identities or similar preferencing techniques to deliver future context-aware programs that are relevant to the user. In addition, edge computing, where analytics are brought closer to the source of data, will also play a significant role, particularly where real time decision-making is required.

In this new world, ethics must play an important and active role in guiding human-centered approaches to technology development. Examples might be services interacting with sensors and implants, natural-language services, and social virtual reality services.
It will be important for the geospatial community to take ownership of the tools available to us as creators of knowledge and users of technology. The global digital infrastructure, including positioning systems, space, the Internet, mobile and fixed digital networks, cloud and service platforms, APIs, automated systems, analytics and applications, IoT and user devices (EUROGI, 2021) – all influence how geospatial technologies develop into the future. While all elements, alone or together, contribute to greater economic benefits, social well-being and environmental management (EUROGI, 2021), it will be up to the geospatial community to guide the innovation trajectory with a social conscience. ■

In summary, as we move beyond SDIs to a new geospatial information ecosystem, innovation will shift in focus (Figure 11):

- **Technological Advances:** *From* the digitization and diversification of data sources, and cloud computing; *to* 4IR technologies, Internet, geoanalytics, semantic tools, sensor networks, AI and edge computing.
- **Innovation and creativity:** *From* business innovation focused on data, products and services; *to* social innovation focused on knowledge on-demand and ethical human-centered design.
- **Process Improvement:** *From* digital transformation, increased productivity and improved data quality; *to* enriched knowledge economies, responsive communications and enhanced reliability of knowledge.
- **Bridging the Digital Divide:** *From* Government to Government (G2G) relationships that deliver hardware, software and knowhow; *to* knowledge-sharing that delivers inclusivity and digital equity for communities.

Standards

This strategic pathway establishes and ensures the adoption of standards, best practices and compliance mechanisms for enabling data and technology interoperability to deliver integrated geospatial information and create location-based knowledge.

Voluntary consensus standards[17] are one of the most successful initiatives of the SDI paradigm. Geospatial data and technology interoperability has succeeded, to a situation where geospatial data from different domains, collected at different times, at different scales, and potentially in different formats can be easily and seamlessly integrated, reused and repurposed (EUROGI, 2020). Standards for SoS engineering also exist, and these are generating operational efficiencies when considered at the outset of any system design.

Consensus-based open standards will play an even more crucial role as we head towards the Geoverse. Geospatial data on the web requires that the relationships between data, and the meaning of objects within data, be accessible. A machine does not know what to do with data on the web if there is no associated intelligence.

This is where knowledge representation methods come in. Knowledge representation methods (such as vocabularies and ontologies) are used to create knowledge graphs[18] (or networks between objects, events, situations and/or concepts) that illustrate the relationship between real-world entities (IBM, 2021)

However, standard models for knowledge representation are yet to be developed for many domains of knowledge. They do however exist. A good example of mature foundational knowledge representation (ontology[19]) models are NASA's

[17] Voluntary consensus standards referred to here are developed by **OGC** – Open Geospatial Consortium, **ISO** – International Organization for Standardization and **IHO** –International Hydrographic Organization

[18] A knowledge graph is a structured Knowledge Base, that stores facts in the form of relations between different entities/objects. It was popularized by Google in 2012, where it is used to enhance search engine results.

[19] An ontology, like a data vocabulary, is a method used to represent knowledge.

Semantic Web for Earth and Environment Technology (SWEET) ontologies that have become a pseudo standard for scientists in the Earth and Environmental Sciences (DiGiuseppe *et al*, 2014).

Standardization of knowledge representation models will be important moving forward; the primary aim of which, is to share a common understanding of the structure of data among users and software agents. Standards will mitigate semantic interoperability issues down the track. There are significant benefits to reusing standard knowledge representation models. Currently, locating knowledge repositories is *ad hoc*, and compliance is a cultural change issue. It may take time before reuse of 'real world knowledge representation models' become the accepted norm (Arnold *et al*, 2019).

