Towards a sustainable geospatial ecosystem beyond SDIs[1]

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[1] This paper is the outcome of a series of discussions about a future vision beyond spatial data infrastructures among the authors between November 2020 and July 2021, initiated by the Policies Portfolio Group of the European Umbrella Organization for Geographic Information (EUROGI).

Executive Summary

A new 'Beyond SDI' geospatial ecosystem is needed in response to a geospatial landscape that has evolved radically since spatial data infrastructures (SDI) were first conceptualized in the late 1980s and early 1990s. This evolution includes changes in technology; the volume and nature of geospatial information being generated; the increased importance of location, from government policy-making to an individual user's daily living experiences; the rise of large and well-resourced private companies providing geospatially based platforms and services; the skill sets needed to exploit the new opportunities which have opened up; data management and governance, including the importance of protecting privacy and dealing with bias and cybersecurity issues; more advanced analytical tools, such as artificial intelligence/machine learning (AI/ML); a widening digital divide between developed and developing nations; and the roles, relevance and capabilities of different organisations and institutions.

SDI concepts are based on the notion of an infrastructure, a platform on which products and services are provided or built, with governments playing a central role in its establishment, operation and maintenance. Railway, road or electricity infrastructures provided the model for data infrastructures.

Our vision is for a future state where the entire global community interacts in a sustainable geospatial ecosystem, leveraging high-quality and reliable location-based information and powerful geo-analytics which are communicated through dynamic geomedia at any time, in many different ways, and on a wide variety of devices. The geospatial ecosystem comprises literally billions of 'actors' (citizens, companies, governments, civil society organisations, Internet of Things (IoT) devices, and increasingly also 'intelligent' machines) producing and consuming geospatial information, mediated through ever changing platforms, an increasingly diverse set of geo-analytical tools, and dynamic, constantly evolving networks. This vision will not happen overnight, but it is already in the making and the geospatial community needs to be more aware of and get ready for this new, much more dynamic and ever-changing, state of affairs.

Major components of the future geospatial ecosystem include next generation e-governance processes; modern data licensing; user-centric technology platforms and services enabled in part by AI/ML; application programme interfaces (APIs); open data and open analytical software; and stakeholder collaboration mechanisms. New rules of engagement and standards will be necessary to help manage growth and change. The use of consensus frameworks such as the United Nations Global Geospatial Information Management (UN-GGIM) Integrated Geospatial Information Framework (IGIF) can help to bridge the digital divide between developed and developing nations.

Moving towards this modern and more diverse vision can have profound and important implications for stakeholders in the geospatial community: the public sector at all levels, the private sector from large powerful companies to small and medium-sized enterprises (SMEs), academia, and for civil society as a whole. Some of these implications in the form of action guidance are set out in the paper.

The authors are putting forward this paper to initiate a global exchange of ideas around the 'Beyond SDI' theme. Our hope is to accelerate engagement both within and outside the geospatial community around the issues raised (and others), resulting over time in a new geospatial ecosystem, beyond the SDI model, which can help address the profound problems which humanity is facing, and at the same time optimally exploit the exciting opportunities which could benefit our own geospatial community.

1. Introduction

The fourth industrial revolution is fundamentally changing the way in which we live and work. While we do not yet know the extent to which this revolution will unfold and reshape our economic, social, cultural, and natural environments, we do know that the changes are unprecedented in terms of size, speed, and scope. The main drivers of this revolution include the development and rapid adoption of technologies such as increasing storage and computing power; high speed communication networks; all kinds of sensors in an expanding Internet of Things (IoT); pervasive computing (also on smart phones); satellite constellations of all shapes and sizes; and artificial intelligence/machine learning (AI/ML). The resulting interconnectedness of people, devices, and information, anytime and anywhere, raises the importance of geospatial information (Schwab, 2016).

In the geospatial community, these technologies have led to a huge increase in available geospatial data, at much higher resolution levels and higher frequencies of capture. In many cases, such as traffic and weather, a real-time data feed is not only available but expected. These technologies and processes are disruptive, and are continually evolving, providing new opportunities or requirements for innovation and for industry and governments to become more agile, to adapt and transform their internal processes, and to scale-up capabilities much more quickly than in the past. Institutional stakeholders need to adapt to these changes – which does not mean doing the same things faster, but rather restructuring and rethinking the way in which things are done.

The global community of geospatial practitioners, especially from within government and academia, have been strong proponents of spatial data infrastructures (SDIs) since the late 1980s/early 1990s – developing them, growing them, tuning them, and trying to effectively implement and sustain them. The central focus of SDIs has been making (mostly public sector) geospatial data available and usable. A key function is to ensure that the data are interoperable and follow consensus standards, so that geospatial data in different domains collected at different times, at different scales, and in different formats can be easily and seamlessly re-used and integrated. Through best practice guidance, and sometimes legislation, SDIs provide a basis on which to achieve these aims. The SDI conceptual model also includes measures related to governance, licensing, and data integration.

SDIs were not designed, decades ago, for the modern digital age and data requirements, including the diverse range of providers, users, and stakeholders. The SDI conceptual model was developed when much geospatial data (e.g., aerial photography, elevation data, placenames, etc.) were prohibitively costly to create for any organization other than a large government organization. The technological, market and social environments have changed dramatically in many ways since then. To maximize benefits of using geospatial data to address a host of global problems, it is time to rethink how it is collected, made available, quality-controlled, and utilised. We should do it now, before organisations spend another decade on SDI development aimed at the old reality rather than on the fast-emerging digital world.

During the early 2000s, many global geospatial practitioners, especially from within government, were grappling with the role of the SDI as the national geospatial information system that provides reliable fundamental geospatial data, and as both the enabling platform and connection point to other national information systems – and to national development. There was a sense of a significant gap in the understanding, recognition and management of geospatial information and SDIs and the need to consider the changing environment in which SDIs operate. This went as far as the global level, where there was a lack of a consultative and decision-making mechanism among countries and practitioners for setting global norms on geospatial information, developing common tools, and bringing geospatial information to bear on global policy issues.

In July 2011[2], after three years of preparatory work by the global geospatial community, recognising the urgent need to take concrete action to strengthen international cooperation in global geospatial information management, the United Nations Economic and Social Council (ECOSOC) established the

[2] https://ggim.un.org/documents/E_Res_2011.24_en.pdf

United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM) as the apex intergovernmental mechanism for geography. UN-GGIM was established to make joint decisions and set directions with regard to the production and use of geospatial information within national, regional and global policy frameworks; to promote common principles, policies, methods, mechanisms and standards for the interoperability of geospatial data and services; and to provide a platform for the development of effective strategies on how to build and strengthen national capacity concerning geospatial information, especially in developing countries. In essence, to close the considerable global geospatial information gaps that existed and to promote the greater use of geospatial information as part of a new frontier in harnessing science and technology for advancing sustainable development.

Now, a decade later, UN-GGIM is globally recognized as an effective and productive intergovernmental mechanism of the United Nations. Such recognition also extends into key geospatial areas of academia, industry, the private sector, and international geospatial societies. The global geospatial landscape, including greater understanding and awareness, has grown significantly because of UN-GGIM, especially when considering the location-based policy and development demands that are increasing significantly, and how SDIs evolve to support globally adopted frameworks such as the Integrated Geospatial Information Framework (IGIF). It is therefore appropriate that the re-thinking and re-alignment of geospatial information management and governance is considered and debated through the UN-GGIM with its global reach and impact.

This position paper takes some first steps towards a 'future vision' and aims to initiate a re-thinking and re-imagining of the way in which geospatial information is shared, analysed and used in the rapidly changing environment of today and into the future. It provides thoughts and ideas to enable the global geospatial community to be more adequately prepared and to drive and facilitate the transition to a sustainable geospatial ecosystem beyond SDIs. The paper is the outcome of a series of discussions among the authors between November 2020 and July 2021, initiated by the Policies Portfolio group of the European Umbrella Organization for Geographic Information (EUROGI)[3], about a future vision beyond SDIs.

Section 2 of this paper briefly reflects on the evolution of SDIs and argues that we have moved beyond them. In section 3, we present new and emerging conditions of the future geospatial environment and consider their impacts on SDIs. Section 4 sets out a vision of a geospatial ecosystem that goes well beyond today's SDI conceptual model. The vision is intended as a constructive critique: a basis for discussion regarding 'what comes next' in the geospatial domain. Section 5 calls for action to drive and embrace the transition to a geospatial ecosystem beyond SDIs. In this 'where do we go from here' context, we target four key groups:

- Governments and other public sector bodies – as the custodians of public good data for a nation, region or city;
- The geospatial industry – as data, technology and service providers and innovators;
- Academia – as the providers of new knowledge and technologies through research, as producers and users of geospatial research data, and as educators of the future generations of practitioners; and
- Civil society – as the users, consumers, and producers of data, technologies and services.

Such a diverse provider and user community acknowledges the many broad and horizontal functions that geospatial information plays in our modern world – being integrated and interoperable. Section 6 provides concluding remarks.

[3] https://eurogi.org

2. SDI evolution

Despite the official definitions[4] in the late 20th and beginning of the 21st centuries, experts failed to reach agreement on a working definition of an SDI; depending on their background and circumstances, practitioners, researchers, and governments adopted different views of SDI (Williamson et al., 2003).

In 2005, Ian Masser observed that SDI development did not necessarily translate into a fully operational SDI, rather SDI projects make advancements in terms of collaboration and standardization but then they often lose steam when it comes to implementation. Craglia (2015) acknowledged that SDIs turned out to be more complex than originally anticipated and that they are more about people and social networks than about technology and standards.

An SDI requires agreement among multiple stakeholders, about what an SDI is, why it is needed, how it should operate, who should maintain it, who should fund it, etc. Yet there still is no strong consensus regarding the necessary and sufficient conditions for a project to qualify as an SDI. Must it be officially sanctioned by a government agency? Must it provide geospatial data download capability? Can it be a data portal from a single organization, or must it be a collaboration between multiple stakeholders and providing data through their own avenues? Consequently, there are no two SDIs alike and there is also no agreement on how to assess or measure the success of an SDI. One of the basic success measures for online systems, web statistics regarding SDI visitors, downloads, registrations, etc., are rarely reported. Normally successful web-based projects flaunt their statistics.

Now in 2021, twenty years after the main boom in SDI popularity and more than 30 years after the SDI conceptualisation was first articulated, what has been achieved? Undeniably a huge amount, as evidenced by the thousands of publications on the topic and the hundreds of SDI projects, standards, geoportals, and community demonstrations. The geospatial community has learned a great deal about technical and organizational interoperability and cooperation, even if the results have not always been as expected. After a considerable investment of time, public funding, research, development and implementation, the SDI panorama globally remains both varied and complex – and not well understood or even known by those outside the geospatial community. For geospatial insiders, the world of SDIs is not a single system but rather a highly diverse collection of portals, datasets, experiments and demonstrations that they have learned to navigate. In the meantime, private industry often bypasses national SDI achievements by reinitiating data collection and making geospatial data available, according to user demands and its own business needs. This fact deserves further introspection and analysis. Do SDIs meet today's expectations regarding content, currency, ease of use, service and support, speed, and flexibility?

While there are some examples of success as measured by certain user groups, generally speaking, SDIs continue to be 'work in progress' and are constrained by geographic and economic differences between the developed and developing world. There are examples where countries and regions – mostly in the developed world – have reached certain maturity and are attempting to advance their SDIs by leveraging digital transformation and technological innovation. However, the SDI dream of users sitting at a GIS desktop or holding a mobile app and gaining access to the right geospatial data at the right time to answer questions – like turning on a tap and getting water from the water services infrastructure – is not yet a reality in many contexts. In cases where that does work there normally is a tightly coupled relationship between data providers, integrators, and consumers. An example is weather forecast apps for mobile phones: the service chain from data collection to service provision works well thanks to specific agreements and tight integration. Furthermore, the road from data download towards (open) services is still beyond the capabilities of most SDIs. Despite progress in governance (see UN-GGIM earlier), for more than a

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[4] The 1994 USA Executive Order 12906 states *"National Spatial Data Infrastructure" ("NSDI") means the technology, policies, standards, and human resources necessary to acquire, process, store, distribute, and improve utilization of geospatial data."* The 2007 European INSPIRE Directive (a form of European Union law) states *'infrastructure for spatial information' means metadata, spatial data sets and spatial data services; network services and technologies; agreements on sharing, access and use; and coordination and monitoring mechanisms, processes and procedures, established, operated or made available in accordance with this Directive;'.*

decade the technological situation has not evolved: SDIs still appear to be simple catalogues offering data downloads of historical data (e.g., past censuses, aerial or satellite imagery taken some months or years ago, etc.) and online map viewers found within government silos (e.g., ministries, open data agencies). This is not through lack of opportunity to change. It has long been argued that SDIs are enabled by, and a product of, information and communications technologies (ICT). But again, as Craglia noted, the social and institutional issues are more difficult to address than the technology issues.

