The Power of Where

A GEOSPATIAL KNOWLEDGE INFRASTRUCTURE TO ENHANCE THE WORLD ECONOMY, SOCIETY AND ENVIRONMENT

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https://www.geospatialworld.net/consulting/gki-campaign.html

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Summary

This is the age in which humans and machines come together. We call it the Fourth Industrial Revolution (4IR); it is characterized by knowledge derived from data, networks and powerful tools. Interdependence between the digital (machine) world and human world is total; humans design the machines but cannot exist without them.

Many of the world's greatest challenges are place and time related. For example - poverty and land rights, circular economy, climate change and sea level rise, renewable energy and how we efficiently harness it, and protection against pandemics and the geospatial science of epidemiology. The defense sector has also long recognized the value of geospatial knowledge, often calling it geospatial intelligence.

Be it advanced medicine, automated vehicles or online dating, a combination of sensors, data and analytics support human decision-making. They also influence human decision-making. Automation is increasingly seeing changes that exclude humans from final decisions. The first driver-less taxi service is now operational and automated drone corridors are being established.

But we have not yet reached a state of Nirvana, not even nearly. How often have we heard leaders across the world say that they "don't yet have the data to know" (and by implication cannot decide what to do), in the context of the Covid-19 pandemic? This one question encapsulates the whole purpose of this Paper. Data is not the endpoint. Knowledge, decisions, services, satisfaction are the value chain that data feeds. Whilst we call data 'the new oil', knowledge is perhaps 'the new capital'. Its value is determined by the application of that knowledge, which is derived from the data. Sadly, data producers often do not know that value either because they are far removed from data integration and the applications, models and machines that deliver the knowledge, and value, for the user.

Data comes in many forms, from many directions and portrays many realities, including the real world. Data and applications largely sit on the global digital infrastructure, which has matured considerably in recent years. Digital Twins represent this world in cyberspace but can only do so if place and time are digital too. Digital place and time are therefore critical components in our digital age, but the associated 4D mathematics is complex science. Geospatial technologies and data have met this complexity and developed alongside the wider digital ecosystem, often leading it. This has led to great successes, but also a degree of separation from the wider digital and knowledge ecosystem.

Some data has location as an organizing principle or attribute, other data does not.

> **"We don't know when the next epidemic will strike, but I believe we can protect ourselves if we invest in better tools, a more effective early detection system, and a more robust global response system. There are also some interesting advances that leverage the power of computing to help predict where pandemics are likely to emerge and model different approaches to preventing or containing them."**
>
> *(Bill Gates, April 27, 2018)*

Location and time are powerful attributes, the most powerful means to integrate and analyze data to enable understanding through knowledge. Knowledge in the digital world is derived from combining a problem, data and analytical tools virtually, and increasingly in real-time, but this carries far more value if place and time are brought into consideration. In fact, 'what', 'where' and 'when' questions cannot be answered in the virtual world without the use of geospatial technologies.

Over a three-year program (Jan 2020 to April 2023), a global partnership will develop the concepts of and a blueprint for a Geospatial Knowledge Infrastructure (GKI). In Year One, concepts have been developed from a geospatial perspective, resulting in this Paper, which is concerned with knowledge, be it machine or human, as that is where the value lies. It brings the geospatial ecosystem firmly into the wider digital ecosystem and ensures far greater use of location across industry sectors and government agencies. In order to make things work it encompasses government and industry stakeholders and focuses on the whole digital/knowledge ecosystem. Year Two will bring engagement with defined broad industry sectors to further develop the concept, including from a technical perspective, and Year Three will engage with government digital policy leads to further develop and advocate GKI adoption as part of integrated government policies. This Paper is based on Year One and will develop and re-fined through the three-year program.

We have a vision for 'geospatial knowledge at the heart of tomorrow's sustainable digital society'. This Paper provides a blueprint to integrate digital economies, societies and citizens with geospatial approaches, data and technologies and in so doing deliver the location-based knowledge, services and automation expected in the Fourth Industrial Revolution. It is a journey that seeks to benefit people and the planet by driving inclusive growth, sustainable development and global well-being.

This Paper examines how geospatial technologies, data, people, processes, and algorithms make up the geospatial component of knowledge across the whole digital ecosystem. It provides direction for geospatial agencies seeking to move up the value chain and examines how 4IR technologies can improve the use of location in the virtual world. It calls upon thought leaders in government, in the digital ecosystem, in the geospatial ecosystem, and in the business world to work towards a common end — better knowledge and decisions. It goes beyond data and current bespoke geospatial technologies to decisions, automation and knowledge on demand.

Governments have an enabling role in delivering GKI, as part of a wider integrated digital policy. In a world of uncertainty there is also an absolute need for authoritative foundation data to support and anchor decisions, whether as a trusted Digital Twin or to improve Artificial Intelligence models. Partnerships are essential; knowledge is born through collaboration in the real the world and so, likewise, in the digital. Increasingly, industry is leading many aspects of knowledge creation and should partner with governments to deliver GKI for the benefit of all. The Analytics, AI, Modeling (and Gaming) communities are vital to knowledge and are no longer customers but one and the same as the data providers. Finally, the geospatial ecosystem is part of the wider digital ecosystem, and both must coalesce.

This GKI leverages many new opportunities enabled by 4IR. It accelerates automation and knowledge-on-demand. It is as relevant in the poorest countries as it is in the rich. It supports the United Nations Vision - The 2030 Agenda for Sustainable Development. Indeed, this Paper advocates that the United Nations Integrated Geospatial Information Framework (UN IGIF) be the framework of choice for nations to build the geospatial information essential to a digital ecosystem. GKI supports this but is far wider, with the Geospatial Information enabled by UN IGIF being but one element of GKI.

GEOSPATIAL KNOWLEDGE

There are more than one billion monthly active users of Google Maps' services. Using customer location to generate revenue, Google Maps is moving towards a 'super-app' status, with revenues estimated in billions of dollars.

In 2018, cholera cases in Yemen were slashed by analyzing detailed UK Meteorological Office rainfall forecasts, and local infrastructure and population data to predict where outbreaks would occur.[1]

Altitude Angel, supported by investors Octopus Ventures, is building a unified traffic management platform for authorities to manage the super-highways of the future – networks of interlinking automated drone corridors that will revolutionize transportation of goods. [2]

Climate Change impacts everything from loss of cities by flooding to loss of food supplies, and new diseases to security challenges. One company fighting back is Indigo Ag; it combines satellite imagery and AI to support regenerative farming practices, measure crop health and predict yields.

Small Island Developing States (SIDS) depend upon the blue economy, yet we know less about the oceans than the Moon. Seventeen Commonwealth SIDS are working in partnership with hydrographic, environmental and fisheries organizations to develop the data and knowledge to manage this economy and help achieve UN Sustainable Development Goal 14 (conserve and sustainably use oceans, seas and marine resources).[3]

Virtual Singapore is a co-funded Singapore Land Authority Digital Twin of the city-state of Singapore. It enables users from different sectors to develop sophisticated tools and applications for test-bedding concepts and services. It also helps in planning, citizen engagement, decision-making, and research on technologies that could solve complex and emerging challenges in the country.[4]

Introduction

Humans are thirsty for knowledge. For millennia, maps have guided exploration, supported trade, helped defend against enemies, maintained the social fabric of our societies and influenced history. The precise surveys provided the raw location data of the time which was the base for the map. However, maps are but one output of vast amounts of location data and analytics in our interconnected world - a world of discovery and opportunity that is growing through smart technologies like, Big Data, Artificial Intelligence (AI), Advanced Robotics, Automation, continuous internet connectivity, sensors everywhere, and digital disruption. It is the 4th Industrial Revolution (4IR). We may see it as evolution, but history will regard it as a true revolution, almost as extensive as the first. It is merging human, physical and digital environments and leading to unprecedented societal changes that embrace living, health, leisure, work, wealth and poverty, industry, and our social selves.

Through contextualized on-demand knowledge, people and machines can achieve independence and interdependence never previously imagined.[5] Problems are solved, opportunities taken, services delivered, and decisions made through a partnership of users, data, technologies, and people, all interconnected through the web. There is no single way to navigate this incredibly complex system but the trajectory is such that that we can increasingly solve yesterday's 'wicked problems' at scale and get knowledge at the press of a button. This encompasses all walks of life, from the desire for instant gratification to the speed of development of Covid-19 vaccines.

Epidemiology is a recent example - it is about determining the spread of disease by pulling together many sources of existing knowledge with powerful analytics to model the future. Time and place become ever more powerful integrators in providing that knowledge. The knowledge provided by epidemiology then contributes further – towards complex analyses of health, economies and human behavior to enable evidence-based government decision-making in near real-time. Decisions then become actions in place and time, and change is enabled. Another example is that of driverless cars. It is similar but real-time - instead of the human brain making spatio-temporal predictions and decisions, machines do it automatically.

Time and place are the essence of the terms 'geospatial' and 'location'. It is generally considered in two overlapping contexts. First, it is a location-based approach to gaining understanding and includes the people and technologies that manage, integrate and analyze information, with associated location, be it GPS position, physical address or relative position. Second, and related, 'geospatial' is the digital representation of the physical world that provides the scaffolding upon which much of the world's physical, human, social and digital activity takes place.

The strength of our 4IR networked and data-centric world is its ability to integrate many varied data sources, whether real-time or historical, with varied analytical capabilities, to model real-world challenges for humans and machines.[6] Often unappreciated, much integration is anchored in location, making 'geospatial' central to 4IR, whether for one-off COVID-19 tracing apps or for enabling safe automated drones above city streets[i].

[i] For Covid, South Korea re-used applications developed for previous pandemics. This re-use of applications illustrates the Findable, Accessible, Interoperable and Re-Usable principle for data also applies to applications. This is described later in this Paper.