The adoption of FAIR data principles by custodians will be integral to optimizing the use of geospatial data in the future geospatial information ecosystem - SDIs, SoS and the Geoverse. The importance of FAIR data (Findable, Accessible, Interoperable and Reusable) is expressed in its principles, which are designed to (ARDC, nd):

- Support knowledge discovery and innovation both by humans and machines;
- Support data and knowledge integration;
- Promote sharing and reuse of data;
- Be applied across multiple disciplines; and
- Help data and metadata to be 'machine-readable', supporting new discoveries through the harvest and analysis of multiple datasets and outputs.

Machine-readable data is one of the pillars for knowledge on-demand. Publishing guidelines for machine-readable data are articulated in the 5-star Open Linked Data Scheme, as a standard for publishing data on the web (Holborn, 2014). However, standards are still required to communicate the quality and reliability of interpreted information, which is pivotal to understanding the trustworthiness of knowledge (Peng *et al*, 2021; Peng *et al*, 2022).

Strategic Pathway Elements	Spatial Data Infrastructures	Future Geospatial Information Ecosystem
Standards Governance and Policy	A commitment to assess, establish, and maintain a common standards framework	A commitment to adopt standard models for knowledge representation
Technology and Data Interoperability	Voluntary standards for data and technology	Anticipatory regulations, FAIR data and human-centered standards for knowledge creation
Compliance Testing and Certification	Regular assessments, training, government mandates, performance metrics, testing and certification	Regulatory sandboxes, proof of concepts and incentives for deploying and scaling 4IR technologies
Community of Practice	Sharing and leveraging data and technology standards	Inclusive and participatory roles in data vocabularies, digital twins, and other 4IR standards development

Figure 12. Standards Strategic Pathway – the Step Change

Standards will need to evolve as we transition forward. It is anticipated that open geoprocessing and analytics tools will be created at a rapid rate, potentially creating personalized or niche market ready outputs. These tools will ideally, be developed in a standards framework managed by the global community, and potentially through a creative commons licensing framework (Mohamed-Ghouse, 2020) to encourage the sharing and reuse of code, as is currently done with data.

Moreover, machine-human interfaces will increasingly be articulated through voice and visual query commands rather than just through tapping on keyboards or swiping screens. How geospatial concepts, questions, statements, hand and eye gestures, and local dialects will be interpreted and managed will become an important area within which standards and protocols will be required (EUROGI, 2022).

The standards community has a huge role ahead in leading and incentivizing the use of standards for deploying and scaling 4IR technologies. Open standards will be an underpinning element. However, the pace of technological change is likely to outstrip standards development, with de facto standards playing an early role in innovation (OGC, 2022). New rules of engagement and standards will be necessary to help manage growth and change, particularly with the development of new systems and applications.

Regulatory sandboxes will be important to standards development. Take drone delivery service as an example. Who will manage delivery box IDs and their ownership; oversee installation and relocation; what will be the standards for drone speed, height and quotas; and how will you know if the delivery box is empty? Geospatial standards and human-centered design will be integral to applications that depend on location-based technologies and how consumers want to use this technology. ■

In summary, as we move beyond SDIs to a new geospatial information ecosystem, standards will see a shift in focus (Figure 12):

- **Standards Governance and Policy:** *From* a commitment to assess, establish, and maintain a common standards framework; *to* a pledge to create a responsible knowledge representation standards framework.
- **Technology and Data Interoperability:** *From* voluntary standards for data and technology; *to* anticipatory regulations, FAIR data and human-centered standards for knowledge creation.
- **Compliance Testing and Certification:** *From* regular assessments, training, government mandates, performance metrics, testing and certification; *to* regulatory sandboxes, proof of concepts and incentives for deploying and scaling 4IR technologies.
- **Community of Practice:** *From* sharing and leveraging data and technology standards; *to* an inclusive and participatory role in data vocabularies, digital twins, and other 4IR standards development.