The evolution of SDIs is a long-term process, and their adoption and implementation often reflect the extent to which (government) organisations reinvent themselves in response to changing political, institutional, socio-economic and technological circumstances. Some projects labelled as 'SDI' have resulted in new national or regional standards being drafted, in other cases increased availability of open data, and in many others a public facing 'geoportal' was created. In such situations, public sector organisations 'checked off' several boxes and declared the SDI mission completed. Many European organisations are just now complying with INSPIRE implementation rules, based on specifications (and a reality) defined initially circa 2003. The speed of progress is not commensurate with the surrounding technological and social changes happening.

Today, there is indeed much geospatial information available, but many users, especially from 'outside' the geospatial community, are still unable to easily find it, access it, and consume it in ways which meet their particular needs. SDIs are "essentially a data infrastructure in a knowledge environment, a petrol car in a carbon-neutral world"[5]. The application of technology alone will not magically upgrade SDIs to be ready for a new generation of users and uses. Strong realignment of business models, based on real consumer demand and the evolving and diversified data stakeholder community is needed. Evolution from a top-down push to produce an SDI in every jurisdiction to a mixed model including bottom-up pull from the market regarding what people and organisations really need, is now due. A modernized or evolved SDI will need to satisfy all the key stakeholders. A simple set of carrot and stick government programs will not be enough to assure sustainability and widespread and effective use. The next evolution of SDIs cannot rely on government subsidy for their survival. The geospatial community needs to seriously reflect on the suitability of the SDI conceptual model and its incentive structure in our rapidly changing environment.

3. New and emerging conditions and their impact on SDIs

This section draws on our discussions, several reports, including the future trends in geospatial information management by UN-GGIM[6], geospatial technology trends identified by the Open Geospatial Consortium (OGC)[7] (OGC, 2020 and 2021), and future research topics on SDIs put forward by members of European Spatial Data Research (EuroSDR)[8]. The aim is not to provide an exhaustive description of new and emerging conditions, but rather to point out significant changes and how these inevitably force us to think beyond the original and current conceptualisation of an SDI. Table 1 provides a summary.

[5] https://geospatialmedia.net/pdf/GKI-White-Paper.pdf
[6] https://ggim.un.org/meetings/GGIM-committee/10th-Session/documents/Future_Trends_Report_THIRD_EDITION_digital_accessible.pdf
[7] https://www.ogc.org/OGCTechTrends
[8] http://www.eurosdr.net/research/project/future-research-topics-spatial-data-infrastructure

Table 1. New and emerging conditions and their impacts on SDIs

New and emerging condition	Impact on SDIs
Location in decision-making will be commonplace	– The catalogue and portal approach is not sufficient for decision-making by a wider and more diverse user and provider community.
New geospatial data sources and services	– The SDI concept is not suitable for the emerging collection of new producers of geospatial data and services. – Static metadata records and catalogues which relate mainly to historical data[9] are not suitable for many of the new data providers, data types, and applications. – Certain key data themes, such as Earth Observation (EO) imagery, are available from multiple commercial sources.
Technological advances	– SDIs driven by governments cannot keep up with today's technological advances or the massive amounts of location information being produced in real-time or near real-time. – SDIs focussed mostly on data availability; geo-analytics availability is now also very important. – IoT devices raise privacy concerns that were not present in 'traditional' SDIs. – Developing countries need SDI good practice examples that are based on modern technologies and practices.
More automation, analytics, and intelligence	– The moral and legal issues arising are beyond the scope of SDIs, and even the geospatial community. – The way in which data is searched and accessed can be re-invented to be much more efficient and human friendly. – Increasingly machines are autonomously undertaking much geospatial data processing and applying increasingly sophisticated geo-analytics, leading to an increasing number of cases where algorithms make final action-orientated decisions. Traditional SDIs are not at all suitable for dealing with this major emerging reality. – Ad hoc analysis of real-time or near real-time data is fundamental for many automatization processes (e.g., in industry 4.0 applications). However 'real-time' has never been seriously addressed in traditional SDIs.
User expectations are changing	– The overwhelming bulk of users are not geospatial experts, and they expect much more than digital libraries (clearinghouses) provided by SDIs. A supply-driven SDI cannot provide the geospatial data and visualizations that they expect and increasingly demand.
Organisations are changing	– Organisational hierarchies, which were appropriate for national SDIs, will be replaced with more agile, multiparticipant team-based structures. – Organisations must cater for users outside the 'traditional' user base of geospatial experts.

3.1 Location in decision-making will be commonplace

Location in decision-making has always been important, but it is increasingly possible to incorporate location information into decision-making at all levels, from global to local, thanks in part to the wider availability of geospatial data.

[9] As distinct from real-time or near real-time data.

At the global level, location-based information will increasingly be used to address major challenges such as climate change, biodiversity loss, energy production and distribution, mass migration, and the wealth divide between developed and developing nations.

At the local level, location-based information will increasingly be used for evidence-based decision-making and daily operations. There will be an ever-increasing realization that location can be a common feature of virtually all information, thereby providing a common basis for supporting integration of information from different sources and contexts. This brings opportunities for all four target audiences of this paper: for public sector organisations there are opportunities for addressing the above-mentioned challenges and for example to better manage both their cities and rural areas and to effectively address their Sustainable Development Goals (SDGs); the geospatial industry can develop new and innovative solutions and provide useful services based on location-based information; academia will have location-based and regionalized information at their disposal to solve a wider range of research challenges and to contribute to widespread locationally informed capacity building; and the general public can hope for a better quality of life in a sustainable world.

The COVID-19 pandemic has reinforced the critical role of and need for geospatial data, technologies and tools to deliver timely and reliable information in a systematic way across all countries and regions for effective decision-making. It has also brought unsolved location-based privacy issues into the social discourse. Very early in the pandemic, the ongoing 'geospatial' problem quickly arose – an inability for countries and key actors to integrate timely fundamental data with new data sources, enabling technologies, and national capability, to measure and monitor what was happening where, when, and how. While much of the urgently needed data might have existed in some form somewhere, maybe even in an SDI, it was often not discoverable, structured, interoperable, or standardized. Critical data could not be readily accessed, shared and, more importantly, integrated with other data for decision-making.

If more people in more areas of interest are to be able to access and exploit geospatial data, then the current SDI model of expert-oriented catalogues and access to large collections of official data will not be sufficient or efficient. We need to transform our catalogue and portal approach into something that is compatible with a wider and more diverse user and provider community.

3.2 New geospatial data sources and services

In the 1990s the main reason for creating SDIs was to harmonise and disseminate official geospatial data mainly from public sector sources. Alternative sources for data on topography, statistical areas, roads, land parcels, and to a large extent ground imagery, were not readily available outside of the government offices within which they had been collected. Many laws assured that this was the case. This situation has changed in many countries, and we expect the trend to continue around the world.

Today for example, one can access global population density maps, created and freely published by Facebook in collaboration with Columbia University[10]. Microsoft used its AI tools to create and openly publish building footprints for many millions of buildings in the USA and Canada, with further experimentation in Uganda and Tanzania[11]. Esri recently released a global landcover map at 10-metre resolution, derived from the European Union's Sentinel-2 satellite imagery. The Esri classification was undertaken in one week using AI techniques on Microsoft's Azure cloud, proving that regular weekly updates of landcover are possible using this methodology[12].

Waze, a crowdsourced navigation app, provides free, real-time traffic information to 140 million active user drivers in many countries around the world, including information generated by the drivers themselves, for example to warn others of a nearby crash or a mobile speed radar measuring device. Waze partners with

[10] https://dataforgood.fb.com/tools/population-density-maps/
[11] https://www.microsoft.com/en-us/maps/building-footprints
[12] https://www.bbc.com/news/science-environment-57615408

cities, a fine example of public-private partnership, to provide the city with a feed of traffic data in exchange for access to other city data and for its own promotion[13].

OpenStreetMap, the crowdsourced map of the world, recently reached the milestone of 100 million community edits. Many individuals and businesses rely on OpenStreetMap to build specialized routing and other map-based applications[14].

Satellite imagery is now a staple data layer in many GIS-related software systems including Google Maps, Bing Maps and ArcGIS Online. Not only is it now easy to include an imagery layer in almost any geospatial data viewer, but an increasing amount of raw imagery for analysis is now available from both government and commercial sources.

Weather information is now available from hundreds of sources, commercial and public, under a wide range of business models and licensing schemes. One of the more popular commercial services is AccuWeather, which provides numerous data feeds via Application Programming Interfaces (API) to provide almost any popular app with weather forecast, mosquito activity, sailing wind information, sunburn warnings, stargazing advice, etc.

Many possibilities now exist for virtually anyone to fly a $1000 UAV (unmanned aerial vehicle) and collect large amounts of imagery and 3D point cloud data, for a quite extensive area, and to create a very detailed and realistic 3D models on a daily (or more frequent) basis if necessary.

The list of available geospatial data sources could go on and on, and today official government data sources now represent a much smaller, although still important, part of the overall geospatial information ecosystem. Many apps which use and process geospatial information do not necessarily require an SDI to enable them to operate effectively. Governments should identify the particular data and services that require a framework of principles and measures to manage and control their production and use and focus their efforts on them. Examples of important public sector information related for example to land administration are address data and cadastral and administrative boundaries.

3.3 Technological advances

The digital revolution is continuing apace. Computing devices are becoming faster, smaller, and 'cleverer', and increasingly they communicate with each other in real-time. As a result, there will be a vast increase in the volume of geospatial and other data in future, driven for example, by the ever-increasing numbers of IoT devices broadcasting location information, the multiple sensors on driverless cars, mobile phones, watches, RFID tags, etc. Amongst others, this brings location-based privacy concerns to the fore.

More and more geospatial data and spatial analytics will be retained and undertaken in the cloud, but increasingly, edge computing, where analytics are brought closer to the source of data, will play a significant role, particularly where real-time decision-making is required. Apart from data storage and processing power, there will also be substantial improvements in the communications infrastructure which will enable access to vast amounts of geospatial data in real-time or near real-time. We currently assume that data are connected and easily accessible until it is not, but such connectivity issues will decrease over time. Discussions on 6G have started[15], satellite-based internet backbones are being developed[16], and further into the future, a quantum communications infrastructure is increasingly likely to become a significant reality[17].

[13] https://www.innovations.harvard.edu/blog/waze-drive-towards-successful-public-partnerships
[14] https://techexec.com.au/?p=2855
[15] https://www.lifewire.com/6g-wireless-4685524
[16] https://www.starlink.com/
[17] https://digital-strategy.ec.europa.eu/en/funding/assessing-user-needs-quantum-communication-infrastructure

Increasingly, there will be reduced need for ground-based facilities to enable highly accurate real-time positioning as this task will be provided by satellites, including, for example, by the very many CubeSats (miniature satellites)[18] which will be circulating in space in the near future and which will provide positioning and connectivity to earth-based IoT devices. Technological advances will continue to improve the spatial resolution at which location information can be collected[19] with increasing privacy and security concerns being brought to the fore. Satellite and aerial imagery are already collected at centimetre level resolution and in future, vast amounts of centimetre level accurate information will be generated by millions of driverless vehicles. This highly accurate geospatial data could well be collated within vehicle manufacture proprietary systems as a basis for the delivery of services only to owners of their vehicles. Conversely, it is interesting to note that although the amount and resolution of land areas data acquisition is increasing rapidly, the search for Malaysia Airlines flight MH370 has revealed huge gaps in temporal resolution and spatial coverage of our oceans[20]. These gaps are expected to shrink but will require vast amounts of storage space.