'Geospatial' is no longer a specialist domain but is everywhere, from ubiquitous smartphones applications to deep space exploration. As a result, the geospatial ecosystem of the last century has been overtaken by new 4IR industries that consider 'geospatial' as one facet of business models in today's knowledge economy. Most of these industries do so on the biggest infrastructure in the world - the Internet. The 4IR technologies coupled with internet penetration have set a new bar for the whole geospatial ecosystem. Expectation is, providing 'what was where yesterday' to enabling 'what is going to happen when, where, how and why?' The Geospatial Knowledge Infrastructure (GKI) aims to fulfil this new expectation set.

New data-hungry and digitally driven technologies operate in a complex world. There is just too much information for humans to process, making understanding more difficult. Singular linear technologies will be replaced by integrated technologies, forged on new partnerships and multiple sources of data and analytics. Quality foundation geospatial information is valuable when portrayed as a map. However, as a scaffolding for data and application integration it truly adds value. With a known provenance and quality it can help overcome uncertainty and risk. National geospatial agencies, as part of the ecosystem, provide that trusted scaffolding, hence the importance of the UN IGIF in helping all nations deliver improved geospatial information management.[7] GKI is a far broader concept but supports the UN IGIF by setting out the means for governments and industry to collaboratively bring together geospatial and wider digital agendas and infrastructures in an increasingly automated, dynamic, and real-time global environment.

Aim

The aim of this Paper is to set out the concept of a Geospatial Knowledge Infrastructure that supports governments and industry deliver sustainable economic, social and environmental benefits to Planet Earth and its people, as part of emerging digital and knowledge ecosystems and infrastructures.

This Paper builds on a July 2020 discussion paper, GKI Summit held in February 2021 and a series of consultations across the World.[8] One common theme expressed by participants during these consultations was the need to integrate geospatial thinking with wider digital thinking over the next decade, welcoming that the GKI seeks to do this. This report is a geocentric view but provides the basis for an infrastructure that integrates government, industry, citizens, and academic geospatial capabilities with the wider digital drive to better the world economy, society and environment. Over the next two years, engagement with industry and Government digital policy staffs will lead to significant further exposure and development of the concept. It is intended that this include a blueprint for a technical architecture.

Tomorrow's World

Technology

Technology affects all business sectors - from agriculture to infrastructure, the blue economy to retail, health to transport, and others. Data and applications are the common themes in the 4IR technology revolution. Data, increasingly, has location and time attributes, thanks in large part to Global Navigation Satellite Systems (GNSS) which have democratized 'position' for humans and their machines, and is the single most valuable enabler of this GKI. Data is exchanged, value is added and measured, money is made. However, the true value of data lies in the use of data, people and technology to derive knowledge that is applied to solving problems and meeting needs.

4IR technology will continue to develop over the decades ahead and there are no signs of its development slowing, indeed predictions towards the fifth industrial revolution are already being made.

Developments in the quality and reach of GNSS and wider positioning, navigation, and timing continue. The European GNSS Agency 2019 report predicts 1.1 GNSS devices per person in the world by 2029, with 0.2 m absolute accuracy to smartphones being the norm.[9] As governments have provided 'open GNSS service' in the world, GNSS has driven trillions of dollars in economic value and demonstrates why fundamental geospatial data and services should be high quality, open and free.[ii]

The volume of data is quadrupling every five years and it is estimated that by 2025 it is will be worth 5.8% of EU's GDP.[10] Sensors will be everywhere, from space to smartphones and cars, and even clothes and food products, all providing geo-located data. This will lead to an explosion in the volume of geospatially referenced data linked to value-chains and provide a new understanding of how society behaves and the processes we have created. Conversely, distrust in data, information, analytics and knowledge will also increase and the need for a trusted, in many cases authoritative, information baseline will also grow. This, coupled with connectivity through technologies such as 5G and satellites, will create both opportunities and privacy issues as data is integrated and analyzed to become knowledge. It will also increase concerns about cyber-security.

Real time geospatial data collection from sensors has been increasing, especially from space and on vehicles, but much is not used or is single use at best. 'On-the-fly' edge computing enables processing of this data to

> **"Really, the only thing that makes sense is to strive for greater collective enlightenment"**
>
> ***(Elon Musk)***

[ii] To demonstrate the value of GNSS, London Economics in 2017 estimated the economic impact to the UK of a five-day disruption to GNSS at £5.2bn ($7 bn). London Economics, Economic impact to the UK of a disruption to GNSS, Showcase Report, April 2017 https://www.gov.uk/government/publications/the-economic-impact-on-the-uk-of-a-disruption-to-gnss

provide re-usable information, some of which will enable automatic updating of foundation geospatial information. The journey towards automation across society will continue, under-the-sea, on the ground, in air and space, in factories, and in digital services such as finance and retail. For years defense, the extractive industries and agriculture have used geospatial data in automated machines. Now, automotive industry are also using automation.[iii]

Most of the investments in Artificial Intelligence (AI) will be centered on automated vehicles, face recognition and health. Continued development of AI and Machine Learning (ML) applications and modeling will enable the 'knowledge-on-demand' that is increasingly expected by society, with immersive technologies aiding rapid understanding and decision-making. This will result in an ability to predict at speed and scale, and for a wider population, than previously imaginable. Although trust in answers will be more difficult to assure.

The interaction between people and machines will change faster than at any time since the First Industrial Revolution (1IR), impacting lives, jobs and skills directly or indirectly. We will see growth in new work and leisure experiences, such as virtual and augmented reality, especially as user device prices reduce. Gaming, mission rehearsal, advertising, architecture, medicine, and city planning are just some of many use cases that can incorporate geospatial data. Businesses will develop new digital products, services and experiences, and seek new markets. Internally, worker experiences will be enhanced and operations streamlined but continuous skills development will be essential. Planned business process changes have been accelerated during the Covid 19 pandemic as end-to-end online workflows and digital user experiences have become essential. Technology is not the answer to everything; human social needs and the impact on poorer nations or elements of society not so able to adapt must be considered in policy.

Increasing the pace of change is leading to increasing innovation and disruption, particularly at the boundaries between technologies. New businesses are agile and can meet niche requirements, some of which quickly become mainstream. However, there is some uncertainty here as the cost of new developments may proportionally outweigh the potential rewards. Investors will have to become more selective.

The complexity of the knowledge ecosystem and the range of use-cases are such that no one organization or company will deliver end-to-end solutions; partnerships and collaborations are commonplace, increasingly cross-sector, and with a greater need for rewards to be shared across the value-chain. Likewise, users are spread across this value-chain and a distinct end-user for geospatial information becomes increasingly difficult to identify. It is not quite like 'cash' but demonstrates why data is increasingly considered as capital.

Governments and institutions will have to adapt policy and regulations around technology and sensor use, data and knowledge governance, use and ownership. It may eventually be technologies like Blockchain that give control data back to the individual and enable data brokering. Many of these technologies offer opportunities for improved and efficiently maintained national foundation data for all nations.

[iii] In our world of GNSS and absolute position it is also worth reminding ourselves that humans evolved over the Millenia to think spatially in a relative "self-centered" way, not by absolute position. Amazingly, in a few decades humans have developed machines to do the same

Knowledge

Data, Information, Knowledge.[iv] The Data-Information-Knowledge-Wisdom (DIKW) pyramid in Figure 1 explains the conceptual relationship between data, information and knowledge. Over the last decade, AI and other techniques have progressed sufficiently to turn pixels and wider data into information, unlocking the content and allowing real integration. It is cognition that derives knowledge from information, described as "the mental action or process of acquiring knowledge through thought, experience and the senses".[11] Going forward, machines will enable some of these thought processes to be simulated using self-learning algorithms that draw on data mining, pattern recognition and natural language processing. 'Experience' is available across the web and Cloud as existing algorithms and knowledge, and the 'senses' are increasingly automated, real-time and everywhere. The conditions for automated knowledge generation through analytics, modeling and applications are here and being used. This will develop further as a powerful combination of the semantic web and analytical and integrative techniques, including AI development, and derive knowledge for new sectors and use-cases.

Knowledge on Demand. It is recognized that the knowledge necessary for solving many challenges is constructed over time and cannot be delivered 'on demand'. However, users along the value-chain seek to generate

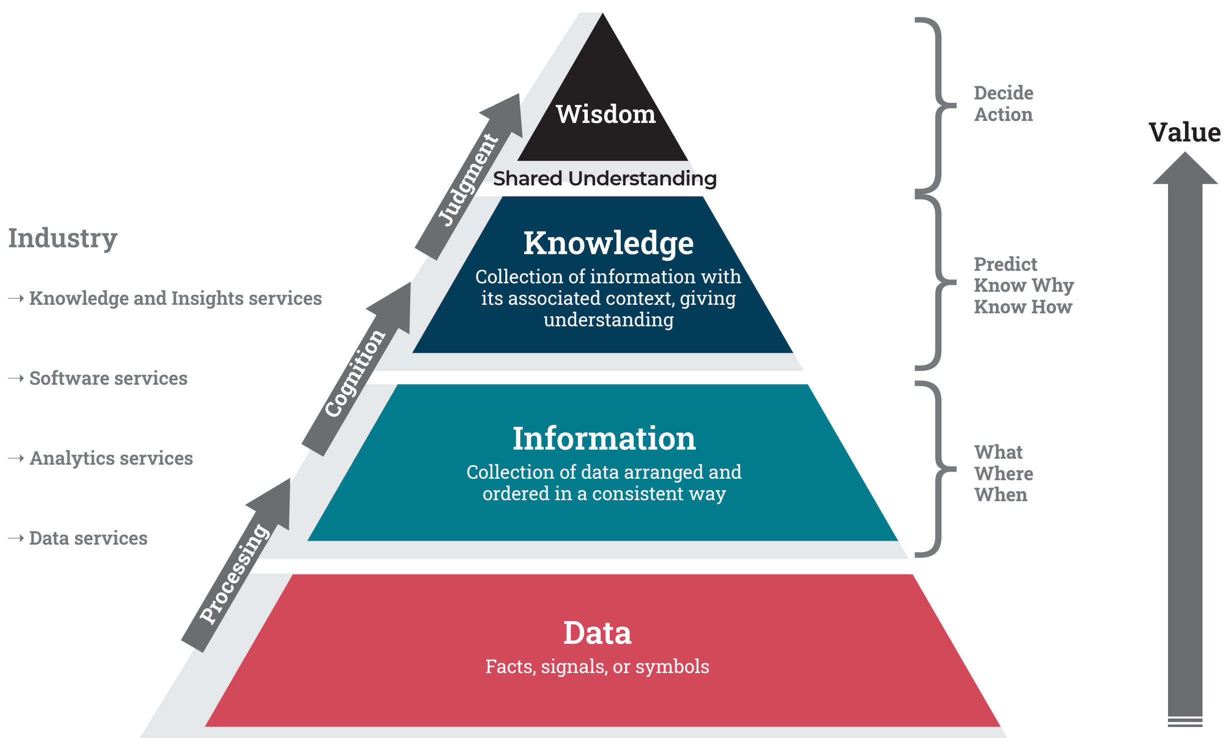


Figure 1: The Knowledge Management Cognitive Pyramid demonstrates the relationship between data and knowledge. 4IR technologies increasingly enable knowledge to be generated 'automatically', improving decision making and adding value.