Partnerships

This strategic pathway establishes cross-sector and interdisciplinary cooperation, coordination and collaboration with all levels of government, the geospatial industry[20], private sector, academia, and the international community, with the objective to deliver on the drivers for change.

Partnerships are essential to achieving the future geospatial information ecosystem and creating value for those who participate. The knowledge-value of geospatial data is amplified when it is combined, contrasted and analysed with other datasets (GW, 2020). The partnerships and collaborations established today, will be a crucial starting point for transitioning to the new future.

Today's digital networks enable more holistic and inclusive partnerships to evolve; empowering governments to widen their partnership network to include cross-sector and interdisciplinary collaborators, and partnerships with the private sector and academia. These partnerships underpin the success of SoS and research challenges. Data sharing and coordination strategies between organizations maximise system integration and value activities within the supply chain.

We are currently at a juncture between traditional partnership models and new models enabled through the decentralization of the web. While the web is still evolving in terms of partnership potential, the notion of a Geoverse as a decentralized network, lends itself to promoting partnership opportunities through peer-to-peer networks in which the entire community of users can participate. This concept is different from the centralized network, where communication is largely via a cloud of physical servers, owned and operated by a few large corporations that act as third-party providers.

[20] In some countries and regions, Africa in particular, the term 'geospatial industry' is an inclusive term that captures the entire geospatial sector as a 'geospatial discipline'.

With decentralized peer-to-peer protocols now a viable option, direct partnership channels can be established for data, technology, resource, knowledge and process sharing etc; creating opportunities for a wider range of partnerships to materialise and providing new horizons for 'knowledge' innovation. These collaborative and creative partnerships are likely to have a profound effect on the way users interact with geospatial information in the future to gain knowledge and new insights.

However, we are yet to realise the full potential of a decentralized multimodal network for generating geospatial intelligence; where AI, geoanalytics and blockchain deliver a new era in decision-making abilities. There is much work for the geospatial community to do, to put into practice the geospatial data, processes, standards, policies, governance and technologies needed to deliver knowledge on-demand to every citizen – leaving no one behind.

Traditionally, partnerships have been led by government, with public-private-partnerships being a regulated area. As we move to the new ecosystem, we are likely to see a reversal, with the private sector instigating partnerships through decentralized autonomous business models. While it is difficult to know how these new models will evolve in the long term, it is likely that payment tokens, enabled by blockchain technology, will provide a new way for the private sector to do business with government.

Global resource sharing partnerships will take on a new level of importance as countries move to implementing more integrated systems and adopting the decentralized web as a new way to innovate. For example, sharing geospatial information 'economic studies' will be key to helping countries plan geospatial investments and forecast returns on investment. A simple benefits transfer[21] can make cost-benefit analysis more accessible for policy makers in developing countries, by reducing the cost and time involved in producing an assessment from scratch.

It is expected that the Open Source Community will be a major partner and contributor to the high-performance collaborative development environments needed to realise the full potential of the Geoverse. For decades, OpenStreetMap, Open Source Geospatial Foundation,

Strategic Pathway Elements	Spatial Data Infrastructures	Future Geospatial Information Ecosystem
Cross Sector and Interdisciplinary Cooperation	Investment, data and resource sharing	New horizons for innovation and knowledge creation
Private Sector and Academia Collaboration	Government led regulated public-private-partnerships	Private and academia sector led decentralized collaborations
Community Participation	Use of VGI and crowdsourcing to collect local information	Citizen sensing technologies that lead to new innovations and problem solving
International Collaboration	Strategic partnerships that support national initiatives and agendas	Collaborations that support both national and global innovations

Figure 13. Partnerships Strategic Pathway – the Step Change

[21] The benefits transfer method is used to estimate economic values for geospatial information and services by transferring available information from existing studies already completed in another location and/or context

GitHub and many others have contributed to the development of geospatial data and software for the benefit of many and, in particular, developing countries.