Geospatially relevant technologies, such as building information modelling (BIM) and GIS, Sensors, IoT and remote sensing via satellites, UAVs, etc., will each evolve at a different pace and in different directions, but at the edges they will be influenced by each other, as well as by developments in the wider IT environment. These influences will initially push in the direction of fragmentation but will be countered by increasing levels of integration facilitated by geospatial and other standards.

When viewed from a global perspective a key challenge is how these technological advances can be used in meaningful ways in developing country contexts. They should be seen as opportunities that allow such countries to address their development issues by 'leapfrogging' from where they are at present to adopting and implementing cutting edge or near cutting edge technologies. Examples in some countries of successful leapfrogging is the widespread use of mobile phones and mobile banking. Building an SDI that is based on outdated technologies and practices will not best serve developing countries' needs, and focussed consideration should be given to how best 'leapfrogging' in such countries can take place. The solutions are unlikely to be only government conceived and driven but experience with mobile phone banking suggests that solutions lie in there being a partnership between government and the private sector.

SDIs driven by governments are not keeping up with today's pace of technological advances. To date, SDIs have focused on data harmonisation and availability, but to reap the benefits of increased data volumes, higher levels of spatio-temporal resolution and massively increased processing power, the availability of increasingly sophisticated geo-analytics (e.g., open algorithms and processing protocols) is of critical importance. Without suitable analytics the data cannot be put to best use. Traditionally, SDIs were concerned with low resolution geospatial information about static objects (e.g., aerial photography taken months or even years past), which did not hold any privacy concerns. With mobile, wearable and implanted sensors, their location features give rise to significant privacy concerns which need to be addressed based on agreed human rights values and globally accepted best practices.

3.4 More automation, analytics, and intelligence

Technological advances are leading to increased automation, improved analytics and intelligence, opening up many opportunities for geospatial information and technologies. Some of the implications of this trend can be identified. Firstly, certain geospatial tasks such as spatial referencing, geocoding and symbolization will be increasingly automated.

Secondly, there will be substantially more machine-to-machine interaction, with machines independently undertaking (real-time) data processing and applying analytical tools and taking final decisions which will be implemented. This leads to many opportunities for automated location-based services or decision-making, such as for example, safe and reliable autonomous vehicles.

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[18] https://www.space.com/13283-small-satellites-cubesats-research-technology.html
[19] Currently commercially available satellite optical imagery at 30cm resolution is available
[20] https://eos.org/opinions/airline-flight-paths-over-the-unmapped-ocean

Thirdly, the machine-human interface will increasingly be articulated through voice and visual queries and commands rather than just through tapping on keyboards or swiping screens. How spatial concepts, questions, statements, hand and eye gestures, local dialects will be interpreted and managed will become an important area within which standards and protocols will be required.

Fourthly, the importance of semantics can only increase, with the real-time incorporation of location-focused semantic tools into geospatial information processing becoming a growth area of significance. The availability of ontologies and geospatial linked data will facilitate semantic queries and processing. Over the coming years, there will be a rapid expansion in the number and nature of geospatial digital twins, for example, for cities, crop fields, wetlands, aquifers, community markets and tourism destinations. Such twins will be linked to increasingly sophisticated models, often incorporating AI/ML analytics, on which alternative scenarios and 'what if' queries can be tested virtually. Interaction with such twins will increasingly be engaged and enhanced through holograms, and virtual and augmented reality interfaces[21]. The digital twins can even be used to train machines, as for example would be the case if autonomous vehicles could be 'trained' to improve their driving skills in a digital twin of the traffic environment of a city.

As AI-based decision-making becomes more prevalent in more and more fields, the question of built-in (location-based) bias in algorithms and neural networks will become an increasingly important and contested issue. A key challenge, not only for the geospatial community but also more generally, will be to identify which tasks and decision-making processes should be automated and under what conditions. For example, at what points should humans be involved in automated processes and what form should such intervention take? How can automation best support efforts by developing countries to address their developmental challenges? How does one ensure that automation supports ethically appropriate use of geospatial information?

3.5 User expectations are changing

In contrast to users in the early days of SDIs, who were mostly geospatial specialists, today's users are less interested in the characteristics of the data or the analytical engines providing them with the services they expect. They are sophisticated users from diverse backgrounds, many of them digital natives, who engage with their devices to seek information, advice, knowledge, insights, and predictions. They expect human-friendly and understandable responses to their queries and want to search or input comment using natural language and/or gestures. As we have seen in the past, market forces (e.g., Google Maps) will lead users to demand similar, simple and fast functionality from both governments, and private companies.

Today's overwhelming majority of the billions of daily consumers of geospatial information are not geospatial experts and never will be, and they expect much more than the digital libraries provided by SDIs. A data supply side driven SDI cannot provide the geospatial data and visualizations that they expect. End users from a plethora of user groups, ranging from subsistence farmers who want to know where there is a new source of underground water because climate change is resulting in reductions in their current supplies, to environmental activists who want to estimate carbon emissions of their airline flights, would benefit from a wide variety of types of virtual analytic workbenches, delivered through widely available web platforms. These workbenches, for example as hosted notebooks for scientists, could host open geoprocessing and analytic tools that even only moderately technically savvy users can customize without undue difficulty in order to generate rapid personalised or niche market ready outputs. These analytical tools could be managed through the creative commons license framework, maintained by the user community.

[21] The Facebook CEO wants Facebook over the next five years to become a 'metaverse' company. A metaverse is an online world where people can game, work and communicate in a virtual environment, often using VR headsets. He states that such a universe is "an embodied internet where instead of just viewing content - you are in it". "People shouldn't live through "small, glowing rectangles (computer screens)"' instead they would virtually 'live' in 4D environments. Zuckerberg wants Facebook to become online 'metaverse' - BBC News

In the past a revolution occurred in the use of the Internet, from a place to mainly provide information online, to a place where users can actively and easily input and exchange information, the most notable example of this being social media. This change into an exchange network has enabled the development of such community-based initiatives as OpenStreetMap and the rise of what is termed volunteered geographic information and citizen science where citizens participate in scientific projects or monitoring systems. This full citizen two-way engagement trend will almost certainly continue, also in the geospatial domain.

3.6 Organisations are changing

According to McKinsey[22], organizations will have to adapt to these new and emerging conditions in various ways. To survive in a rapidly changing environment, organizations will have to start emphasizing continuous learning opportunities and instil a culture of lifelong learning, also for geospatial skills. Cross-functional collaboration and team-based work will provide agility and increasingly replace traditional organizational hierarchies. SDIs are based on the idea of a top-down national government (or other organization) coordinating and controlling the infrastructure, not a suitable governance structure for the rapidly changing geospatial environment. The UN-GGIM report on future trends in geospatial information management[23] predicts an increase in collaboration agreements with industries outside the traditional geospatial sector and a rise in non-geospatial start-ups providing location-based services or solutions. These developments also point to a wider use of geospatial information across many application domains, well beyond that occupied by the traditional geospatial experts. Organisations will need to change their structures and operating procedures in order to retain relevance.

4. A vision for the future

In this section we present our vision for the future – a geospatial ecosystem – and explain how it is different to the SDI conceptual model. We relate the geospatial ecosystem to Linked Data and a Spatial Knowledge Infrastructure, the Geospatial Knowledge Infrastructure (GKI)[24], the UN-GGIM Integrated Geospatial Information Framework (IGIF)[25], European Union initiatives, such as INSPIRE[26] and the European Union Location Framework[27] and to geospatial digital twins. We discuss how skills requirements, geospatial data management and governance, organizations and society are impacted by new and emerging conditions and how we think this will pan out in the context of a geospatial ecosystem. Prediction, particularly in the medium to long term (10-20 years), is an exercise fraught with difficulties and uncertainty. Predictions are even more problematic when dealing with technology matters, and this is particularly the case when predicting future geospatial environments, where technological developments will play a crucial role. Here, rather than predict, we outline what we expect and would like to see happen in the context of the emerging trends that are already playing a role in shaping our thinking on a future geospatial environment as a sustainable, interconnected, multi-stakeholder ecosystem.

4.1 The geospatial ecosystem

[22] https://www.mckinsey.com/featured-insights/future-of-work/skill-shift-automation-and-the-future-of-the-workforce
[23] https://ggim.un.org/meetings/GGIM-committee/10th-Session/documents/Future_Trends_Report_THIRD_EDITION_digital_accessible.pdf
[24] https://geospatialmedia.net/pdf/GKI-White-Paper.pdf
[25] https://ggim.un.org/IGIF/
[26] INSPIRE Directive | INSPIRE (europa.eu)
[27] https://joinup.ec.europa.eu/collection/european-union-location-framework-eulf

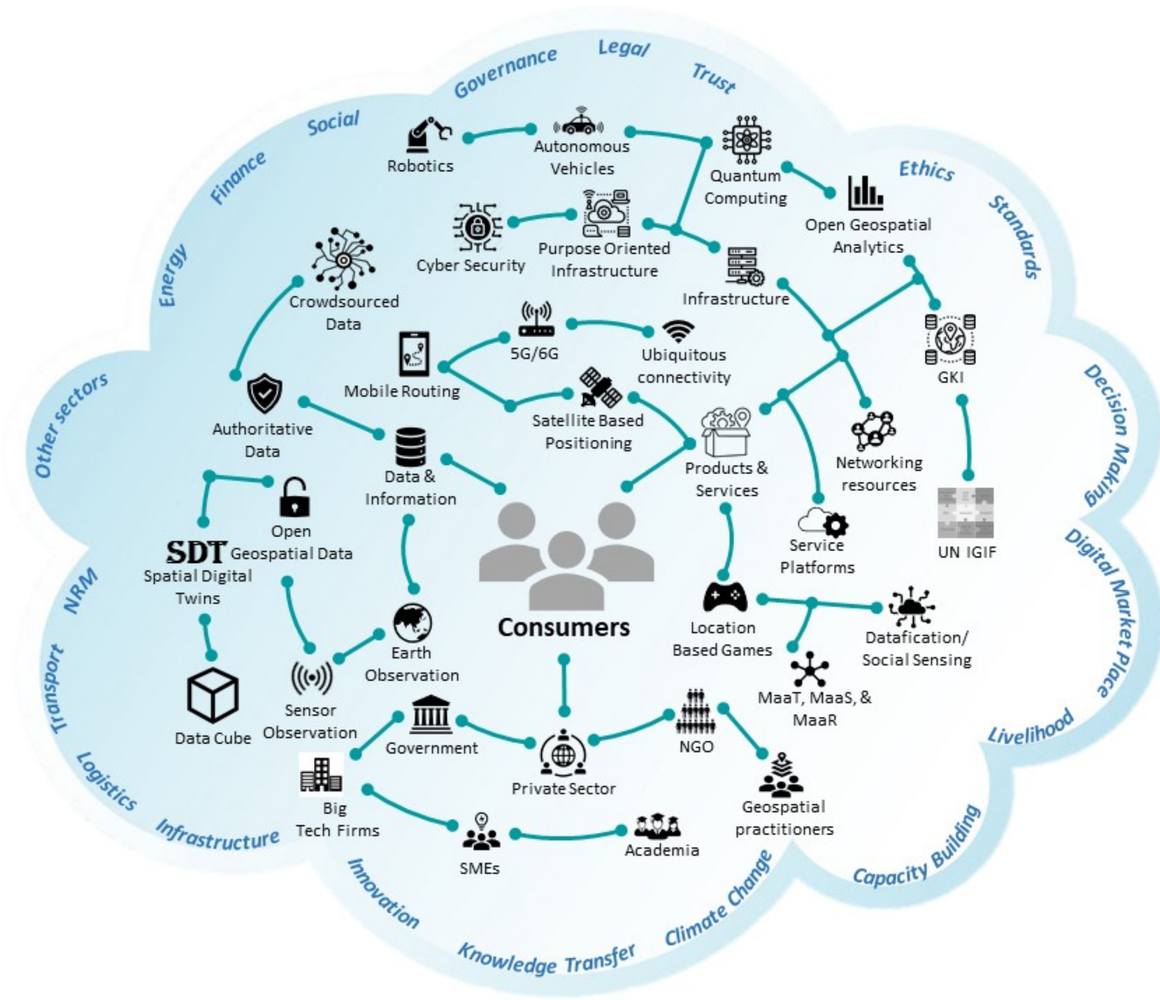

Figure 1. The geospatial ecosystem

Our vision for the future is of a geospatial ecosystem in which virtually all members of the global community ubiquitously interact with each other directly or indirectly, leveraging quality and reliable location-based information and powerful geo-analytics which are communicated through dynamic geomedia. This vision follows the model of a digital[28,29], data[30,31] and software[32,33] ecosystem, informed by natural ecosystems, sustained by self-organization, and competition and collaboration among very many diverse actors. Ecosystems are characterized by high levels of inter-connectivity between actors and their environments, continuous adaptation, and the ever-present possibility that once-off random events can give rise to significant, possibly even catastrophic, changes.