Source: Adapted from DIKW Model for Knowledge Management and Data Value Extraction

iv The term Intelligence is often used to cover knowledge, the most prolific being Geospatial Intelligence primarily used in the Defence and Intelligence community, Environmental Intelligence, Retail Intelligence, Business Intelligence and Location Intelligence.

knowledge quickly or the moment passes, the impact diminishes. With knowledge, decisions are made, benefits accrued and capital realized. In our 'on demand' world, 'timely' is not days and weeks but minutes and seconds for both humans and machines. Value, therefore, lies in effective and efficient methods to extract user-specific knowledge from vast amounts of data, information and existing knowledge from relevant sources anywhere. This derived knowledge needs to be trusted, determined in required timeframes, contextualized for the user, and increasingly delivered from machine-originated and natural language queries.

The geospatial ecosystem is far wider than ever before, across the digital ecosystem's modeling and applications communities, and across most industry sectors. The geospatial ecosystem now needs to play into this wider digital, or knowledge ecosystem. Focusing on data and information alone does not achieve this, even though fundamental geospatial data is a foundation element of a GKI.

Global Challenge

Much has been written about the major global challenges we all face, but there is far less recognition about the role geospatial capabilities play in managing them. Let's select five challenges from many:

- **Climate Change** is altering the very fabric of the earth's ecosystem upon which humans depend. After decades of wrangling, many nations are now moving to implement carbon neutral policies. Hard evidence-based decisions lie ahead for governments, businesses and citizens; geospatial knowledge underpins them. Whilst Earth observations help, it is the complex interaction between climate, the environment, geography, people, politics, infrastructure, businesses, resources, and the deployment of capital that makes it necessary to integrate data and analytical models.

- **Health** has improved massively over the last century and will remain a leading priority for most nations over the coming decade. Covid-19 has shown the disruptive nature of pandemics and brought home the need for preparedness, predictive modeling, evidence-based decision-making and efficient planning. It is a microcosm of the climate-change challenge but at least there is a vaccine. Understanding human location, movements, behavior and interactions is necessary to manage pandemics.

- **Urbanization** is making massive new demands on cities, particularly as most populations age. But equally, cities create wealth and economic opportunities. The sheer confinement of people, assets and resources in a dynamically changing 3D environment increases need for real-time knowledge for responsive smart city management and engaged long-term planning. This knowledge is derived from detailed data on the fixed and dynamic elements of a city's infrastructure.

- **Changes in social fabric** of societies, businesses, work, and leisure are taking place due to 4IR which is further accelerated by Covid-19. The economy is increasingly digital which, without concentrated action, could lead to further inequality by, for example, opening more markets to established global companies rather than offering opportunities to new local enterprises. Global businesses tend to derive knowledge from their own sources of geospatial data; by opening-up national digital infrastructure and data, governments may assist local businesses to create local wealth.

- **Security** is important because geopolitical uncertainty is on the rise. Security in its widest sense is cross-cutting, related to everything from terrorism to water security, and from cyber security to health. 4IR technologies have the potential to 'harm' as well as 'do good', especially because much conflict is now a 'battle for minds', often fought on the internet and seemingly regulated and policed by business owners, not governments. Security, Intelligence and Defense will remain major consumers of geospatial intelligence.

4IR technology and innovation are driving new business models and a new 'knowledge economy', based upon data, applications/analytics and existing knowledge. From the smallest use cases to these grand global challenges, geospatial is ubiquitous as a powerful integrator and as essential underpinning data.

> **"Every business in the future will use geospatial information"**
>
> ***(Daniel Zhang, the Chief Executive Officer, Alibaba Group[12])***

The Geospatial Response

The halcyon days of the late 20th and early 21st century, when geospatial data, Geographic Information Systems (GIS) and Spatial Data Infrastructures (SDI) were regarded leading edge, are gone. This is reflected even within the geospatial industry by the statement by Jack Dangermond and Michael Goodchild; "decisions that were made during periods of very limited computing power become enshrined in practices that may be very hard to shake".[14] The recent explosion in geospatially-enabled applications and technologies across many areas - from retail and ridesharing to gaming and dating - has taken place outside the traditional geospatial sector, embracing user needs, connectivity, analytics, data, and location. These 4IR companies do not recognize a 'geospatial sector' – they just use data, analytics and user interfaces in which location plays a greater or lesser part. Innovative, geospatially-enabled businesses are the norm now and have set high user expectations.

For several years, the annual GeoBuiz Report has provided a geospatial industry outlook. In 2018, the Report estimated that the geospatial industry value would reach $439 billion in the year 2020, growing at the rate of 13.6% annually. The 2019 report noted that 'leader' economies like The Netherlands, USA, UK, Singapore, and Canada have managed to successfully integrate geospatial solutions at multiple levels of industrial, governmental and public adoption. These nations are not standing-still and continue to take measures to ensure the geospatial plays an increasing part in the economy, society and environment – GKI is intended to help.

Aside from the recent explosion of geospatial data across 4IR industry, the geospatial ecosystem of governments and businesses has taken great strides over the last 40 years - be it Global Navigation Satellite System (GNSS), Geographic Information Systems (GIS), Earth Observation (EO) or the provision of quality government, commercial and participatory geospatial data on a global scale.[15] Most of the focus on geospatial by governments has been on delivering and 'opening-up' government geospatial data, providing a 'create once, use many' ecosystem, and making geospatial data and information accessible to all. In many jurisdictions, National Spatial Data Infrastructures (NSDIs) have delivered significant local, national and regional benefits. In others, they have not proceeded beyond an intent. But NSDIs are essentially a data infrastructure in a knowledge environment, a petrol car in a carbon-neutral world. Progressive governments are now looking beyond accessible data to value-creation through knowledge. Figure 2 shows some aspects of NSDI and GKI to illustrate the ongoing journey and the geospatial environment in a 4IR world.

For geospatial data agencies, changes required to level up to the next stage of development

> **Systems thinking is key to geospatial information. We need to unlock ecosystems, economics, and entrepreneurship.**
>
> ***(Nigel Clifford, Operating Executive, Marlin Operations Group and Deputy Chair UK Geospatial Commission[13])***

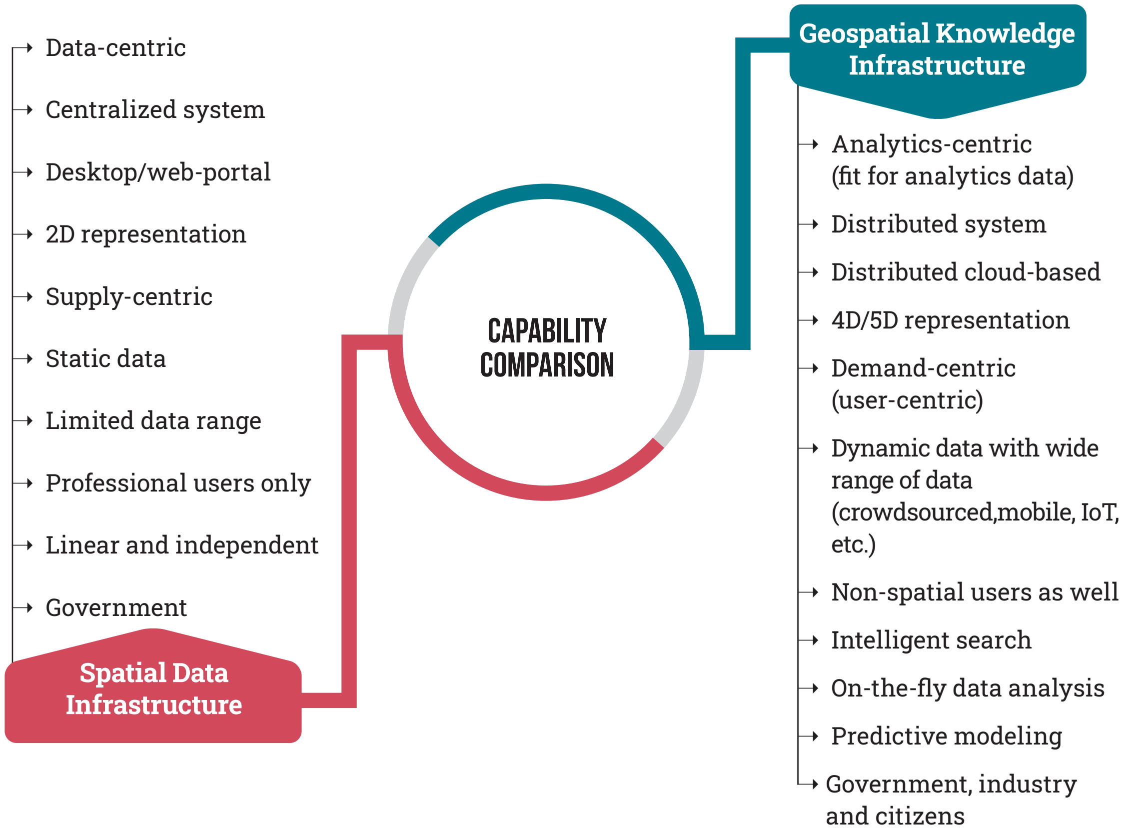


Figure 2: Aspects of the journey from Spatial Data Infrastructure thinking towards a Geospatial Knowledge Infrastructure.