With the rise of collaborative consumption, sharing platforms, sensor technologies and wearable sensing devices, Volunteered Geographic Information (VGI) is expected to become far more sophisticated. Body sensors, mobile GPS and self-driving vehicles can collect and filter data at rapid rates. With the right protections and validation processes in place, it is likely that citizen sensors will become much more prominent than they are today. Citizen-derived data is expected to grow considerably and be used in increasingly diverse ways (Antoniou *et al*, 2017).

At present, it is unclear if the technology to enable new partnership models with come first, or if partnerships will need to be established first to drive the implementation of collaborative technologies and enable them to thrive. What we do know, is that knowledge is born through collaboration, and inactivity will not help us to achieve our goals. ■

In summary, as we move beyond SDIs to a new geospatial information ecosystem, partnerships will see a shift in focus (Figure 13):

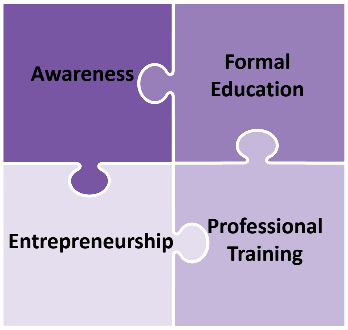
- **Cross Sector and Interdisciplinary Cooperation:** *From* investment, knowledge and resource sharing; *to* new horizons in innovation and knowledge creation.
- **Private Sector and Academia Collaboration:** *From* government led regulated public-private partnerships; *to* private and academia sector led decentralized collaborations.
- **Community Participation:** *From* the use of VGI and crowdsourcing to collect local information; *to* citizen sensing technologies that lead to new innovations and problem solving.
- **International Collaboration:** *From* strategic partnerships that support national initiatives and agendas; *to* collaborations that support both national and global innovations.

Capacity and Education

This strategic pathway establishes enduring capacity development and education programs so that the value and benefits of integrated geospatial information management is sustained for the longer term.

This paper has raised new concepts and methods. Whilst it is tempting to leave some out for readability; they serve to illustrate the importance of the capacity and education pathway. Geospatial scientists are entering an era where geography, cartography, art and computing science are merging to a point where geographical study, the artistic rendering of the Earth, and innovative computing is expanding our sphere of study and creating a juncture where the fields of learning collide in the creation of knowledge.

A new 'workforce ready' skills development framework is required to understand capacity development needs going forward. Ideally, this should be championed at the global leadership level, providing guidance to both developed and developing countries, alike.
The framework needs to consider the future paradigm, the foundational concepts in computing and 4IR technologies; guidelines for education curricula; targeted and prioritized areas for professional development programs; and strategies to promote entrepreneurship and awareness raising generally.



How to tackle the education of undergraduates is one of our first challenges. The approach needs to deliver deep subject expertise in surveying, geospatial, geography and geodesy, but also generalist understanding and competency across diverse application domains within the broader IT domain (EUROGI, 2021). A more formal education in the fundamentals of computer science will be needed, particularly in how to set up machines to do geospatial tasks, and how to teach machines to teach other machines how to undertake tasks, which have a significant geospatial component (EUROGI, 2021). University courses will need to extend GIS-specific subjects to include broader geoanalytical education; bringing geospatial knowledge, AI, data science, sensor technologies, software development and business information systems together in differing degrees (GW, 2021, EULF, nd).

In addition, given the need to develop and broaden interdisciplinary partnerships, it makes sense to embed geospatial concepts into other disciplines – much like mathematics and English is done today (EUROGI, 2021). This will lead to cross pollination of task-oriented analytics for specific use cases; enriching ways to generate new knowledge and stimulate innovation opportunities.

Organizations need talented geospatial scientists to create digital twins, deliver location intelligence, conduct data integrations etc.; but there is massive demand for these skills across the tech industry (GW, 2011) and this will have an impact on how fast we move forward. Attracting new talent to the geospatial industry will be crucial. Capacity development plans will need to combine a range of awareness raising methods to target, engage and be inclusive of candidates from diverse backgrounds, age groups, cultures, values, abilities and knowledge.