[28] http://www.hp.com/hpinfo/execteam/speeches/fiorina/ceo_worldres_00.html
[29] http://www.digital-ecosystems.org/dbe-book-2007
[30] https://www.mckinsey.com/business-functions/mckinsey-digital/our-insights/tech-forward/data-ecosystems-made-simple
[31] https://documents1.worldbank.org/curated/en/738531592553760735/pdf/Sustainability-in-OpenStreetMap-Building-a-More-Stable-Ecosystem-in-OSM-for-Development-and-Humanitarianism.pdf
[32] David G. Messerschmitt and Clemens Szyperski (2003). *Software Ecosystem: Understanding an Indispensable Technology and Industry*. Cambridge, MA, USA: MIT Press.
[33] https://www.igi-global.com/dictionary/software-ecosystem/53609

Drawing on knowledge about natural ecosystems, we define a geospatial ecosystem as a system in which a community of actors (individuals or organizations and increasingly 'intelligent' machines) interacts via the geospatial information and technologies in their environment. Similar to natural ecosystems, the geospatial ecosystem is dynamic: its balance may be disturbed at any time and it is forever recovering from a disturbance in the past. The geospatial ecosystem is coordinated and shaped by a multitude of stakeholders and self-organises through both competition and collaboration. Actors form collaborations for a specific purpose and for their own benefit or profit, and these collaborations may be temporary or longer term. The nature and abundance of communities of actors and the adaptive and dynamic networks which are created shapes the geospatial ecosystem. In this regard the diversity of actors is important: if they do not differ and add value in some fundamental way, they will competitively exclude each other. Certain keystone actors, e.g., national mapping agencies or big tech companies, may significantly impact the ecosystem, with an effect disproportionate to their numbers. Information is continuously exchanged, but in contrast to natural ecosystems, consumption does not deplete the source of information. However, information also moves through a life cycle from its initial creation via data collection to its use and eventual archiving or destruction. The geospatial ecosystem provides a variety of goods and services on which people depend. Ecosystem goods can be 'tangible', such as a single dataset or the results from a sophisticated chain of geoprocessing events, or less tangible, such as navigation of autonomous vehicles or location-based services.

Figure 2. Geospatial ecosystem description for context

The geospatial ecosystem is logically a subset of the wider digital information ecosystem, and comprises a multitude of stakeholders, not only government data providers and expert users as we typically have in an SDI, but a much wider range of organizations, individuals, and machines. These include providers of data and services from the private sector, academics, citizens, and NGOs who contribute by improving information and technologies through their research, and a plethora of users and information producers from the general community. Technical standards and norms of community behaviour will continue to facilitate interoperability and exchange of information and services, predominantly developed and adopted in a bottom-up manner, based on demand and individual projects rather than on de jure mandates. In contrast, in the SDI model, data and services are supplied in a single direction, with little effective regard for demand or user requirements. The SDI model was aimed at making it easier to access data, and at the time of initiation it was a substantial improvement over analogue method. However, since then, the perception of 'easy access to data' has changed and the bar has been raised significantly.

Actors in the geospatial ecosystem will interact with each other anywhere and anytime. For example, a private sector company may use IoT sensors to collect air quality data that are provided to a government agency or other private company in real-time where it is used to automatically disseminate emergency warnings when the quality drops below a certain threshold level. Through collaboration with another private company the same data could be part of a location-based app used by the general community, for example, by journalists and activists who incorporate location-based air quality information into their social media posts. In some cases, for example, windows that open or close depending on the air quality outside, we may not even realize that location-based data are being used. In contrast, the SDI model assumes a 'clearinghouse' where one has to search for and acquire geospatial information provided by government or other public sector agencies. The information normally materializes as a geoportal web interface, designed for patient human visitors, not for large-scale, real-time and interoperable automation.

In a geospatial ecosystem, public good geospatial information will be accessed in an integrated manner without regard to the administrative barriers which now exist. Someone requesting data on flood zones will not need to know which specific agency or agencies have jurisdiction over those data, and which protocols and data formats are necessary or available. And it will be simpler to access geospatial information across boundaries. Just as phenomena such as forest fires, floods, immigration, and weather events seamlessly cross administrative boundaries, so too should the information regarding that area of interest. A harmonized search will reveal potentially useful information coming from multiple sources; some from government sources, some from perhaps an NGO or a university, other information from crowd sourced datasets and others from interconnected machines where no direct human intervention has taken place.

Self-organisation implies that the geospatial ecosystem is not controlled by a single actor, or a very small number of actors. Instead, collectively, the actors shape the nature of the system and its outcomes through their motivations, intentions, actions, and interactions. In the case of 'intelligent' machine actors, in particular autonomous continuously learning algorithms, will be the 'brains' controlling the 'needs and requirements' which they express. These behaviours could be more transparent, as there will be more eyes watching and commenting. However, they may also be obscured by the complexity of the ecosystem, or through deliberate intent or as a matter of national or commercial policy. An ecosystem is vulnerable to malicious actors, especially if they become powerful. Collectively, the benevolent actors in the ecosystem will have to take responsibility to maintain the openness, integrity and balance of the ecosystem.

The traditional cartographic and geospatial information agencies may continue to play a role, but not as the top-level authority in charge of the remainder of the system. Through their governmental function of setting guardrails to control and to facilitate certain national or regional activity, they can become keystone actors with a significant impact on the ecosystem. However, the relevance of slow-moving administrations will decrease and may eventually almost disappear if they cannot find and nurture their niche area of relevance in competition with other increasingly powerful and agile actors in an ecosystem environment.

The geospatial ecosystem is a socio-technical system, similar to an SDI, in which the interplay of people, machines and technologies play an important role in the provision and consumption of location-based information and services. The ecosystem is largely distributed, open and adaptive, but may contain walled off areas (e.g., 'closed' or proprietary platforms, subscription or licence fees for data or regionally isolated internet backbones). The silos of geospatial information will largely be transformed into open and loosely coupled systems, driven by demand and not by supply. A distributed system can provide redundancy so that if one actor (e.g., a service provider) disappears, another one from anywhere in the world can take its place. There will be considerable flexibility and adaptability in order to meet real needs from different parts of society.

When we consider the urgent 'local to global' needs of the SDGs, the ongoing response to the COVID-19 pandemic, growing climate change concerns, the consequences of disasters, impacts on our oceans and the environment and many other challenges, the geospatial ecosystem must (and can) be able to respond in a more timely and integrated manner. With the available technologies, tools, and methods to bring data in all its forms together to understand '***where'*** things are happening, the geospatial ecosystem will also assist developing world countries to bridge the geospatial digital divide, and ensure they become more resilient, healthy, equitable and sustainable.

It is our hope that the emerging geospatial ecosystem provides all countries and sectors of society, including business and civil society actors, with the opportunity to participate fully and effectively in transformational change, by minimising the digital divide with geospatial information and analytical capabilities for policy formulation, decision-making and innovation, providing knowledge, insights and shared understanding towards ensuring socio-economic prosperity, environmental integrity, peace, justice and national development, and a global to local thriving information economy.

4.2 The geospatial ecosystem in relation to other models and frameworks

4.2.1 Linked Data and Spatial Knowledge Infrastructure

Technologies, such the Resource Description Framework (RDF), linked data and ontologies were used, e.g., by communities from North America, Europe, Asia and Oceania, to progress and improving data exchange and interaction in meaningful ways. An example describing SDI transition was the white paper[34] on Spatial Knowledge Infrastructure (SKI) prepared by the Cooperative Research Centre for Spatial Information in Australia, which defined an SKI as a network of data, analytics, expertise, and policies that assist people, whether individually or in collaboration, to integrate in real-time spatial knowledge into everyday decision-making and problem solving.

4.2.2 The Geospatial Knowledge Infrastructure

Another view of the future is the so-called Geospatial Knowledge Infrastructure (GKI)[35]. The GKI vision expands from an SDI focus on 'data provision' to 'knowledge creation' and foresight. With a vision for "geospatial knowledge at the heart of tomorrow's sustainable digital society", the GKI promotes a knowledge infrastructure to integrate geospatial approaches, data and technologies into the wider digital ecosystem. In this paper we do not explicitly recommend a simple name change from SDI to GKI. However we do support the idea of moving from information to knowledge within the future geospatial ecosystem. The growing role of AI/ML in our data collection and analysis workflows makes us confident that a move from information (products) to knowledge (proposed or guided decision-making) is inevitable.

4.2.3 The UN-GGIM Integrated Geospatial Information Framework (IGIF)

In terms of the road ahead for national SDIs, the United Nations Integrated Geospatial Information Framework (IGIF)[36] places SDI in its rightful place, inside a larger framework, and which is gaining significant momentum. The IGIF is a globally adopted multi-dimensional framework aimed at strengthening national geospatial information management arrangements in countries - developing countries in particular. Notably, in the Implementation Guide – anchored by nine strategic pathways and influenced by governance, technology, and people – the IGIF provides detailed guidance on integrating geospatial information with other meaningful information to provide understandings and benefits from the perspective of a country's national development priorities.

This necessary information integration must be seriously contemplated and planned for. Professionals, researchers, and citizens alike are hungry for analysis-ready information, not files to be downloaded and reformatted. Analysis-ready information is often formed by the integration of geospatial and other data, and often is created on-the-fly rather than being precomputed and archived for later retrieval. It is possible to plan ahead regarding the typical cases of integration needed by users in government, research, civil society, and commerce. These cases can then be used to create capacity development plans and materials, practical exercises, and technology and boxes for protected experimentation. The COVID-19 pandemic as a globally unique and high impact event, reinforced the applicability of the IGIF as an overarching framework; the role and contribution of geospatial data, technologies and tools to deliver timely and reliable information – in this case, for public health and safety – in a systematic way across all countries and regions is clearly of paramount importance. In the case of these and other major regular global events (pandemics, heatwaves, flooding, etc.), all countries need to possess at least a minimum standard of information organization to be able to respond quickly and effectively inside and across national borders.

A key takeaway from the IGIF Implementation Guide: Strategic Pathway 1 (Governance and Institutions), is that of the four key elements where success is necessary – governance model, leadership, value proposition, and institutional arrangements – the first and the third will need to be implemented in a hand-in-hand, complementary way. A strong and viable governance model will probably only come to fruition if the other major stakeholders are convinced of the value of participation. The model must clearly articulate not the 'what' (we will build it), but the 'why' (to save money, increase efficiency, assist in reaching climate goals, save lives, etc.). Besides the collective 'why', each stakeholder will have their personal reasons for participating or not. Clarifying this will facilitate the other two elements. Leadership will become apparent, and agreements will be signed when the other two first succeed.

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[34] https://www.crcsi.com.au/spatial-knowledge-infrastructure-white-paper/

[35] https://geospatialmedia.net/pdf/GKI-White-Paper.pdf

[36] https://ggim.un.org/IGIF/

4.2.4 European Union initiatives

The INSPIRE (Infrastructure for Spatial Information in Europe) Directive[37] was established as European Union (EU) law in 2007. It aims to create a Union-wide spatial data infrastructure for the purposes of developing and reporting in relation to EU environmental policies and practices or activities which may have an impact on the environment. An EU wide INSPIRE SDI is based on the infrastructures for spatial information established and operated by the Member States of the Union. The Directive addresses 34 spatial data themes[38] needed for environmental purposes. The INSPIRE initiative has reached its final implementation and compliance phase. Although it has been seen in many quarters as a good practice example of a large scale SDI, it is not fundamentally premised on an ecosystem conceptualisation of the geospatial environment. As its name implies, it is seen as an infrastructure. It is nevertheless noted that the 2021 INSPIRE Conference has two tracks which indicate a willingness to evolve and to move forward, a track dedicated to a Political Roadmap and another to an Architectural Roadmap.