Source: Geospatial World

will happen in many ways. Changing production economics by capitalizing on the explosion of source data, combined with machine intelligence, analytics and user applications, is one such change that is required. Delivering knowledge-ready data is another. Equally, it lies in recognizing that value lies in new effective and efficient collaborations to extract knowledge from vast amounts of geospatial data.[16] This was recognized by global geospatial agency leaders at the 2017 Cambridge Conference at Oxford University, United Kingdom, when they agreed that geospatial agencies only had a future if they changed.

Better knowledge is needed just to take measures to meet Sustainable Development Goals at a time that the geospatial digital divide is broadening. Global challenges require global solutions, and so it is no longer acceptable that many nations should fall behind in the global desire for knowledge, better decisions, and services. Hence, the UN Integrated Geospatial Information Framework (UN IGIF) has been developed to help all nations realize the benefits from the creation, management and use of geospatial information. 'National Government' focused, it is the basis for nations to create, share and use geospatial information.

Geospatial Knowledge Infrastructure – The Future

Past success will not deliver future success - it is time for an increasingly dynamic and liberalised geospatial infrastructure. GKI expands from NSDI focus on 'data provision' to 'knowledge creation' and foresight. The GKI concept takes that step by maximising the power of location within the digital ecosystem, making use of the 4IR technologies and the growing digital infrastructure. The name is not material but to make a clear statement that this is aimed at knowledge, not data, the term Geospatial Knowledge Infrastructure (GKI) is offered.

GKI positions geospatial, a general-purpose capability encompassing governance, technology, data and people, at the heart of knowledge co-creation. It will be co-joined with the wider data infrastructure on the same infrastructure (Web, Cloud, Networks). This is illustrated in Figure 3. Other integrative technologies exist, but location is a critical element of data science in its widest sense, not separate from it.

Keeping up is not enough, we need to transform the way we think and lead progress. Geospatial is not 'bolted on the side' but must become a first order consideration across all Government and business activities, albeit in most cases without recognition.

With the combinations of various technologies making it virtually impossible to predict how applications may develop in just a few years, GKI sees agility as a key principle.[18] GKI sets the groundwork that helps human ingenuity to

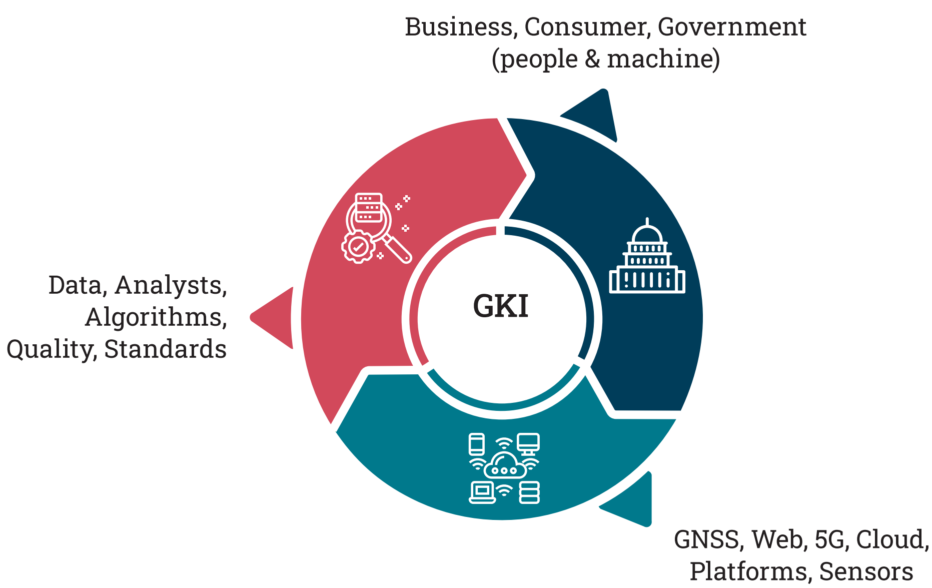


Figure 3: GKI integrates a system of systems in which geospatial, complex though it is, is regarded as part of the wider digital ecosystem.

Source: Geospatial World

> **Digital Transformation is just beginning... We need to come together and think about what's coming next, now is the time to go faster – not to slow down!**
>
> ***(Jack Dangermond, President of Esri[17])***

prosper and lead us to new places. It aims to ensure geospatial is everyone's business. It is developed in nations supported by UN IGIF and uses the very same web infrastructure and concepts that are driving wider knowledge, societal change and economic growth. Centred on users, it helps governments, industry, academia and citizens build a digital economy and society that can embrace knowledge and automation.

GKI recognises the importance of the UN IGIF as the basis for nations to create, share and use geospatial information. But, as described, this is one part of GKI, which moves beyond this objective to joining it with industry thinking and the far wider digital ecosystem.

Vision

Geospatial knowledge at the heart of tomorrow's sustainable digital society.

Definition

GKI is an infrastructure to integrate geospatial approaches, data and technologies into the wider digital ecosystem. In so doing it delivers the location-based knowledge, services and automation expected by economies, societies and citizens in the 4IR age.

Geospatial Knowledge Infrastructure Goals

- Geo-located data is the norm. Widespread geolocation grows the capital value of data, information and knowledge across governments, industry and civil society.
- Continuously updated, trusted and authoritative fundamental geospatial information is available at community, national and global levels — the digital scaffolding for wide-ranging initiatives from knowledge-on-demand to Digital Twins, Robotics and Automation.
- The global digital infrastructure fully enables geospatially enabled knowledge, with industry and governments supporting this. In so doing, geospatial becomes part of the mainstream digital ecosystem.
- An attitude of collaboration across data, analytics and technology communities to use location as a foci of Digital Twins, predictive analytics, modeling and autonomous operation.
- Government digital policies and strategies are optimized to maximize the value of location to governments, institutions, businesses and citizens, whilst protecting necessary security and privacy interests.
- A full understanding of the contribution geospatial knowledge makes in a sustainable society, economy and environment.

Geospatial Knowledge Infrastructure Principles

- Geospatial technology should integrate with established and emerging wider digital infrastructures to be a **single digital ecosystem**.
- **Knowledge is the focus.** Humans and machines seek knowledge, not data, to make decisions.
- **Predictive.** Be it in milliseconds or years, geospatial moves from insight to foresight.
- Be **led by users,** based on the knowledge needed, not data and applications available.
- **Take achievable actions now** and then scale; success cannot be achieved overnight.
- **Agility** is inbuilt. Innovative, dynamic and agile solutions are far better able to respond to global challenges, technology change and people's expectations in a rapidly developing world.
- **Decentralized.** The web is naturally decentralized, with data and application value-chains becoming more complex across wider ranges of partnerships.
- **Collaborative.** To more quickly meet societies' global sustainability challenges, including the digital divide.

Geospatial Knowledge Infrastructure Elements

The GKI concept sets out an integrated set of six elements (Figure 4) and associated initiatives that support the achievement of the goals mentioned above, matched with the principles.

Governments will create an **integrated policy framework** to ensure that their nations establish the environment for a digital economy and society that utilizes location. Data and knowledge cross boundaries; alignment and integration of policies across departments maximizes benefit and clarity. Their policies will establish the role of location approach in integrating data to model policy-making and ensure a nation has a position, navigation and time strategy. They will liberalize industry to partner with government to improve government services. Ministries, science and businesses will collaboratively ensure coherent national digital policies that establish digital twins, enable innovation and increase the economic, social and environmental benefits of geospatially enabled knowledge.

Trusted and authoritative **foundation data** is an essential element of national infrastructures. The geodetic reference frame upon which position and height are references

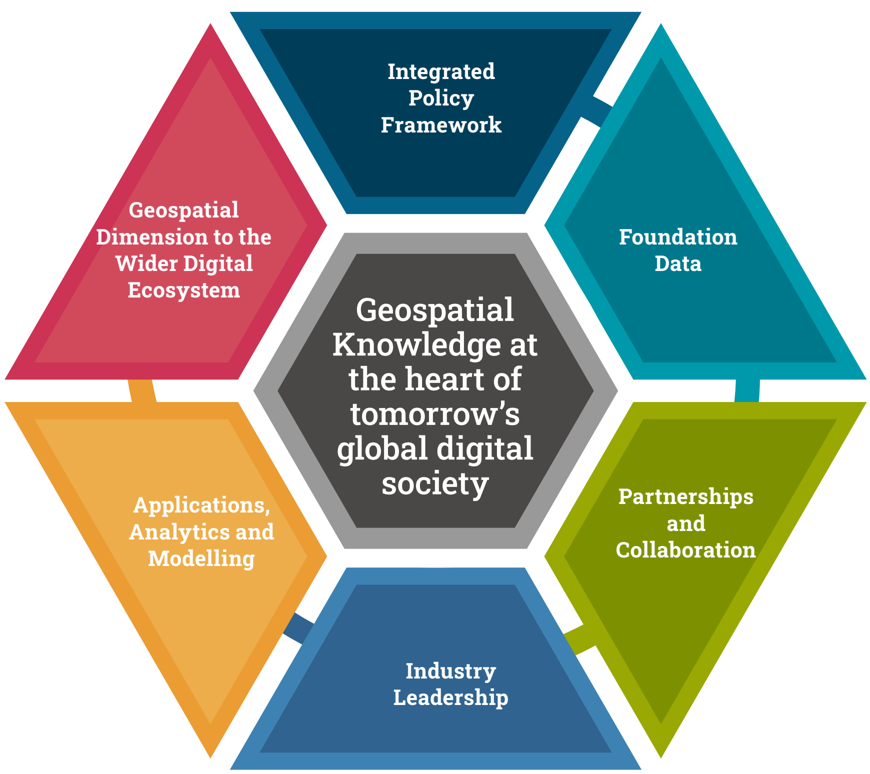


Figure 4. The six elements of a Geospatial Knowledge Infrastructure. All elements contribute to improved national outcomes, both individually and collaboratively

Source: Geospatial World

and continuously updated, findable and accessible fundamental geospatial data. Together with analytics, these enable nations, businesses, citizens, and machines to derive the knowledge they seek to solve their problems, exploit opportunities, and deliver new value. Equally foundation data provides greater assurance in knowledge-based digital outcomes.