Current messaging is focused on the power of geospatial information for social, economic and environmental benefit. This messaging needs to continue as it aligns with many peoples' values. However, we also need to attract imaginative and creative people; this means showcasing how a career in geospatial leads to their involvement in disruptive innovations that make good things happen.

The same approach applies to encouraging more entrepreneurs in the 'knowledge creation' space. Entrepreneurs will need professional development opportunities that provide intensive training in new and emerging paradigms, as well as an agile development environment that provides flexibility and fosters creativity, which are pivotal to growth in interconnected products, value chains, business models and ultimately knowledge on-demand applications and services.

Strategic Pathway Elements	Spatial Data Infrastructures	Future Geospatial Information Ecosystem
Awareness	Advocacy and promotion on the value of geospatial information	Education and outreach on the potential of disruptive innovations using integrated data
Formal Education	Deep subject expertise in surveying, geospatial, geography and geodesy	Foundational concepts in computer and Internet science and 4IR information technologies
Professional Training	Lifelong learning and development through hands-on experiences	Intensive development in new and emerging paradigms
Entrepreneurship	Capacity development leading to innovation and new business ventures	Collaborative innovation hubs that stimulate growth in interconnected products, value chains and business models

Figure 14. Capacity and Education Strategic Pathway – the Step Change

Capacity development is crucial to bridging the digital divide, and immersive 'hands-on' learning programs will 'best' contribute to ongoing workforce development and staff retention. In the short term, the emphasis on capacity development still needs to focus on the modernization of data resources, the implementation of sharing technologies and policy and governance – all of which underpin SoS implementations and participation in the future Geoverse.

Virtual 'professional development' environments will play a complementary role to on-the-job training; providing a broader global reach for academic institutions and networks to collaborate and deliver one-on-one or group training in foundational concepts in computer and Internet science and 4IR information technologies. This will be important to upskilling tomorrow's workforce.

Consumers of 'knowledge services' are expected to be the winners in the new paradigm. Non-GIS professionals will be able to speak their questions in normal conversational language to receive answers to complex questions; with AI (natural language processing and machine learning) operating in the background analyzing data and delivering answers; a process that would otherwise require human GIS operators.

Will automated 'knowledge services' mean the end of the geospatial professional? No. Knowledge services are simply a new interface with which we can use maps, charts, text, graphics etc., to convey visualizations of data in the context of the individuals' specific requirements. Nonetheless, to remain relevant in the longer term, geospatial scientists, professionals and practitioners will need to adapt their skills to the new paradigm. This includes being able to tap into the growing network of interconnected devices to access more data about the real world and being able to develop knowledge representations of the real world so that machines can do the heavy lifting in terms of locating, analyzing and processing Big Data. ■

In summary, as we move beyond SDIs to a new geospatial information ecosystem, capacity and education will see a shift in focus (Figure 14):

- **Awareness:** *From* advocacy and promotion on the value of geospatial information; *to* education and outreach on the potential of disruptive innovations using integrated data.
- **Formal Education:** *From* deep subject expertise in surveying, geospatial, geography and geodesy; *to* foundational concepts in computer and Internet science and 4IR information technologies.
- **Professional Training:** *From* lifelong learning and development through hands-on experiences; *to* intensive development in new and emerging paradigms.
- **Entrepreneurship:** *From* capacity development leading to innovation and new business ventures; *to* collaborative innovation hubs that stimulate growth in interconnected products, value chains and business models.

Communication and Engagement

This strategic pathway recognizes that stakeholder engagement, and strategic communications are essential to successfully deliver integrated geospatial information management arrangements nationally and sub-nationally, and crucial to delivering the future geospatial ecosystem.

While people use geospatial data every day, they are largely unaware of what the term 'geospatial' means, and where it comes from. As a consequence, there is limited awareness, in the general community, of the value of geospatial information to society, the economy and the environment.