The European Union Location Framework (EULF) Blueprint[39] is a guidance framework for using location information in policy development and the provision of digital public services. It is fully aligned with the European Interoperability Framework (EIF), through its consideration of all aspects of 'location interoperability'. The EULF Blueprint is now being adapted to be aligned with the UN-GGIM IGIF Implementation Guide, as there are strong synergies between the two. This approach means that public administrations, in planning advances in their use of location data for policy making or the provision of digital public services, can now access in an integrated way the combined resources of both Frameworks. This represents a meaningful advance.

4.2.6 Data cubes and Digital Earth

The Australian Geoscience Open Data Cube, otherwise known as the Open Data Cube (ODC), aims to realize the full potential of Earth observation data holdings by addressing the big data challenges of volume, velocity, and variety that otherwise limit its usefulness (Lewis et al. 2016). The data cube approach allows analysts to extract rich new information from Earth observation time series, including through new methods that draw on the full spatial and temporal coverage of the Earth observation archives. The Australian Government announced an initiative called Digital Earth Australia, based on the Open Data Cube background. Australia partnered with the Group on Earth Observations (GEO) and announced the Digital Earth Africa initiative. Similarly, INEGI (Mexican Government) collaborated with the Australian Government to invest in a Digital Earth platform for the Americas. It is good to see partnership and knowledge sharing is taking place from a regional initiative. This Digital Earth platform relies on several technologies and, although the code developed is open source, there is little community of practice to enable or coordinate technical expertise. Hence, coordination and capacity building are needed to help practitioners' access and work with the data (Mohamed-Ghouse et al. 2020). Decision-makers and researchers are currently grappling with harnessing the Digital Earth platform to create saleable products (apps and APIs), where analytics is a well-established and supported opportunity for the industry beyond delivering funding for such initiatives via government grants. The geospatial ecosystem will take advantage of the data cube and Digital Earth investments to provide a rich experience to the user, also including other components of the ecosystem, such as IoT sensors.

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[37] [INSPIRE Directive | INSPIRE (europa.eu)]

[38] Addresses; Administrative units; Cadastral parcels; Coordinate reference systems; Geographical grid systems; Geographic names; Hydrography; Protected sites; Elevation; Geology; Land cover; Orthoimagery; Agriculture and aquaculture; Area management/restriction/regulation zones and reporting units; Atmospheric conditions; Bio-geographical regions; Buildings; Energy resources; Environmental monitoring facilities; Habitats and biotopes; Human health and safety; Land use; Meteorological geographical feature; Mineral resources; Natural risk zones; Oceanographic geophysical features; Population distribution and demography; Production and industrial facilities; Sea features; Soil; Species distribution; Statistical units; Utility and governmental services.

[39] https://joinup.ec.europa.eu/collection/elise-european-location-interoperability-solutions-e-government/solution/eulf-blueprint

4.2.7 Urban and rural geospatial digital twins

The United Kingdom's (UKs) National Digital Twin Programme – Centre for Digital Built Britain has developed concepts of national digital twins as part of the UK's digital transformation[40]. ANZLIC, the Australia New Zealand Land Information Council, in its Strategic Plan 2020-24 has discussed the principals of Spatial Digital Twins and focuses on 3D and 4D foundation geospatial data delivery in the near future for built and natural environments[41]. The New South Wales and Victorian State Governments in Australia have built successful pilots to integrate Building Information Models (BIM) in respective public facing Digital Twin Platforms to cater to the planning and construction industries. Similarly, work in Europe, e.g., the Netherlands, and North America, has been focusing on piloting city-based digital twins. The geospatial ecosystem provides the platform to utilize the power of analytics, processing through quantum computing and integration of smart sensor networks within the geospatial digital twin environment. Capacity building the workforce to develop and maintain geospatial digital twins will be a future challenge that needs to be addressed.

4.3 Skills in the workplace

4.3.1 Geospatial to be increasingly subsumed into IT

In the geospatial ecosystem, which includes the fast-growing space imagery sector, repeatable tasks of 'traditional' geospatial work will increasingly be subsumed into the wider IT sector. The IT sector dominates the cloud and mobile telecoms, two key pieces in our day-to-day information consumption activities. In its report about the Future of Jobs, the World Economic Forum[42] includes geographic information systems as a digital skill under 'Technology design and programming'. The latter is placed eighth among the top 15 skills perceived to be in growing demand by 2025. However, it is common that specialist geospatial expertise is needed for geospatial products within this wider IT environment, as it is not the job of IT specialists to 'reinvent geography'. In this increasingly complex and diverse ecosystem, there will be a need for geospatial practitioners who master special narrowly focused areas of expertise, but also for geospatial generalists who have an understanding and competency across diverse application domains within the broader IT domain.

A key challenge for the geospatial community is to identify what these specialist geospatial focus areas are, and based on these, how best the geospatial sector can fit into this wider environment such that the important role of geospatial can be fully and optimally realised. It is suggested that this specialist role will need to be defined and occupied quickly and practically, by just doing it, rather than by convening committees and drafting long documents which will eat up precious time and will probably not be much paid attention to by fast-moving implementers. With location information becoming ubiquitous, geospatial services as a horizontal function (i.e., applied and used in many different application domains) will lead to an increase in the demand for geospatial skills and expertise. A related challenge will be to get people from all application domains conversant in at least basic geospatial information and technology issues.

In the normal context of a start-up company, that company survives and thrives when one or more of its key members identifies real needs within their community and can translate those needs into terms the IT people can understand and implement. Historically, an important part of the specialist role has been the close contact that many in the geospatial sector have with end users, working at municipalities and mining companies, for example, making the geospatial expert a valuable and necessary intermediary to help determine real and feasible user needs, performance criteria, and business models. Geospatial experts will come from a variety of sectors—public, private, education, NGO, and the informed citizenry—many of whom are more versed than traditional geospatial information providers in business models and collaboration. The new geospatial information ecosystem will to a large extent be created by these partnerships.

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[40] https://www.cdbb.cam.ac.uk/what-we-do/national-digital-twin-programme

[41] https://www.anzlic.gov.au/sites/default/files/files/principles_for_spatially_enabled_digital_twins_of_the_built_and_natural_.pdf

[42] http://www3.weforum.org/docs/WEF_Future_of_Jobs_2020.pdf

4.3.2 Different level of skills and expertise

Whilst machine-to-machine communication and autonomous machine-centred processing and decision-making will be more prevalent in the geospatial ecosystem, people will still play crucial roles in shaping the manner in which geospatial and other information is processed and used: behind every powerful machine, there is a human being who conceptualized and produced it. Machine learning is increasingly being used for tasks such as feature extraction and satellite imagery classification. In many cases the algorithms are trained by expert humans, and the results checked for accuracy also by humans. However, in the rapidly evolving technical environment of the future, increasingly it will become the case that behind every successful machine there will be another machine and even the role of human experts in the algorithm training process will be reduced as other algorithms will play a dominant and interventionist role. Already unsupervised training of deep learning neural networks is a reality, although in many cases there is still a way to go for this approach to be fully mature.

A current example of machine teaching machine is a research institute in Europe which is developing a 4D digital twin of an orchard so that this imagery can be used to train robots to undertake fruit picking without human intervention. In essence it amounts to a machine teaching a machine to do what has traditionally been a labour-intensive task. As another example of the encroachment of machines into the traditionally exclusive human domain will be the case where non-GIS literate people will be able to speak to their computers in normal conversational language and over time increasingly complex GIS type functionalities will be undertaken, with AI/ML operating in the background to take decisions which trained human GIS operators would traditionally have taken.

There will be multiple projects or attempts at producing the same geospatial information products using AI/ML, and the geospatial experts will need to be able to sort them out, perhaps recommend one over another, and to flag warnings when perhaps key assumptions or prerequisites are not met, producing suboptimal results for a certain use case.

We therefore have to adapt how we educate and train people. The focus should shift to assessing the output or outcome of a task in terms of needs and requirements, instead of training people to do the task. This would be another example of the implications of the changes where a key type of expertise which is required is not technically oriented. The geospatial community will need to have more people who are trained in the key kinds of soft skills needed to direct projects, negotiate with stakeholders from at least three subcommunities – public sector, private sector, citizen groups and NGOs – to build the partnerships needed to support a truly useful geospatial information ecosystem.

Therefore, upgrading the level of expertise, particularly in developing countries, is of critical importance, not only for the countries concerned but from the perspective of overall global stability. To get to the required critical mass of expertise, the entire education system, from the early primary level to the postgraduate level, needs to be reconsidered, with geography playing a significant role. Tertiary geospatial education establishments will also have to radically rethink their curricula and teaching methods so that their students are prepared for a future market environment that requires significantly different types of geospatial skills. Instead of teaching students to complete tasks largely by themselves, they have to be prepared to work in a world where they will use or interact with powerful machines or software to complete tasks. They not only need to have an understanding of the workings of the relevant machines and the software which guides them, but also the ethical and security consequences of using them.

The above is a lofty goal, not easily attained in less than a decade even in a developed world context. However, there can be quick wins in terms of the creation and dissemination of tutorials, intense 'bootcamp' trainings, sample datasets for experimentation, IT sandbox environments, North-South style mentorship programs, and more. Good use could be made of a few realistic case studies of public-private-partnership (PPP) successes, especially small win-win scenarios. Retraining resources can be aimed not only at new students coming through education institutions but also at existing government officials, technicians at mapping authorities, among other groups, such that an ongoing adult capacity building programme exists which begins to address the dynamic changing digital environment in which we will all exist.

4.4 Data management and governance

4.4.1 Principles

In a geospatial ecosystem where location information is ubiquitous, guiding principles are needed to direct people and organizations who will be using this information to develop new technologies and tools. For example, principles related to ethics, the need for truthfulness, ease of access, privacy, intellectual property rights protection, and openness would all be needed. However, even with guiding principles in place and them being widely supported, implementation and monitoring of the principles remains a key issue (who should do this?), as well as what might be the ramifications of not abiding by such principles. Guidant principles are discussed in section 5.6 below.

4.4.2 Trust in the data

Trust in information is a critical issue today and will no doubt remain an issue of considerable significance in a future geospatial ecosystem. The data or information consumed through the geospatial ecosystem needs to be adjudged for its fit for purpose usage before utilisation. Due to the ever-increasing volumes of geospatial information being produced and integrated, not necessarily by professionals, it will be necessary to develop new methods or indicators for assessing the trust it is possible to have, and quality of data, e.g., based on lineage or contributors.

Not only trust in data or information is of relevance, but also trust in the geo-analytics that use geospatial data and other information for decision support is a necessity. Information about provenance and the functionality of such analytics will also be required to facilitate appropriate levels of trust in the outcomes which they produce.

4.4.3 Integrated data management

The environment of the geospatial ecosystem comprises sources of data, such as satellites, drones, IoT devices, in-situ measuring equipment, etc., as well as analytical tools, such as specific algorithms which use geospatial data; regulatory authorities; individual companies which provide geospatial data or undertake geo-analytics; and individual consumers of geospatial information. These actors and their environment may be viewed from a variety of perspectives, including levels of connectivity, positions in power or influence relationships, levels of resource availability, and basic underlying motivations. Interconnectivity between geospatially relevant elements would be mainly characterised by geospatial information flows, with the nature and volume of such flows being of critical importance to the evolving geospatial ecosystem.

Information management and government practices within the geospatial domain will have to adapt to the dynamic emerging ecosystem environment. The geospatial ecosystem will support accurate collection of data, efficient processing, effective dissemination, and smart and open analytics which use location information in real-time or near-real time, often based on machine-to-machine communications and on-the-fly predictive analytics using artificial intelligence which will enable the global markets to utilise services through the ecosystem. The silos of geospatial information will disintegrate into an integrated framework of managing and governing diverse geospatial information from many different sources.

4.5 Organizations and institutions

4.5.1 Power balance between big and small companies

A matter of significant public good concern is the increasing dominance of big tech companies in the current and future geospatial ecosystem, a situation which requires extra-national oversight and regulatory or enforcement bodies, or at least the coming together of national states into groups which can use their combined economic and other powers to set bases for the operation for the powerful companies[43].

The question of who controls what geospatial information will increasingly be an important factor in the future, also in the context of an ecosystem where competition between different actors plays a key role. While large IT platform companies such as Google, Microsoft, Amazon, and Facebook may become even larger and more powerful in future, rapidly changing technology and data environments running on those platforms will have a considerable impact on small to medium sized enterprises (SMEs). Irrespective of large companies or SMEs, the geospatial ecosystem provides a participatory approach and allows for organisations to be agile in producing or utilising the ecosystem.