Most innovation, autonomous and knowledge services will be delivered by **industry**, and faster than Governments can understand implications or act, therefore giving industry an increasing **leadership** role. With leadership comes responsibility, both to citizens and the planet, a clear need to work with governments to help best policy development and a need to develop appropriate skills. This includes geospatial knowledge. Governments will increasingly work to enable and regulate the development of a knowledge economy and society but should also ensure the availability of trusted foundation data as part of the national infrastructure.

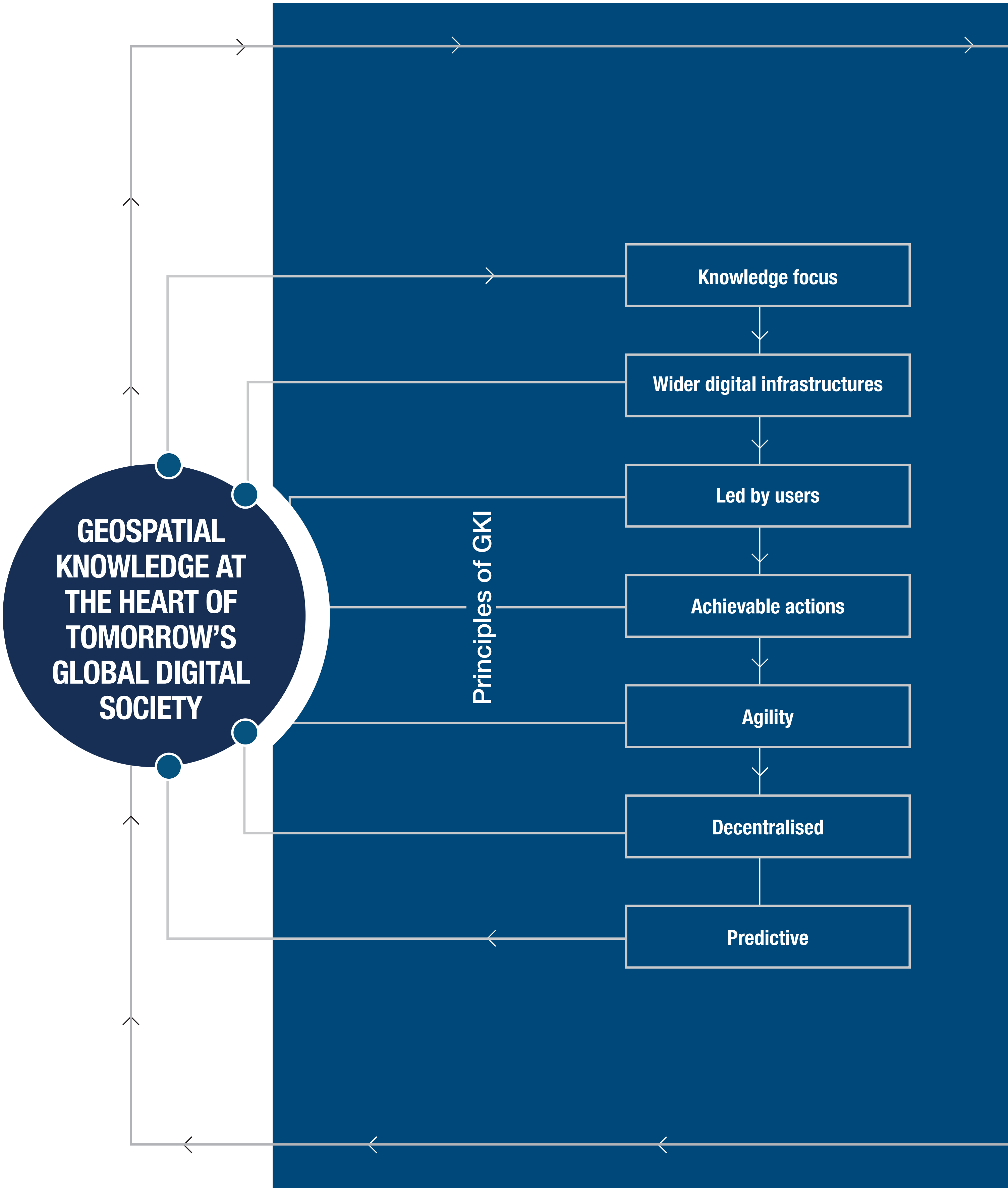
Given increasing technological change and the increasing sources of data and analytics across the private sector, **partnerships and collaborations** will be increasingly common in co-creating value in data and knowledge. Costs and benefits will be shared across the value-chain, which crosses government, industry and citizen. New partnerships will emerge - be they ad hoc collaborations to solve singular challenges, long-term business partnerships, or public-private knowledge co-creation partnerships, distinct from the PPPs of yesteryear. This element of partnership and collaboration includes the important partnership with citizens, both as users and data providers, especially as citizens gain more rights to data about them and their location.

Knowledge is essential for human and machine decision-making, including all automation. It is created through the combination of data with **applications, analytics** and **modeling** that will exploit insights from vast quantities of data to deliver illusive foresight based on the context of the question or use-case. These algorithms ensure that automated vehicles avoid pedestrians, that the vulnerable can be evacuated ahead of a flood, that consumer advertising is targeted. Applications, analytics and predictive modeling increasingly use location and geospatial technology and data. For the sake of knowledge, these will sit as part of the digital infrastructure with data, findable, accessible, interoperable, re-usable, and of known quality.

Ultimately, GKI integrates with and supports a **geospatial dimension to the wider digital ecosystem**. Geolocation through an open positioning infrastructure, geospatial information, expertise, technologies, and analytics are important elements of the digital infrastructure, which must be designed with location, geospatial data and geospatially enabled analytics at its core. In doing so, location becomes a powerful means to derive knowledge, from across data and application sources sitting in the Cloud. This loops right back to integrated digital policy.

These elements take advantage of the developing global digital infrastructure, including positioning systems, space, the internet, mobile and fixed digital networks, cloud and service platforms, APIs, automated systems, analytics and applications, the Internet of Things and user devices. All elements, alone or together, contribute to greater economic benefit, social well-being and environmental management. Each element consists of a number of initiatives. These will be refined as the concept develops and many already happening in some nations and businesses. National GKI maturity is based upon all initiatives, but in reality each one alone will add value in a nation.

The next section looks at these Six Elements in more detail, breaking them into GKI initiatives and some recommendations. The complete set of GKI elements and initiatives is summarized in Figure 5.



Source: Geospatial World

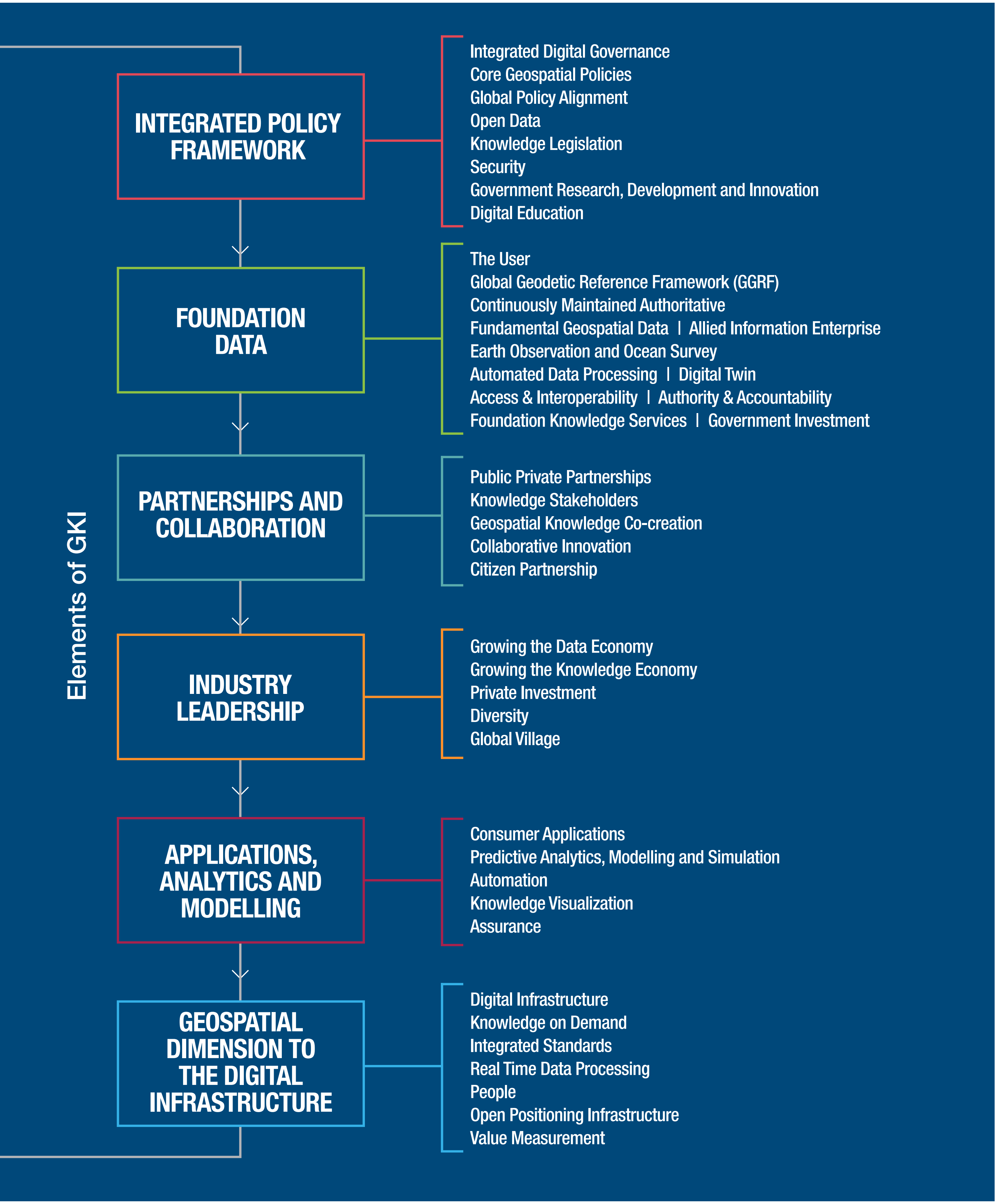


Figure 5. Geospatial Knowledge Infrastructure comprises 5 goals, 7 principles, 6 elements and several initiatives. These are described in the rest of the document.