Anecdotally, many geospatial professionals find it difficult to explain what they do; focusing on the technology that is often difficult to comprehend. This lack of understanding and recognition is principally due to limited brand awareness, lack of common messaging on benefits, and the inconsistent use of terminology in our field. As an industry, we use different definitions for the terms like infrastructure, ecosystem, blueprint, framework and systems – creating confusion for professionals and policy makers alike; and the terms spatial, cartography, mapping, GIS and geospatial are used interchangeably – creating confusion for the lay person.

This communication challenge is compounded by the fact that University courses in geospatial science, around the world, have different names (cartography, geomatics, geoinformation, spatial science etc.). This confusion is one of the contributing factors leading to few secondary school graduates opting for a career in geospatial. The other factor impacting career choice, is that the terms 'infrastructure and ecosystem' are less appealing when compared to modern terms like the 'Metaverse' that grabs attention generates impactful and meaningful conversations. Who wouldn't want to be part of an industry creating and managing data that contributes to the Metaverse?

As we embark on another evolutionary phase in our geospatial information management journey towards infinite possibilities, brand awareness and key messaging will be crucial to:

- Influencing policy makers and investors to make 'change' viable.
- Establishing collaborative partnerships to make 'change' happen.
- Building stakeholder cooperation to stimulate and sustain the 'change' journey.
- Broadening engagement to gather a diversity of views.
- Being more inclusive of targeted audiences by varying language and communication styles.
- Attracting and retaining a skilled and engaged workforce to deliver the 'change' needed.
- Creating a geospatial identity that attracts investment.

Key messages for the future global geospatially connected digital world will not only need to include conversations on the 'Why' in the national context, but also on 'How' we can achieve this new future as a global geospatial community.

This new and exciting 'knowledge on-demand' value proposition effects everybody. It has the potential to revolutionize, in every single sense, the way we live, learn and look after our planet; constantly alerting us to shared challenges, such as building disaster resilience, so that everyone can play a part.

Now is an opportune time to take stock of who we are and what we represent. Clear messaging needs to start at career exhibitions and also reach the political level. Our messages need to spark conversations - *"Welcome to the Geoverse – a digitally connected geospatial world that supports humanitarian and sustainable development."* At the moment "surveying and geospatial science, and spatial data infrastructures" are a hard sell. ■

In summary, as we move beyond SDIs to a new geospatial information ecosystem, communication and engagement will see a shift in focus (Figure 15):

- **Stakeholder and User Engagement:** *From* a narrow focus on government user engagement; *to* broad spectrum, diverse and inclusive engagement.
- **Strategic Messaging:** *From* having limited brand awareness, complicated messaging and inconsistent terminology; *to* a unified brand and terminology, and clear messaging that sparks conversations and imagination.
- **Communication Strategy, Plans and Methods:** *From* project and program focused communications; *to* strategic, targeted and impactful communications that keep pace with changing times.
- **Monitoring and Evaluation:** *From* surveys and metrics on effectiveness and efficiency of communications; *to* knowledge analytics and metrics on participation rates, understanding and change in usage.

Strategic Pathway Elements	Spatial Data Infrastructures	Future Geospatial Information Ecosystem
Stakeholder and User Engagement	Narrow focus on government user engagement	Broad spectrum, diverse and inclusive
Strategic Messaging	Limited brand awareness, complicated messaging and inconsistent terminology	Unified brand and terminology, and clear messaging that sparks conversations and imagination
Communication Strategy, Plans and Methods	Project and program focussed communications	Strategic, targeted and impactful communications that keep pace with changing times
Monitoring and Evaluation	Surveys and metrics on effectiveness and efficiency of communications	Knowledge analytics and metrics on participation rates, understanding and change in usage

Figure 15. Communication and Engagement Strategic Pathway – the Step Change

Conclusion

This discussion paper explores the geospatial landscape using the IGIF as a critical thinking tool to examine the SDI construct and look proactively towards the future geospatial information ecosystem.