Consensus-based open standards play an important role in maintaining a power balance and ensuring that geospatial information remains accessible to the entire global community. Open standards level the playing field and facilitate rapid innovation (also for SMEs). It is necessary that standards can continue to fulfil these roles so that we do not end up with an imbalanced situation where there are excessively powerful actors who provide little or no real public good but retain their ongoing dominance though exercise of their market domination. It should be noted however that in a dynamic agile ecosystem such domination is likely to be eroded through competitive processes even without focussed anti-competitive measures.

4.5.2 The role of government

The Rio+20 background document by the UN Committee of Experts on Global Geospatial Information Management[44], prepared in 2012, recognized that institutions had been slow to make the changes necessary to allow for a modern geospatial infrastructure:

"Both the Earth Summit in 1992 and the World Summit on Sustainable Development held a decade later recognized the need for the integration of very different types of information on the environment and both social and economic development into a common framework but both the technical and institutional challenges to achieve this have proven to be very difficult to overcome. The institutional challenges have proven to be particularly recalcitrant although significant progress has been made in technology" (page 4)[45].

In 2021 it is not possible to report that this situation has improved significantly in any general sense. Much work remains to be done on several fronts: raising awareness of the value and benefits of geospatial information at the policy level; liberating it from the traditional closed information silos at the technical level; integrating across the wider government sector; and establishing new alliances across a much broader and diverse stakeholder community all need to be developed. National policies, flexible geospatial infrastructures, technical capacities and capabilities, still need to be developed, better aligned and considerably strengthened so that all countries have the opportunity to develop and contribute to benefit from a vibrant national geospatial information ecosystem, and through that, a global and thriving information economy (Scott and Rajabifard, 2019).

Private sector companies operate very differently than governments, and this difference is compounded in a rapidly changing technological environment. In the case of companies, few individuals make the key decisions and then ensure that they are implemented almost immediately. Larger private sector companies have enormous resources to bring to bear on whatever issue they care to focus on. By contrast, to a large extent, governments take decisions through reaching consensus often meaningfully involving the wider

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[43] A topical example is the agreement by the G7 to create a framework for dealing with tax issues for big global companies. The OECD, which although it is not itself a body with executive enforcement authority, can also provide an important avenue to advance frameworks for regulation and control of global companies.

[44] https://ggim.un.org/meetings/GGIM-committee/documents/GGIM2/GGIM%20paper%20for%20Rio_Background%20paper_18May%202012.pdf

[45] https://ggim.un.org/meetings/GGIM-committee/documents/GGIM2/GGIM%20paper%20for%20Rio_Background%20paper_18May%202012.pdf

citizenry, at least that is the case in democracies. Reaching consensus takes time and thus governments tend to be operating from the back foot and in a reactionary rather than proactive mode.

Governments are beginning to realize that their roles must change in a fast-evolving digital environment. They cannot implement decisions at the same pace as private sector companies, so should focus on those aspects of the geospatial ecosystem that contribute most directly to enhancing the public good. For example, governments could provide authoritative data (e.g., by mapping agencies or municipalities); they could continue to provide regulatory environments to shape the context within which companies and citizens operate; and they could play a facilitating role to ensure that the broader public interest is retained as new technologies are developed and new data sources become available.

While needing a high level of governance to succeed, the future may hold potential alternatives to the traditional regulatory role of geospatial information being in the exclusive domain of public sector bodies because of their unique ability to make and uphold national legal and policy arrangements. In a geospatial ecosystem, regulation (and possibly non-legal sanctions) of whole swaths or sectors could be carried out by major private sector companies based on their deep resources and global reach. The regulations set by such companies will not be backed by the authority of the state but instead by the pervasiveness and benefits provided by the 'regulating' companies. This process of non-legal company regulating is currently present and will likely only deepen and spread. Again, public sector bodies can see this process of privatisation of regulation as a threat to themselves and the public good (which it certainly can be) or also as an opportunity to enable them to focus on what exclusively only they as governments can do. From a regulation perspective, finding an optimum way through the ever-changing regulatory aspects of the ecosystem environment is one of the more critical challenges for the relevant public sector bodies.

4.5.3 The dilemma of local governments

While metropolitan cities tend to have large budgets for maintaining geospatial information and the application of analytics required to manage their areas of jurisdiction, local governments and municipalities of smaller cities or towns, including in predominantly rural areas of both developed and developing countries, tend to be under-resourced. In a relatively free-for-all ecosystem which has competition as a key driving force, they will increasingly struggle to keep pace to find the human and other resources required to manage and maintain the geospatial information and technologies that they need. One possible solution would be to partner with other organizations, for example by creating clusters of local governments that support each other, through public-private partnerships, or by national governments stepping in and taking a leadership and 'integration' role in supporting local governments.

4.6 Society

4.6.1 Propagation of location-based misinformation

In the largely self-organized geospatial ecosystem, misinformation propagated through social media and other means will become an increasingly important problem with potentially serious implications for societies in many ways, including for example, using (abusing) geospatial information as a means for promoting the weakening of democratic values and governance systems. Misinformation regarding location topics can constitute a serious problem and one which will require concerted and sustained investigation and action within the geospatial community. However, the converse also applies. Geospatial information can also be a useful feature in efforts to determine the truth, an example in this regard is the Bellingcat initiative, which has successfully used location information to trace human rights abuses[46,47] .

The role which geospatial information and analytics can and should play in identifying and limiting malicious actions and interventions needs to be more thoroughly evaluated and discussed. In a more globally interconnected digital environment, particularly where more and more information is spatially tagged, the consequences of such malicious actions can be severe, in some cases even life-threatening.

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[46] https://www.bellingcat.com/resources/case-studies/2019/03/04/geolocation-and-a-philosophers-stone-in-kashmir/

[47] https://www.bellingcat.com/resources/2020/08/12/historic-bombing-runs-the-memphis-belle-case/

4.6.2 Geospatial ethics and the challenge of protecting personal location information

The International Association for Promoting Geoethics (IAPG) is a multidisciplinary, scientific platform for widening the discussion and creating awareness about problems of Geoethics and ethics applied to the geosciences.[48] Similar to the geoethics of IAPG, we require geospatial-ethics which will provide guidelines for producers and consumers of data and information from geospatial ecosystems to conform and comply with widely accepted ethical principles. Professional associations and civil societies are presently discussing digital ethics, which could be upgraded and extended with the inclusion of location-based ethics.

The question of personal information ownership and control will remain a controversial issue, whether we think of the geospatial environment as an infrastructure or an ecosystem. Billions of sensors capable of recording and broadcasting personal information, and companies and governments willing and able to exercise varying levels of control, will make the role of mandated data protection organisations very difficult for governments. In democratic societies, major breaches of good practice contribute to reduced trust in at least certain elements of the all-embracing digital environment within which citizens, companies, civil society, and public sector bodies will exist. The consequences of these breaches will be difficult to predict, particularly bearing in mind the benefits which can be delivered so easily and often free of charge to the denizens of this digital world.

In the case of highly regulated societies, where key elements of government's digital information processing and distribution arrangements are able to set restrictions on citizen freedom of expression and movement, appropriate checks and controls need to be recognized and applied to spatially tagged information of a personal nature. For example, the exact location of every citizen could at least in theory be known in real-time by national organisations. From a democratic perspective these types and levels of intrusion and control will likely be unacceptable and give rise to heightened tensions between societies and groups within societies. These will be critical policy and legal issues to consider, especially 'location' can and possibly will play a crucial role in being able to record the 'movement', in almost real-time, of everyone and everything.

5. How can the geospatial community drive the transition to a sustainable geospatial ecosystem?

At this stage it is not the end state that is so important, but the start of the change towards the end state. But how do we get there? We are already on the journey to the emerging new environment. In this respect, we are all aware of the many emerging technologies, which are well documented. But what is not so much documented is how these many, often interconnected technologies, can be holistically adopted, applied, and implemented. In this section we provide suggestions for governments, the geospatial industry, academia, and society at large for getting ready and moving forward so that they can survive and prosper in the dynamic geospatial ecosystem, and more importantly, that they can exploit the benefits that such an ecosystem brings. A large part of the geospatial community is eager to adopt technological advancements, but an important group is either worried (and/or unprepared) about the speed of change and updates, or else is rather left-out as victims of the digital divide. With our suggestions we aim to provide some guidance for each target group, or at least bases for focussed discussion, and conclude with a set of guiding principles. We relate each suggestion to the relevant strategic pathway (SP) in the UN-GGIM IGIF.

5.1 Suggestions for governments

Replace control with coordination. *Related to IGIF SP1 Governance model, Leadership; SP7 Partnerships and Joint Ventures; SP9: Stakeholder identification.*

One of the main contributions that the current lead SDI government organizations can do is to relinquish and devolve control to multiple stakeholders, while at the same time continuing in a coordinating capacity, for example, on the acquisition of aerial or other imagery, in order to avoid duplication. The emphasis should not be to control what is done (other than in clearly defined areas) but to recognise, understand and derive advantages from an understanding of the diversity of approaches, data, processes, analytics,

[48] https://www.geoethics.org/

and output display forms used. An overriding aim should be to ensure that new project-based silos do not emerge again and that optimum opportunities are created to share information. Public sector bodies, whether at national, regional, or local level, will have to play their part in this.

Develop agile frameworks to facilitate interoperability and avoid project silos. *Related to IGIF SP1: Institutional structures; SP2: Norms, Policies and Guides; SP5: Process improvement.*
Governments should take care to develop agile frameworks within which the plethora of distinct user-needs-driven tightly focussed initiatives or projects can become interoperable. This applies to initiatives or projects which the public sector bodies undertake themselves, but also where they fund projects undertaken by consultants. In this latter case, public sector bodies should continue to insert into the contracts of appointment that the consultants provide all the relevant data, and details about the processes followed and the analytics used. The question may be asked, what an agile framework is and how does one develop and implement such a framework? For example, an agile framework could take the form of a set of guiding principles (see section 5.6 below) which are evaluated on a regular basis, importantly by a diverse set of stakeholders. Making such principles a practical and effective basis for decision-making across the geospatial stakeholder spectrum would involve raising awareness of the principles and evaluating potential public sector funded projects on the basis of such principles.

Continue with policy development. *Related to IGIF SP1: Institutional structures; SP2: Norms, Policies and Guides; SP5: Process improvement.*
A whole suite of policies is required to develop and maintain an agile framework, for example, policies regarding pricing, licensing, use and reuse[49], and standards. In the ecosystem environment, governments will not be able to enforce these using a 'big stick' approach only, there will also have to be some 'carrot' incentives in the mix, i.e., something to incentivise the custodians (or the individual representing the custodian organization), for example, something related to their performance criteria, or saving money.

Identify niche geospatial information themes and custodians. *Related to IGIF SP1: Institutional structures; SP2: Implementation and accountability; SP3: Benefits realization; SP4: Custodianship, acquisition and management; SP7: Cross-sector cooperation; SP9: Stakeholder identification.*
SDI committees or coordinating bodies should continue to identify essential geospatial information themes and custodians for them. The focus should however be on information that is critical for governance and the functioning of society and that is not readily available elsewhere. Efforts by the public sector to stall or prohibit alternative data sources for many other areas and themes, should not be the case. Here also collaboration is key: for example, there may be a custodian for the municipal data and a coordinating custodian for the national dataset.

Widen representation on SDI coordinating bodies. *Related to IGIF SP1: Governance model; SP7: Community participation.*
SDI committees or coordinating bodies should have representation from the entire user community, i.e., not only from government, but also from industry, academia, and civil society, and from a wide range of application fields.

Re-focus on niche areas. *Related to IGIF SP3: Financial Partnerships; SP5: Process improvement; SP7: Partnerships and cross-sector cooperation.*
Public sector bodies should plan ahead for an ecosystem that is self-organized around the demand for geospatial information, technologies and services (and not the supply thereof). This implies that they need to understand what their niche or area of specialization is, and what the demand for that is. For example, unless legally required to do so, national mapping agencies should consider stopping production of topographic data at scales that are readily available on other platforms, such as OpenStreetMap and Google or Bing Maps. Instead, they could provide active citizen support for OpenStreetMap, or in the case of private sector topographic data providers, they could enter into partnerships which guarantee price and supply duration time frames in order to address the potential problem of such providers arbitrarily cutting

[49] An example is the European Union's Directive (EU) 2019/1024 on open data and the re-use of public sector information.

their services or raising prices. (Note that governments and key people also change, so continuity is needed there too.) Staff and other resources within the mapping agencies could be redeployed into the types of coordination and facilitation roles which have been mentioned elsewhere in this paper.