Element 1: Integrated Policy Framework

Governments have a major role to play in setting frameworks for economic growth, social wellbeing and environmental protection. They also intervene and deliver services where the market is not suitable, is broken or is in crisis. They are accountable for the delivery of national infrastructure, including the digital infrastructure, although delivery will be through a range of public bodies and private companies.

The speed at which the 4IR technological change and its associated societal change is happening, is challenging existing policy-making institutions. This will require new, different and integrated policies, changing the way governments are structured and work, with policy decisions increasingly based upon cross-Government evidence. Governments, globally, are tackling digital policy issues like automation, privacy, and data ownership. If 'knowledge' systems are to be attained then geospatial data and geolocation must feature within this complex policy cauldron.

Some outcomes of the Integrated Policy Framework would be:

- Improved, integrated, evidence-based government policies and services.
- Established frameworks that maximize the benefits of digital knowledge to nations.
- A digital infrastructure and economy.
- A resilient nation that is prepared in a crisis.

1.1 Integrated Digital Governance. Recognizing the value of a digital economy, governments will have clear digital knowledge management strategies that enable value of data to be realized, ensure wide access to assured foundation information, and open doors for government/ industry partnerships. Geospatial

> **Geospatial Knowledge: The Singapore Geospatial Masterplan is a national blueprint to maximize the impact of geospatial information and technology. It combines a trusted public service to empower effective geospatial policy-making, planning and operations, a thriving geo-powered business environment that improves productivity and encourages innovation, and an able workforce.[19]**
>
> **Geospatial Knowledge: As part of its wider digital agenda, the Government of Norway seeks an open national geospatial knowledge base, shared solutions and technology that support effective problem solving and enable new applications. It recognizes that, in the future, geospatial information will interact with new technologies, sensor systems, big data and learning computers. To succeed, Kartverket is automating work processes and seeks to partner with business and citizens alike to create a true national geospatial platform.[20]**

governance, espoused in the UN IGIF, will be aligned with national digital governance. National digital strategies will aim to achieve this alignment although, in the short term, linked national geospatial strategies may still be required within this wider framework. Government policy, legislation and regulation for knowledge management and digitization will be aligned across all relevant departmental policies, especially data/digital, industry, space, science, technology, innovation, privacy, Artificial Intelligence (AI), innovation, and education policies.

- **Recommendation:** Government creates, aligns and eventually combines geospatial and digital policy and strategy functions. (This can be at national and other levels, as appropriate).

- **Recommendation:** Liberalize the market for geospatial data and knowledge companies and bridge the digital divide by building and operating networks.

1.2 Core Geospatial Policies. Within the integrated governance framework, either stand alone or contained within wider policy documents contained in Initiative 1.1, core geospatial policies will be necessary to address two issues. First, they will be required to address the time and place complexities of geolocation, geospatial data, and analysis, and second the essentiality of foundation data as part of national digital infrastructures to be addressed. Such policies will support user communities, in particular, the growing range of analytics, IoT and automation use cases. Geospatial policies will be aligned to the wider government digital policy and build on the need for integration, including through key registers for use across government and open to the private sector. Core geospatial policies will identify and direct the need for authoritative foundation information and the "create once use many" principle may need to be enshrined in regulation to ensure efficiency and assurance. They will be based on automating the Findability, Accessibility, Interoperability and Reusability (FAIR) principles and set assurance standards.

- **Recommendation:** Governments create and maintain a set of core geospatial policies integrated within the wider government policy framework, aimed at driving increasing social, economic and environmental value from geolocation, data integration and knowledge.

- **Recommendation:** Governments set public foundation data geospatial standards on content, access, quality, coverage and timeliness of data and services provided by national agencies.

- **Recommendation:** Governments liberalize restrictions on the creation and use of geospatial data and information to strengthen national innovation.

1.3 Global Policy Alignment. Whilst national needs take priority, some national policies will be aligned with international practice, particularly in areas such as licensing, geodetic frameworks, disaster risk management, privacy and standards. Important regional frameworks also exist to support nations. In the European Union, the INSPIRE Directive[21] regulates the publication of geospatial data for environmental purposes, with established data specifications and data sharing mechanisms. Complementing INSPIRE, is the European Union Location Framework (EULF) Blueprint. This is a guidance framework for using location information in policy and digital public services and is fully aligned with the European Interoperability Framework (EIF).[22] Rich nations will recognize that measures to reduce the digital divide for the benefit of recipient countries are part of development assistance. The policy should move beyond physical infrastructure to developing foundation data and geospatial knowledge capabilities. Remote-sensing owning nations should also take the opportunity to open data globally as has happened with Landsat and Copernicus.

- **Recommendation:** Geospatial application crosses borders, and governments should support, contribute to and where possible align with global and regional geospatial and wider data policies and frameworks.

- **Recommendation:** Governments collecting global data should look at opportunities to release this and provide commensurate development support to developing nations to increase the role of data and knowledge in government decision-making, sustainable development, and business growth.

1.4 Open Data. Value exists in the use of data to create knowledge, not in hiding it in vaults where its capital value reduces over time. Foundation data is part of the national infrastructure and must be accessible to all. High value datasets to be open ensuring their availability free of charge, in machine readable formats, provided via Application Programming Interfaces (APIs).[23] However, as location will be an attribute in much government data rather than standard location registers such as addressing, it will be adopted by nations, mandated within governments and open to all (within legal constraints). Committing to open infrastructure also reduces the formation of monopolies that tie organizations into proprietary formats or a particular standard. Only rarely will aspects of fundamental geospatial information be security restricted. Opening government data, services and knowledge through data hubs is increasingly common but should be accompanied by support in the use of such data, from comprehensive metadata release to user training. Some governments express concern about global businesses benefitting from open data. However, by opening-up national digital infrastructure and data, open data assists local businesses in creating local wealth. But open data is two-way and private corporations collecting citizen-originated anonymized location data that has significant public utility, such as traffic data, should open it up for the greater public good. Arrangements would need to be in place for any downstream financial value to be shared along the value chain but this could lead to greater knowledge value.

- **Recommendation:** Governments adopt a common 'open data' policy for fundamental geospatial data including key registers and appropriate quality and interoperability standards.

1.5 Security In the same way that 4IR offers opportunities the same new capabilities are threats, whether national security, business intellectual property of personal privacy. To quote Jeremy Fleming, Director of the United Kingdom's signals intelligence agency GCHQ, "If we don't control the technology, if we don't understand the security required to implement those effectively, then we'll end up with an environment or technology ecosystem where the data is not only used to navigate, but it could be used to track us".[24] Location Intelligence derived from such technologies presents a concern for governments and suitable protective policies will need to be considered. This is a very different concern to the opening up fundamental geospatial data, which is no longer a national security issue although some nations still use it as an excuse not to make data available for social and economic good.

1.6 Knowledge Legislation. *"We know where you are"* is knowledge. Whilst framed as data legislation, it is regulated when it comes to churning knowledge out of the data.

- Data protection legislation is growing, particularly relating to privacy, and includes location, where it might impinge on privacy. To protect security and privacy, national legislation and regulation will include clarity on geospatial data collection, its release and use, derived knowledge and geolocation. Such legislation should be focused on outcomes, such as how geospatial anonymity is defined, as the capability of platforms and sensors will continually change.

- AI legislation is being considered. As with General Data Protection Regulation the EU appears to be taking a lead and recently published a White Paper on the subject, although how this develops into legislation and how that impacts global thinking remain to be seen. It clearly argues against the use of AI in tracking (using the myriad of real time sensors everywhere), including for police forces.[25]

- Industry will benefit from legal frameworks on citizen-derived location data ownership, its exploitation. Further, data markets enabled environment will ensure value to be accrued across the data value chain.

- In the same way that physical infrastructure is regulated and sometimes tested by governments, so too will regulation apply to the virtual. In safety critical applications, governments will set regulation, standards and implement virtual testing and authorization for applications and data (for example as an extension to motor vehicle physical system safety testing).

- Automation introduces a potential liability. Geospatial data producers and software providers will face increased pressure to assure their contribution to safe automation.

- **Recommendation:** Legislators will increasingly focus on the capabilities of digital technologies but the convergence of geospatial data, data integration, analytics, and geolocation technologies add complexity to an already complex multinational set of privacy issues. National geospatial leaders should seek to influence developing legislation to protect the justifiable benefits of geospatial knowledge from the unintended consequences of legislation.

- **Recommendation:** Smart city programs should be transparent about the uses to which collected geospatial intelligence on people can, and cannot be put. Appropriate checks, balances and security should be put in place to prevent misuse.

1.7 Government Research, Development and Innovation. National innovation has global benefit, global innovation has national benefit. The top 4IR beneficiaries are the innovators and investors; large businesses have massive R&D budgets but for most companies it is more a case of building on academic research or gaining support for innovative ideas. Governments will invest in deep ‘blue skies’ research and ‘moon-shot’ projects, particularly where the private sector is unlikely to invest. Themes such as Carbon Neutral, healthcare. AI and automation will drive much spend, many with potential geospatial knowledge requirements or spin-offs. Governments then need to build bridges from this research to enable local industry to operationalise it. They will also support small and medium sized businesses build and operationalise innovative new digital ideas and consider new means of procurement to speed the adoption of such innovation into government services.