The discussion has aimed to assist Member States and national geospatial information agencies in their thinking on future geospatial environments in which technological developments will play a crucial role.

In terms of design, it is becoming clearer that the future geospatial information ecosystem will:

- Interface with a much larger digital ecosystem;
- Be made up of three elements - SDIs, SoS and the Geoverse;
- Be larger than the Metaverse, but will play a key role in contributing 3D models of reality to the Metaverse; and
- Have a continuing role for SDIs as a registry for brokering access between geospatial information and knowledge services.

In addition, while the IGIF distinguishes nine strategic pathways of thought, there are several threads common to all pathways that countries can undertake now to start the transition process, including the need to:

- Strengthen integrated geospatial information management nationally as a pre-requisite for transitioning to the future geospatial information ecosystem;
- Broaden stakeholder engagement to consider diversity of views and needs;
- Make geospatial data available in a machine-readable form to stimulate innovation in knowledge creation straightaway; and
- Share knowledge representations, rule bases and geoanalytics to support reuse and local to global adoption.

There is also need for high-level guidance to assist countries to plan for the future and guide the transition towards the Geoverse. Change will not happen without the leadership and vision of the entire geospatial community. Key IGIF actions at the global leadership level call for:

- **Governance:** A Global Geospatial Knowledge Governance Framework to guide how data is to be created, managed and processed to 'democratize knowledge' in the interest of individuals' needs, good governance, developmental interests, and humanitarian and global crisis management.
- **Policy and Legal:** A coordinated and coherent Geospatial Policy and Legal Framework to guide and globally stimulate technical innovation and achieve democratization of knowledge; balanced with public confidence in how information is used and protected; and how its reliability is consistently communicated.
- **Financial:** A scoping document on 4IR new business models with a view to supporting developing countries.
- **Data:** A Global Use Case Framework to identify, prioritize and specify data collection, quality improvements, geoanalytics, and the policies and standards needed to transform data inputs into knowledge outputs.
- **Innovation:** A Road Map of knowledge-sharing interventions that deliver inclusivity and digital equity for communities.
- **Standards:** Knowledge representation standards - vocabularies, ontologies, FAIR and sematic web etc.
- **Partnership:** Guidance for establishing partnerships in a decentralized multimodal digital ecosystem founded on AI, block chain, Internet communication interfaces and other 4IR technologies.
- **Capacity and Education:** A new 'workforce ready' skills development framework including foundational concepts in computer and Internet science and 4IR technologies.
- **Communication and Engagement:** A common brand, uniform terminology and consistent messaging to spark conversations.

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Terms

4IR	Fourth Industrial Revolution - characterized by Big Data, Artificial Intelligence, advanced robotics, automation, the Internet of Things (IoT), genetic engineering, quantum computing, smart technologies, digital disruption and more.
AI	Artificial Intelligence - the ability of a computer or a robot controlled by a computer to do tasks that are usually done by humans because they require human intelligence and discernment.
API	Application Programming Interface - a way for two or more computer programs to communicate with each other. It is a type of software interface, offering a service to other pieces of software.
BIG data	Extremely large data sets that may be analysed computationally to reveal patterns, trends, and associations, especially relating to human behaviour and interactions.
Blockchain	A shared, immutable ledger that facilitates the process of recording transactions and tracking assets in a business network.
Blueprint	A blueprint is a guide for making something — it's a design or pattern that can be followed.
CRCSI	Cooperative Research Centre for Spatial Information - an Australian Government Research Initiative created by an unincorporated joint venture of industry partners which commenced operation in July 2003.
DRM	Digital Rights Management - the management of legal access to digital content. Various tools or technological protection measures such as access control technologies can restrict the use of proprietary hardware and copyrighted works.
Ecosystem	An environment of something consisting of component parts that interact with one another and with the physical environment.
FAIR	Findable, Accessible, Interoperable, Reusable - The FAIR principles emphasize machine-actionability (i.e., the capacity of computational systems to find, access, interoperate, and reuse data with no or minimal human intervention) because humans increasingly rely on computational support to deal with data as a result of the increase in volume, complexity, and creation speed of data.
Framework	A basic conceptional structure of ideas, conditions and assumptions intended to serve as a guide to how something will be approached, perceived, built and understood.
Geoanalytics	An emerging science in which big data technology extracts meaning, patterns, and insights from complex geospatial datasets.
Geoverse	A globally interconnected geospatial information ecosystem that includes 2, 3 and 4D visualizations, predictive analytics, real time knowledge in all its forms, and a wide range of integrated and interoperable data from across various sectors and disciplines. The Geoverse permits intelligent interactions between SDI web portals, systems, sensors, applications, devices and other things; using a broad range of communication interfaces and machine facilitated technologies such as AI, Machine Learning (ML), Natural Language Processing (NLP), data mining, virtual assistants, digital identities, blockchain etc.
GIS	A Geographic Information System is, a system for storing, manipulating and geographical information on computer.