Another re-focusing opportunity for governments could be to support cities and municipalities of all sizes with their production and use of large-scale topographic data. Cities and other public sector entities 'at the coal face' either have a lot of the topographic data at a scale that is useful for managing their areas of jurisdiction (especially big metropolitan municipalities) or they don't have the resources and could benefit from support from a national mapping agency which has the skills capacity available. The latter would enable national mapping agencies to be directly relevant in the geospatial ecosystem and closer to the public sector 'frontline'.

Actively engage in collaborations. *Related to IGIF SP5: Process improvement; SP7: Industry partnerships.*
To survive and prosper in an ecosystem, smaller public sector bodies should strengthen their competitive advantage through collaborations with others, and collaborators should be understood broadly. For example, for smaller municipalities collaborators could be OpenStreetMap and/or open-source software developers; partnerships with private companies to maintain their datasets, with the IT support division in their organization or with an NGO. This activity should focus on information that is critical for the functioning of the municipality now, not a data warehouse for possible future use.

Provide geospatial information services as a horizontal function. *Related to IGIF SP1: Institutional structures; SP4: Data curation and delivery.*
Due to the widespread use of geospatial information in a geospatial ecosystem, in larger public sector bodies geospatial information support should be provided or shared as a horizontal function, instead of one that is seated in a single division, such as planning or civil engineering. An adequately resourced single entity, which has a clearly defined cross-administration support role, could support automation of data and analytics sharing, problem solving, opportunity seeking, sharing solutions found in one department or agency with other agencies, updating regarding new technical, guidance and legislative developments.

Get involved in e-government and data management initiatives. *Related to IGIF SP1: Institutional structures; SP3: Partnerships; SP4: Data curation and delivery**.***
Those in governments who represent the geospatial community of today should aim to move closer (or even become part of) wider government initiatives that focus on e-government and data management. The e-government and data initiatives often have exactly the same aims and objectives as SDIs, although they are not specifically focused on geospatial data and the delivery of location-based e-services. It makes sense to join them and avoic establishing parallel initiatives. Collaborating or partnering with these bigger and wider initiatives, will help them to achieve their geospatial data management and governance objectives.

Provide authoritative stamp of approval, where necessary. *Related to IGIF SP2: Norms, Policies, Guides, SP4; Data custodianship and management.*
Due to the expected increase in disinformation, an authoritative government stamp of approval on geospatial information, technologies or analytics will become even more important in future. However, governments will not necessarily be the sole source of 'authoritative' geospatial information, as the outputs of certain private sector companies or not-for-profit organisations with a 'fact checking' role will become more prevalent. Public sector bodies may well have to compete with non-public sector bodies in this space and will need to be on top of their game in order to retain their relevance. A role for public sector bodies in this changing environment would be to engage with fact checking bodies and determine ways in which their activities can be supported.

Be strategic when initiating an SDI within the geospatial ecosystem. *Related to IGIF SP1: Value proposition; SP3: Benefits realization; SP 4: Data curation and delivery; SP5: Bridging the digital divide.*
Countries that have not embarked on an SDI, should probably first decide what geospatial information is strategically essential for the country, and then decide (with an open mind) how this can be collected, maintained, and made widely available, not always by the government agencies themselves. They might use competition in the ecosystem to their advantage, i.e., they have the flexibility to choose the provider which best suits their needs based on performance or develop public-private partnerships. They should

focus on immediate requirements rather than trying to solve all potential future use cases. Portals and catalogues can be useful as a first step in making geospatial information available, but they do not solve all problems and are not the end goal. An important consideration is to keep it simple and based on true needs with the first implementation, and then gradually expand to incorporate more datasets and functionality.

5.2 Suggestions for the geospatial industry

Re-assess niche areas and re-organize accordingly. *Related to IGIF SP5: Promoting innovation and creativity.*
Organizations, whether in the private or the public sector, should plan ahead for an ecosystem that is self-organized around the demand for geospatial information, technologies and services (and not the supply thereof). This implies that they need to understand what their niche or area of specialization is, what the demand for that is, and then strategically re-organize themselves accordingly.

Demonstrate product and service benefits through implementations. *Related to IGIF SP5: Technological advances; SP6: Technical interoperability.*
Industry stakeholders should provide working demonstrations of key capabilities operating on basic evolving infrastructure such as the web. In an ecosystem that is shaped by competition, the viability and applicability of industry vendor solutions will be judged by testing (at least) and assessing operative pilot implementations.

Strengthen competitive advantage through collaboration. *Related to IGIF SP1: Institutional structures; SP5: Promoting innovation; SP7: Cross-sector cooperation; SP8: Awareness raising; SP9: Stakeholder identification.*
Industry associations, consortia and working groups are a good way to bring together the diverse range of stakeholders and to discuss the overall needs of the market, who might be key target customers or clients, standards, and other matters. In this regard OGC provides a useful model for private sector companies to share the challenges and limitations in standards adoption and contribute to the community of practice in the geospatial ecosystem.

Niche market opportunities for SMEs. *Related to IGIF SP1: Value proposition; SP3: Business model; SP5: Promoting innovation; SP7: Industry partnerships and joint ventures; SP8: Entrepreneurship.*
Geospatial SMEs are ideally positioned to be innovative, providing uniquely tailored turnkey solutions for an abundance of niche market opportunities. Although the resource and expertise requirements of turnkey solutions may be more than the skills or resources base that SMEs have at their disposal, there will be ample opportunity for them to become more specialised in niche areas and to collaborate or cooperate with others, possibly also SMEs, in providing turnkey solutions. For example, a geospatial SME which develops expertise in such areas as user needs survey skills, institutional dynamics understandings, understanding company or government operational processes, or in how best to unpack the user needs and requirements stage when viewed from a geospatial perspective, etc. would have a competitive edge over non-geospatial SMEs and other types of companies because of their familiarity with the geospatial technological aspects of the potential solution. Also, geospatial SMEs will be able to make meaningful contributions in a wider consortium of companies which, as a whole, has mastery of the solution process from beginning (user needs determination) to end (delivery of final products or services).

Capitalisation opportunities for large geospatial companies. *Related to IGIF SP5: Promoting innovation and creativity.*
Large geospatial companies should capitalise on their global reach, their substantial resources, their ownership of massive amounts of storage space and computing power, their extensive integration into other non-geospatial areas, such as provision of cloud environments, hardware, non-geospatial software, etc., and their ability to create geospatial infrastructures which other players can utilise for their own more unique needs-driven purposes. They should continue to build their geodatabases, but also invest heavily into new types and 'flavours' of geo-analytics, both as consumers of available analytics and as pioneers developing new geo-analytics. Platform as a Service (PaaS) and Software as a Service (SaaS), which are already present, will increasingly supplant Data as a Service (DaaS) as the dominant source of income and reach. A new area of growth will be Expertise as a Service (EaaS), provided not mainly by people but instead by sophisticated algorithms, which have taken considerable resources to develop.

5.3 Suggestions for academia

5.3.1 Suggestions for academia as providers of new knowledge and technologies through research and as producers and users of geospatial research data

Research to understand and support the geospatial ecosystem. *Related to IGIF SP5: Promoting innovation; SP5: Process improvement; SP7: Cross-sector and interdisciplinary cooperation.*
The focus of research should shift to a whole plethora of new and emerging topics relevant in the geospatial ecosystem. For example, what should the formal and informal regulatory environment look like; how best to exploit opportunities and avoid the formation of project linked silos arising from a project focused environment; understanding how privacy and misinformation issues arise from the inclusion of location considerations (data and analytics); new modes of data fusion for creating information products; and understanding how evolving new products and processes deliver both good and poor outcomes for which sectors of society. Whilst much research could have a practical 'real-world' focus, some of the research will need to be at a conceptual or theoretical level in order to provide the necessary overall frameworks and theories for understanding and ultimately responding to new and evolving developments in the geospatial ecosystem.

Engage in trans-disciplinary research. *Related to IGIF SP5: Technological advances; SP7: Cross-sector and interdisciplinary cooperation.*
Computer science and IT programmes at universities have an important role to play in furthering key technologies such as information search, AI-based filtering and suggestions, and data fusion. Geospatial people are the subject matter experts, not necessarily the experts in data or computation. Researchers in the geospatial field should therefore actively engage and partner in trans-disciplinary research with their colleagues in the computer science and IT fields. Equally important, the wide(ning) use of geospatial information calls for trans-disciplinary research in existing and new application domains to make sure that geospatial information and technologies are used to their fullest advantage. Reaching out to business schools and others working on the economic models of such large cooperative ecosystems is also needed. Finally, trans-disciplinary research is required into the social impacts of widespread use of geospatial information and technologies.

Research challenges related to variety and veracity of big geospatial data. *Related to IGIF SP4: Data curation and delivery; SP6: Semantic, Data and Technical interoperability; SP7: Cross-sector and interdisciplinary cooperation.*
Addressing the volume and velocity issues of big geospatial data can largely be addressed through general IT and computer science research and development, however, some issues regarding variety and veracity of big geospatial data will require geospatial expertise and/or spatio-temporal approaches to solving the problems.

Contribute with FAIR research data. *Related to IGIF SP2: Data protection and licensing; SP4: Data curation and delivery; SP6: Legal, Semantic, Data and Technical Interoperability.*
In line with the FAIR (Findability, Accessibility, Interoperability and Reuse) principles for scientific data management and stewardship[50], not only the research findings but also the data, techniques, and methodologies should be widely available for consideration and use by others. Such research data will lead to further growth and evolution of the geospatial ecosystem.

5.3.2 Suggestions for academia as educators of the future generation of practitioners

The emerging geospatial ecosystem calls for a radical rethinking of curricula. For this, geospatial educators will have to reach out to other disciplines, such as computer science, engineering, sociology, psychology, public administration, and management science. Some suggestions in the education and capacity building domain are outlined below.

Shift from training to perform tasks to educating to design tasks and assess results. *Related to IGIF SP7: Cross-sector and interdisciplinary cooperation; SP8: Formal education.*

[50] https://www.nature.com/articles/sdata201618

Due to increasing automation and the availability of geo-analytics, there will need to be a shift away from providing technologists who can perform certain specialised technical tasks to educating scientists or professionals who can design and assess tasks and task results. Increased automation of data acquisition calls for a curriculum shift towards automated analytical information extraction and decision support, particularly, on the emerging variety of AI/ML approaches and tools. For example, students should know wo to choose the right openly available AI/ML tools to solve specific, complex geospatial problems and be able to critically reflect on the outputs of such tools. As another example, competence needs to be developed in how to set up machines to do geospatial tasks, increasingly in 3D with a real-time component, i.e., 4D. A sub-set of considerations in this regard would be how to teach machines to teach other machines how to undertake tasks which have a significant geospatial component.

Produce rounded graduates with soft skills. *Related to IGIF SP5: Promoting innovation; SP8: Formal education.*
Educators should strive to produce amongst their graduates at least an understanding (and hopefully a good operational level of competence) in the soft knowledge and skills, such as negotiation, project management, public speaking, and team-building, needed to manage and participate in all the stages of a geospatial project, from needs assessment to solution provision and implementation. Lessons can be learned from the private sector and from sports. As noted earlier the social issues of building and maintaining an information ecosystem are harder to resolve than the technological issues. The ever-changing geospatial ecosystem requires graduates who are curious, adaptive and flexible, creative and innovative within an increasingly broadly defined geospatial domain area.

Take advantage of open resources. *Related to IGIF SP8: Awareness raising, Formal education; SP9: Integrated engagement strategies.*
Educators should take advantage of the availability of open resources in their teaching and learning endeavours, e.g., by developing a body of knowledge based on research outcomes, or incorporating open data, open geo-analytics and other tools into their teaching. Similarly, sharing open educational resources in a geospatial ecosystem can facilitate competition and collaboration. In addition, students should visit government and other data providers to get an idea of how they operate. At the same time, educators should engage with private sector stakeholders to assure easy access to their (licensed) technology and data.