- **Recommendation:** Governments should support digital innovation in a manner that is inclusive to maximizing the potential of geolocation.

- **Recommendation:** Governments should establish the means to accelerate the transfer of geospatial ideas to solutions, bringing academia, business and innovators, often from different sectors or disciplines, together.

1.8 Digital Education. The digital environment is second nature to most young people. However, adapting education to prepare everyone for the ‘next economy’ requires intervention when these changes are happening fast and can be difficult to predict. As part of this, geospatial knowledge combining data, analytics and processes as one of a range of tools for solving problems and making decisions will be subtly embedded into curricula at all levels from Year 1 to Under-Grad to Post-Grad, from generalist to data specialist. Geospatial courses will become multi-disciplinary, embracing data science, automation and sensor technologies[26], and perhaps more user focused than technology focused. Government policy will demonstrate a clear understanding of future competencies required by employers and address the need for an interoperable workforce.

- **Recommendation:** Geospatial knowledge, as part of wider digital education, should be integrated with data and analytics education throughout the curriculum and arm students with tools to solve problems.
- **Recommendation:** Universities should move from GIS specific courses to broader analytical education, bringing geospatial knowledge, AI, data science, sensor technologies, software development, and business information systems together in differing degrees. knowledge, AI, data science, sensor technologies, software development and business information systems together in differing degrees.

Element 2: Foundation Data [v]

In the context of GKI, Foundation Data refers to national data that is substantially geospatial in nature and seen as part of the national digital infrastructure meeting national public task requirements. A simple example is national statistics, where location enables policies to be differentiated, by local need. Foundation data has traditionally been managed by government agencies or under government contracts and as such should be authoritative[vi] which includes declaration of quality and provenance. It underpins nations, businesses, citizens, and machines in deriving the knowledge they seek to solve their problems, exploit opportunities and deliver new value. Trusted foundation data is an essential element of national infrastructures and should be regarded as such by governments in both policy terms and investment. It is the digital scaffolding for the digital age.[27] Data providers should see foundation data as a trusted input which, when integrated with other georeferenced data and appropriate applications, allows knowledge to be derived from "where" and “when”. Foundation data therefore becomes more important in the future, not less. Governments have to ensure that such trusted authoritative data is maintained, is open and accessible.

Fundamental geospatial data, defined by the United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM), is a sub-set of foundation information that is increasingly included under the label ‘national high value datasets’.[28] In GKI this is beyond the output of current geospatial agencies. It dynamic, continuously

Geospatial Knowledge: Working in partnerships, Ecopia.AI uses machine learning techniques to automatically extract features such as buildings, roads, bridges, water bodies, and trees from remote sensing data, creating essential foundation data for a nation. Examples include the whole of Italy from aerial photography and the whole of sub-Saharan Africa from satellite imagery.[30]

Geospatial Knowledge: In The Netherlands, data from the government used to be fragmented, often duplicated with errors. Policy changed and the country now has a series of high-quality guaranteed databases covering essential data pertaining to persons, institutions, issues, activities or occurrences. These are designated by law as the sole officially recognized registers to be used by all government agencies and, if possible, by private organizations.[31] Kadaster maintains some of these, including topography and real estate

v Foundation geospatial data and Fundamental Geospatial data are different. Fundamental refers to UN GGIM defined data themes; foundation data is far wider.

vi Authoritative data is a difficult concept as it does not mean ‘correct’, hence the importance of trusted in this Paper. The UK Geospatial Commission defines it as ‘Officially recognized data of appropriate quality provided by trustworthy organizations’. The authors of this paper would add to this and state ‘Officially recognized data of appropriate and declared quality provided by trustworthy organizations and effectively governed’.

updated, findable and accessible fundamental geospatial data, including relevant national registers. It also includes the publication of veracity metadata and may include the provision of certain foundation-level predictive analytics that provide 'base' knowledge (for example, environmental forecasts[29]). The cost of maintaining fundamental geospatial data has reduced significantly for most use cases, presenting an excellent opportunity for developing countries to bring in new and disruptive ways of delivering geospatial information management, as described in the UN IGIF.

Outcomes:
This element of Foundation Data helps governments deliver:

- Foundation data as part of a national digital infrastructure

- Fundamental geospatial data from agencies that utilize 4IR technologies and partnerships to meet user requirements, including for continuously updated authoritative data of known quality.

2.1 The User. The user is no longer solely human, but also machine. Foundation data organizations will build their datasets based on both current and assumed future user requirements, defined by collaboratively prepared use cases. They will understand the value chain and how user value is derived and may embed people into key customer organizations to really help derive value. They will be close to user communities across all sectors, not just today's customers but with industry associations or government bodies looking at future development. One pressing concern is Unmanned Vehicle Systems (UVS) - air, sea and land.

- **Recommendation:** Government foundation data organizations establish arrangements to better understand current and future requirements along the value chain, and thus determine what data the market can provide and what authoritative data government should provide.

- **Recommendation:** Use cases be based on the outcome desired and knowledge required, leading both to understand data and analytical requirements.

- **Recommendation:** Transport, maritime and aviation authorities, and associated industry and fundamental geospatial data agencies, collaborate to understand fundamental geospatial data and knowledge needs for UVS use in a nation.

2.2 Global Geodetic Reference Framework (GGRF). The needs for precision and accuracy increase with automation. National geodetic infrastructures, including Continuously Operating Reference Stations (CORS) and datums, should tie up with the United Nations' endorsed GGRF.[32] CORS data will be accessible widely and nations will have in place the necessary measures, such as dynamic frameworks, to cater for rapidly advancing automation. Industry will adhere to these to ensure common understanding of precise location across networked systems.

- **Recommendation:** Nations have clear policies and infrastructures in place to support national positioning, navigation and time requirements.

2.3 Continuously Maintained Authoritative Fundamental Geospatial Data. Automatically and continuously maintained from many sources, this national 4D data sits across all UN GGIM fundamental data themes.[33] It is authoritative, meaning that it is officially recognized, of declared quality and provenance, provided by trustworthy organizations, widely used across government, and accessible to all. It is also designed to meet national public task use-cases across the entire nation, not just the financially lucrative use-cases. This includes government policy formulation, regulation, government services, safety and liability, critical domains and diversity. Fundamental geospatial data is also the scaffolding for digitization because, by dint of its authority, it contributes to and helps assure geospatial knowledge and automation. Data harmonisation will be key for fundamental geospatial data to ensure that they fit together, both with respect to geometry and semantics[34] which will be accessible through APIs, both service and individual transactions enabled and machine-readable licensing introduced.

- **Recommendation:** National geospatial agencies should move from survey and data management alone to data integrator, building on the most efficient and current sources to deliver fundamental geospatial data, services and knowledge, whilst assuring currency, quality and veracity.

- **Recommendation:** National geospatial agencies should build Artificial Intelligence (AI), Cloud and high-performance computing into their capabilities, both to help deliver continuously maintained data and also to offer knowledge services..

2.4 Allied Information Enterprise. Many wider government thematic datasets with national public task requirements are closely related to fundamental geospatial data and will be included in national geospatial information and knowledge developments. Examples include national or city spatial plans, crop growth, flood occurrence, weather data, and statistics. Many of the responsible agencies are already providing predictive knowledge services in addition to data. They are also often partners of fundamental geospatial data providers as users, through NSDIs or through wider partnerships (for example, under national resilience arrangements).

- **Recommendation:** In considering all aspects of GKI, the National Geospatial Knowledge Enterprise should include a defined set of wider foundation data providers.

2.5 Earth Observation and Ocean Survey. The increasing range of commercial and government space and sea/undersea sensors is complemented with both rapid data access and advanced analytics (in particular AI/Machine Learning). Pixels become information and knowledge in near real time. This combination is disruptive and provides a great opportunity to foundation data agencies. Sensors such as Synthetic Aperture Radar will enable persistent Earth Observation (EO) and open doors to precise change management from space, enabling new ways to monitor key infrastructure. Defense will always remain a major user, but the commercial exploitation of space enables far more sectors to be served by EO applications and knowledge services. For developing nations, open source EO and open analytics will support many use cases, including automatically maintaining some fundamental geospatial data themes, whilst commercial providers will add further value and provide new business intelligence services traditionally only seen in government. Increasingly, the private sector will be able to meet many use-cases satisfied by national foundation data agencies. In the fragmented EO sector, data aggregators and data agnostic AI-based knowledge services will help realize potential value, satisfying most customers' desire for knowledge, not data-management.

- **Recommendation:** National foundation data agencies should capitalize upon the commercial sector's democratization of foundation data and knowledge in helping meet the increasing numbers of use-cases.

- **Recommendation:** Nation should adapt processes to capitalize on EO, as a means of efficiently meeting a range of fundamental geospatial data requirements. This may be particularly beneficial in developing nations.

- **Recommendation:** Government space programs, associated research establishments and space accelerators should focus on EO applications and encourage the development of AI based 'downstream' businesses.

2.6 Automated Data Processing. Multi-source geospatial data will be processed into geospatial information without human interaction and meeting the quality standards. As part of this, through edge computing, machine and sensor real-time data will be processed and incorporated into foundation geospatial data.

- **Recommendation:** Foundation data agencies set in place strategies and investment for the achievement of near real-time continuously updated foundation data.

2.7 Digital Twin. Digital Twin is an understandable term and a means of communicating the benefits of digital equivalence of the real world. But the term is not unique to geospatial. There will be a range of Digital Twins built against specific groups of use-cases (from molecular to the universe). Digital Twins replicate 'how' the earth works in a structured way,[35] at the geospatial level having applicability from smart cities through national communications to world health. Digital Twins in this context are not a digital 3D physical model based on foundation data, but rather an ongoing integration of data from many government and industry sources to give a digital approximation of the real world from which knowledge can be gained and decisions made. Details of Digital Twin will increase and, with gaming technology, contribute to predictive and immersive 4D models for government, industry and citizen use. Later, using mixed reality tools, the application of their designs superimposed on the real physical environments can be seen.