IGIF	Integrated Geospatial Information Framework is a basis and guide for developing, integrating, strengthening and maximizing geospatial information management and related resources
IHO	International Hydrographic Organization - coordinates the activities of national hydrographic offices and sets standards in order to promote uniformity in nautical charts and documents.
IoT	Internet of Things – describes physical objects (or groups of such objects) with sensors, processing ability, software, and other technologies that connect and exchange data with other devices and systems over the Internet or other communications networks.
Infrastructure	The physical and organizational structures and facilities needed for the operation of something in a country, state, or region.
ISO	International Organization for Standardization - a nonprofit organization that develops and publishes standards of virtually every possible sort, ranging from standards for information technology to fluid dynamics and nuclear energy.
Linked Data	Structured data that is interlinked with other data, such that it can be read by semantic queries.
Metaverse	A network of 3D virtual worlds focused on social connection where users interact with each other in real time.
ML	Machine Learning – a type of artificial intelligence (AI) that allows software applications to become more accurate at predicting outcomes without being explicitly programmed to do so. Machine learning algorithms use historical data as input to predict new output values.
NLP	Natural Language Processing - a subfield of linguistics, computer science, and artificial intelligence concerned with the interactions between computers and human language, in particular how to program computers to process and analyze large amounts of natural language data.
OGC	Open Geospatial Consortium - a worldwide community committed to improving access to geospatial, or location information. The organization represents over 500 businesses, government agencies, research organizations, and universities united with a desire to make location information FAIR – Findable, Accessible, Interoperable, and Reusable.
Ontology	In the context of geospatial information, ontologies provide a formalized representation of geographic entities and relationships between them in a manner understandable to machines.
SDI	Spatial Data Infrastructure provides a basis for spatial data discovery, evaluation, and application for users and providers within all levels of government, the commercial sector, the non-profit sector, academia and by citizens in general (Nebert, 2003).
SDG's	Sustainable Development Goals - 17 Sustainable Development Goals (SDGs), adopted by the United Nations in 2015 as a universal call to action to end poverty, protect the planet, and ensure that by 2030 all people enjoy peace and prosperity.
SoS	System-of-Systems - the interaction of individual systems dedicated to solve something that is typically a specific complex problem/s.

Call for submissons

UN-GGIM Secretariat invites your comments on this discussion document. Your feedback will help the geospatial community to make informed decisions on what the future geospatial information ecosystem will look like, and how we can achieve the transition to this new future.

Please let us know:

- Are we moving in the right direction?
- What do you think the main challenges will be?
- What are we doing now that works well and will contribute to the future?
- What is the best thing we can achieve moving forward?
- What will be the most valuable outcome for you?

Submissions can be made via email to the UN-GGIM Secretariat (ggim@un.org) with the subject 'Determining the future geospatial information ecosystem'. Contributions are welcome from all interested member states, organisations and individuals. The closing date for submissions is 31 October 2022.

We look forward to your contribution.

UN-GGIM Secretariat
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