Raise awareness of geospatial programs and their importance for society, industry and government. *Related to IGIF SP8: Awareness raising, Formal education.*
To meet the current and future demand for skills in the geospatial ecosystem, there will have to be a significant increase in the number of graduates in study programs that focus on geospatial information and technologies specifically. To achieve this, awareness has to be raised of such programs and the importance of geospatial information and analytics for society, industry and government. Educators from all over the world should intensify their collaboration to achieve this, e.g., by marketing their offerings under a common all-inclusive name, instead of the diversity of unique labels, such as geomatics, geomedia, geomarketing, geoinformatics and geographic information science (GISc or GIScience). The public and private sectors need to collaborate and support this effort.

Provide open educational resources to teach geospatial data and analytics literacy in other disciplines. *Related to IGIF SP7: Cross-sector and interdisciplinary cooperation; SP8: Awareness raising, Formal education.*
Geospatial data literacy should be a core competency in any non-geospatial discipline and thus be part of each core curriculum in a wide variety of study programmes, from business sciences to sociology and many others. Experienced geospatial educators could develop and provide open educational resources for this purpose. Links to the role of geospatial data and analytics in achieving SDGs and mitigating global environmental crises should be made, to provide strong incentives.

Provide life-long capacity building. *Related to IGIF SP8: Professional workplace training.*
In addition to the changes in university curricula aimed at undergraduate and graduate students, skills development and opportunities for mid-career professionals should be developed, particularly those who received their education and training in a pre-ecosystem world. This should not be an option but rather a

regular requirement going forward. The ecosystem will not be well served by propellor-certified pilots trying to fly modern jets.

5.4 Suggestions for civil society

Actively engage in collaborations. *Related to IGIF SP3: Partnerships and opportunities; Investment; Benefits realization.*
There are many open opportunities in the fast-growing changing geospatial ecosystem for NGOs, start-up companies, and public-private-partnerships. This is an excellent moment to seek out partners for the provision of services and products related to location and geospatial decision-making. NGOs should be able to utilise the data and information from the ecosystem in confidence and minimise their investment in data and information for their respective project needs.

Hold the powerful to account. *Related to IGIF SP2: Implementation and accountability; SP8: Raising awareness.*
There is a need for civil society collectives, such as NGOs, citizen science initiatives and others, to help to open up the sometimes murky use of location information to shape decisions, both by humans and by machines. Civil society groups need to hold the powerful organizations, whether from the public or private sectors, to account for their use, or non-use of geospatial information and technologies. This represents a very substantial basic challenge for civil society. The ecosystem should build in transparency by design, not as an afterthought.

Engage in public discourse on acceptable parameters within which geospatial data and technologies are used. *Related to IGIF SP2: Implementation and accountability; SP8: Raising awareness.*
A second call to action for civil society bodies in the broadly defined geospatial domain is to express public views (maybe even emotions) on how geospatial information and technologies are being used or plan to be used. Ideally, they could or should move beyond just expressing such views by providing widely based civil society derived parameters within which the exercise of powers in the geospatial domain should be used, a key feature of such parameters relating to privacy, cybersecurity and misinformation matters.

Foster accountability, integrity and ethical behaviour of professionals. *Related to IGIF SP1: Institutional structures; SP2: Implementation and accountability.*
Professional bodies and societies, as well as public agencies, should not be gatekeepers into the geospatial domain by for example claiming the reservation of geospatial work. Instead, they should focus on accountability, ethics and integrity of their members and on developing guidance regarding what is good and bad practice. For example, professional bodies could develop charters for digital ethics to be followed by their members.

5.5 Suggestions for all four target audience groups

Collectively develop and evolve standards and good practices. *Related to IGIF SP5: Bridging the digital divide; SP6 Standards; SP7: Community participation; SP9: Integrated engagement strategies.*
Standards are critical for an ecosystem where data integration is a pre-requisite for any application or decision support platform, where neither the use cases nor the data sets are fully known in advance. To enable the integration of data at scale and for a multitude of known and unknown use cases, standards, and importantly also good (best) practices, need to be collectively developed and evolved. Everyone should be involved, private, large, small, new, old, geospatial, mainstream, public, national, federal to local and of course academia. Additionally, the wide user base of the geospatial ecosystem – from environmental to smart city and planetary mapping – should be involved in the collective and agile development of standards.

Promote transparency. *Related to SP2: Implementation and accountability.*
Because there is an increasing awareness by policy-makers and others of the importance of geospatial issues in addressing global to local problems and exploiting opportunities, there will be increasing pressure on the broadly defined geospatial sector to 'deliver the goods.' Furthermore, an important component of this process will be the need for the geospatial sector to become more transparent in how it operates, what factors are important in shaping decision-making from the individual geospatial practitioner working from

home to the big global companies using geospatial data and technologies, to the ways in which geospatial matters inform (or do not inform!) public sector decision-making and their use of algorithms which use location information.

Engage in regular discussions about the evolving future. *Related to IGIF SP5: Technological advances; SP7: Community participation; SP9: Integrated engagement strategies.*
Given the importance for many members of the geospatial community in particular, and the wider related community to adequately prepare for a rapidly changing emerging future, it is suggested that the four groups, either separately or jointly, get together every two or three years in conference or colloquium with an exclusive focus on different clearly specified future time horizons, e.g., five, ten or 15 years, or beyond. Such conferences or colloquia could be arranged locally, at trans-national[51], national or regional levels, or within certain thematic focus areas. Doing this was an important aspect of some of the early gains made in the SDI community, and we recommend bringing back some of that community energy.

5.6 Guiding principles

Set out in the above sections are relatively specific calls for action. However, it is important to make progress at setting underlying guiding principles which can provide a broad framework for moving forward, a provisional sample being set out below.

Sharp focus on user needs and requirements. It is considered essential that there needs to be very clear focus on exactly what users of geospatial products and services need or require. All parties need to be driven to deliver meaningfully on both obvious and less than obvious needs and requirements across the user spectrum, from final end users to user participants at all the stages of a geospatially focussed project.

Develop a suitable context within which to address an emerging case-by-case project silo environment. Based on a sharply specific user needs focused approach, it is likely that a narrowly focused project based approach will be undertaken at the expense of consideration of wider issues. Given the enormous diversity of unique user needs and requirements there will be a tendency to develop project-based silos, as distinct from the data silos which SDIs were designed to overcome. To overcome this new form of silo, public authorities and standards agencies should develop new approaches, tools, standards, and other means.

Be involved in all stages from beginning to end. Geospatial practitioners should be intimately involved in all stages of solution implementation. Increasingly it will not be good enough to just be the 'geospatial techie in the back office', although of course there will always be a need for such persons. Integration into all stages will expose the geospatial specialist to a rich and diverse set of challenges when making his/her distinctly geospatial contribution.

It is not all about the technology. Issues of a psychological, institutional, economic, financial, cultural, environmental, governance and historical nature will need to infuse and shape the application of geospatial and other technologies in ways which bring these other issues into sharp focus, and in many instances into 'the driving seat'. Well-rounded geospatial practitioners are necessary in a collective sense to cover all the knowledge and expertise related to the issues mentioned above.

Be agile and embrace change. It is essential that on an ongoing (or at least regular) basis all stakeholders identify how best to become more aware of changing conditions which will impact on themselves and their working or living environments and, closer to home, what measures they need to put in place to enable themselves to adapt to changing conditions.

Behave ethically. A number of features of the future ecosystem give rise to very considerable cause for concern, in particular, misinformation and conspiracy theories; incitements designed to fuel social divisions or even violence based on race, gender, sexual orientation, age, religion, political views or other factors; of significant infringements of personal privacy; and unacceptable biases inherent in the data or the analytics being used, whether deliberate or unintentional. It behoves all stakeholders to have a clearly thought-out policy position regarding identifying and dealing with such potential threats, including for example the use of location for joining (private) data and thus creating a dragnet (joining the dots) for accumulating personal

[51] At this trans-national scale UN-GGIM provides an excellent basis for facilitating such futures reviews as are outlined in this sub-section.

information. The Locus Charter[52] supports this by proposing "wider, shared understanding of risks and solutions relating to uses of location data can improve standards of practice and help protect individuals and the public interest".

***Develop and maintain networks*.** Stakeholders should strive to develop and maintain networks with as diverse an array of actors as reasonably possible, both within the geospatial field and also where realistically possible in related fields. The fundamental aim of building such networks is to enrich the stakeholders themselves and in so doing enable them to cope better with ever changing conditions.

Qualified support for automation. The automation trend holds potential promise, but also potential downsides. Going forward, we should embrace the trend and 'go with the flow' but be alert to potential disbenefits, and where they are identified, vigorously take measures to counter them. In the drive for automation, it is important to always keep humans in critical decision loops.

***Get at least the basics right*.** In the future, there will certainly be what can best be described as fads or fashion events or trends. It is essential that a very clearheaded view is taken of what is the basic information and analytics which are necessary to complete at least the basic, necessary tasks at hand.

Ensure sustainability. In the emerging dynamic geospatial ecosystem ensuring sustainability and relevance of a particular approach which is planned or already adopted to dealing with an issue is not at all a straightforward matter. Regular reviews of the approach and all its key elements should be a basic necessity and built into the costing for a task.

Promote open by default. Over time increasing amounts of geospatial data will be made openly and freely available by public bodies and through civil society groups and individuals. Also, increasingly geospatial analytical software will become widely and freely available. These trends should in principle be supported. An open by default approach in the case of data, analytics, relevant processes, legal restrictions on use and reuse should be adopted at least by public sector bodies and civil society groups.

6. Concluding comments

This paper has made the case for moving beyond SDIs, mainly on the basis of today's radically different geospatial environment, which will further evolve in the future. Technological innovations are a key, but not exclusive, driver in producing this new environment; changing market conditions and societal values are also very much to the fore in creating the new environment.

Whilst recognising the need to move beyond the SDI conceptualisation, it is fully acknowledged that there is still an important role to play for the development and maintenance of SDIs based on the infrastructure concept. Ensuring the availability, accuracy and integrity of interoperable geospatial data, which can be used by modern and yet to be developed geospatial techniques and processes, will be a basic necessity in any dynamic geospatial ecosystem of the future. The adage 'garbage in, garbage out' will still be very much of relevance.

It has been argued that the best way to characterise the emerging environment is as an ecosystem which has as a primary feature the existence of multiple (billions of) geospatial actors (producers, analysts, and consumers, etc.) who are connected in complex and ever-changing ways. The ecosystem is sustained by both competition and cooperation, with shifting alliances and networks where top-down control or direction is difficult, if not impossible. As in the case of natural ecosystems, the complex geospatial ecosystem is characterised by self-adjusting change and adaptation.

Just as complexity is a key feature of the geospatial ecosystem, so is change, increasingly rapid and often unpredictable. In such an environment, infrastructures, such as SDIs which are deliberately designed and built, are necessary but cannot fully exploit emerging opportunities to deal with major societal and environmental issues, from global to local. From a global perspective the threat of such matters as climate change, loss of biodiversity, pollution and other environmental concerns pose an increasingly existential

[52] https://ethicalgeo.org/locus-charter/

threat to humanity on our planet. Within the more directly human and institutional domains there are also pressing and destabilising problems, such as unequal levels of development between nations, and mass migrations with all the tensions and conflicts which these can generate. Furthermore, a world in which misinformation, often with a location component, can proliferate has much potential to erode not just trust in institutions and leaderships, but at a more fundamental level in blurring the line between what is real and what is not. The authors believe that geospatial information and technologies can play a potentially significant role in addressing these unwanted circumstances, particularly if it takes current and emerging realities into account.

Based on our vision, which is shaped by an ecosystem view of the emerging geospatial environment, the authors have set out suggestions regarding what governments, the private sector, academia and civil society should do and also some general guiding principles. We encourage action on the suggestions, and the identification of others, to be taken sooner rather than later, as the challenges which we face demand prompt and decisive action.

The point is made at the outset of the paper that the authors seek to initiate a global discussion around the 'Beyond SDI' theme. They do not in any way regard the ideas expressed in the paper as somehow final, but really just a starting point for a focussed and ongoing process of debate and discussion regarding how best to take current and emerging realities into account. In this regard the authors have the deeply held view that the geospatial community has much to offer across very many spheres and domains, at all geographic scales, from global to local. Let the discussions now commence.

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