- **Recommendation:** The geospatial knowledge ecosystem, both government and private sector, engages with relevant Digital Twins development, also utilizing them as use-cases for foundation geospatial data.

- **Recommendation:** There is consistency in Digital Twin models to support key use-cases in a nation, for example, across urban planning, operations and business services. Equally, nations work together to build consistent global Digital Twins, as we see for some use-cases.

2.8 Access and Interoperability. To provide knowledge on demand and support automation, foundation data will be machine discoverable, machine accessible and machine readable. Government agencies will publish linked geospatial foundation data through Application Programming Interface (APIs) as a key element of this. Increasingly, as well, governments will publish registers to aid integration and knowledge outcomes.

- **Recommendation:** Fundamental geospatial data agencies move from product centered to data centered approaches and maximize access to that data and associated quality metadata though APIs and other machine findable and readable techniques.

2.9 Authority and Accountability. Foundation geospatial information carries authority but currently often not accountability. The gap will narrow. To assist with accountability, foundation data organizations' authoritative data will expose quality and veracity of that data in a human and machine-readable manner.

- **Recommendation:** Foundation data organizations publish the quality and veracity of their data at a granular level and in human and machine-readable formats.

- **Recommendation:** All national foundation data agencies and wider geospatial information providers concerned with safety critical automation should build effective quality and safety critical update mechanisms (a practice familiar to the hydrographic community) to assure their output.

2.10 Foundation Knowledge Services. Knowledge is recognized by nations and industry as a democratized and sustainable commodity.[36] Geospatial organizations will both enable knowledge-on-demand by providing findable, accessible, interoperable and re-usable (FAIR) geospatial information services and by moving up the value chain to also deliver knowledge services.[37] Such knowledge services will build on the understanding of the most common user requirements and of agency data. Different foundation data organizations could collaborate to provide such services or actively partner with the private sector. Weather forecasts and tide tables are well known examples of predictive foundation data organization knowledge services and flood forecasts can bring together several such government sponsored agencies.

- **Recommendation:** Where there is a widespread demand, in particular for pan-government customers, fundamental geospatial data agencies should introduce knowledge services, in addition to providing knowledge-ready data.

2.11 Government Investment. As part of the national infrastructure, authoritative foundation data requires investment by governments, not least because government itself is the major consumer of the derived knowledge and will want assured foundation data as part of it. This is part of a far wider data picture, with the economic value of data and knowledge soaring. It is often little understood.

- **Recommendation:** Governments should make provision for good geospatial data, knowledge and education. The investment in these should be and an element of physical national infrastructure rather than only drive profitable aspects of this.

Element 3: Partnerships and Collaboration

Partnerships have traditionally been based on defined inputs, outputs and investments, often with obvious capital assets. Given the timeframes involved in creating valuable geospatial data and the vagaries of the marketplace, it is perhaps not surprising that geospatial data public private partnership (PPPs) have not materialized. The capital value of data may change this but meanwhile industry, government and investors need to explore new ways to partner across the ill-defined boundaries of geospatial knowledge. This may lead to new value-based partnerships based upon co-creation and sharing the value of derived knowledge through partners or a value-chain rather than long-term traditional PPP arrangements.

More widely, the 4IR era introduces new purposes for partnerships. Such purpose might be that the derivation of knowledge and value requires integration of analytics, digital platforms/networks and multiple sources of information, including real-time sensors. It can also be that disruption through integrating new technologies in novel ways may lead to growth and investment. It may be that collaboration brings separate benefits to both parties, perhaps through data exchange, where the common purpose is efficiency and effectiveness.

Partnerships are wider, though, including with academia and civil society, and individual citizens who can add considerable context to data collection, AI training and solving challenges. For a data driven society, single market for data where integration of government and non-government data is essential for the benefit of businesses, research and public administration.[38] If there is shared purpose, trust and humility between all concerned, then partnerships should be explored as a means of delivering cumulative benefits.

Outcomes:

- Widespread cross-sector geospatial knowledge engagement.
- A new age of industry-government geospatial knowledge and foundation data partnership.

Geospatial Knowledge: The UK Geospatial Commission, established in 2018 to unlock economic value from geospatial data, is working with national agencies and private utility companies to build a single, digital map of underground assets, the National Underground Assets Register. Aiming to reduce expense, accidental strikes and congestion, this represents a game-changing ambition between the public and private sector.[39]

Geospatial Knowledge: Current, accurate, 3D elevation data supports important knowledge applications, including flood-risk management, precision agriculture, infrastructure projects, natural resources management, and disaster response. The United States Geological Survey collaborates with other federal, state, local and non-profit agencies to co-create a national LIDAR collection program, leveraging the expertise and capacity of private sector mapping firms.[40]

- Innovative collaborative digital (and currently geospatial) industry.

3.1 Public Private Partnerships. Foundation data agencies will partner with industry to improve agency-fundamental geospatial data and to deliver value-added knowledge services. Traditional brick and mortar PPPs may not work in a rapidly evolving digital ecosystem; governments cannot commit to long-term arrangements because there are no traditional physical assets to protect investors. But long-term national geospatial agency contracts with industry geospatial data suppliers would encourage industry investment. To improve government assurance that it will benefit from downstream technology developments and to retain flexibility, such contracts might better be placed with intermediary data brokers, aggregators or partner national geospatial data organizations with similar source agnostic approaches. Industry, in return, may need to commit to sharing unexpected revenue with government, sharing risk and incentivizing reward.

- **Recommendation:** Foundation data agencies consider partner options outside the traditional geospatial sector, capitalizing on 4IR business advances.

- **Recommendation:** Industry seeks to build PPP models that share reward as well as risk.

- **Recommendation:** National governments allow Cloud-based solutions within partnership arrangements, aiming at reducing industry capital outlay through multiple uses of the same technology, and thus reducing PPP risk and cost.

3.2 Knowledge Stakeholders. The knowledge economy has many components: IBM describes them as data producers, data aggregators, custodians, platform owners, knowledge providers and presenters.[41] It is rare for a single organization to be built upon all these components, nor is it possible for a knowledge supplier to operate across all industry sectors, where context and user requirements will differ. The range of knowledge stakeholders will increase considerably as more businesses see the value of geospatial knowledge. Industry bodies have an important role to play in opening collaborative doors and cross-sector market development, and representing industry needs with governments. These bodies could change too. Currently, they largely attract established geospatial companies; however, supplying data, product or technology at the shopfront is not a growth strategy. They could usefully focus with an eye to the future, reach out across the value chain, consider geospatial knowledge as a capability, and be inclusive of geospatial knowledge partners across all sectors.

- **Recommendation:** Geospatial Industry bodies refocus from representing a narrow band of survey and geospatial companies to the broad geospatial knowledge ecosystem across industry-sectors.

- **Recommendation:** Foundation data agencies and companies offer wide-ranging partner arrangements with value-added service providers, particularly knowledge service companies, and seek fair profit distribution across the value chain.

3.3 Geospatial Knowledge Co-creation. Knowledge construction is a collaborative process. Many organizations will gain value by partnering to cooperatively collect, process, exchange and improve data to co-create information and knowledge, with each partner gaining different benefits.[42]
Co-creation will capitalize on collaborative opportunities to exchange data and knowledge between organizations. For example, utility companies' sensor-collected infrastructure data is processed by national geospatial agencies to update national fundamental geospatial information for use by both parties. Equally, partnerships to co-create knowledge may include national geospatial agencies, earth observation companies, utility companies and analytical companies co-creating a predictive road

condition service, where not only is there potential financial reward but each partner enhances its own data assets.

- **Recommendation:** Government procurement and tax regulation be open to innovative knowledge co-creation partnerships, including the means for involvement of government agencies.

- **Recommendation:** Industry and Foundation data agencies conduct pilot studies to explore the 'art of the possible' in co-creation of fundamental geospatial data.

3.4 Collaborative Innovation. Innovation is essential, not just for the evolution of operations, products and services focused on knowledge and automation, or to develop new business ideas, but also to substantively disrupt. Innovation thrives on valuable problems, energy, social purpose, networks, data and resources.[43] Great breakthroughs will occur at the boundaries between industries, where two fields collide. AI will often be one of these fields. To develop new '4IR' economic activity, governments, industry and academia will collaborate to support geospatial knowledge start-ups and micro-businesses. Successful commercialization of a digital start-up benefits all collaborators. Smaller or developing nations may choose to cluster resources in Digital or Geospatial Knowledge Innovation partnerships across international boundaries, either formally through organizations such as the African Union, or informally.

- **Recommendation:** Industry, government, investment companies and academia should establish geospatial knowledge innovation programs to support the establishment of new and innovative digital businesses, for example, providing developers access to foundation data APIs, technical advice, investment opportunities, and support to commercialize. These might be stand-alone or as part of wider digital innovation programs.

- **Recommendation:** Smaller or developing nations should consider clustering resources in such partnerships across international boundaries, either formally through organizations such as the African Union, or informally with neighbors.

3.5 Citizen partnership. The citizen in the 'social-media' world of today is naturally interactive and collaborative, effectively both a producer and a consumer of geospatial information and knowledge. Citizens are now a major geo-located data-source for businesses such as retail, analysis of social media, and buying habits. They are therefore partners, no matter even if unknowingly. At the national level, progressive countries engage digitally with citizens in delivery of services and to gain understanding of citizen views. (Who needs focus groups with social media analytics?). But rarely do citizens contribute to fundamental geospatial data maintenance despite the massive potential. There is clear potential when OpenStreetMap is more complete or up-to-date than national data.

- **Recommendation:** Fundamental geospatial data agencies implement the means for citizens to contribute to national data. This collection of location and attribute data by citizens is through their smartphones or crunching the data coming from social media.

Element 4: Industry Leadership

Location based services are common across all industry sectors, capitalizing on the ubiquity of GNSS devices and reducing costs of geospatial data and technology as their basis. Geospatial analysis (including AI) to derive business intelligence (knowledge) is also growing, although from a low base and with much greater potential. Fundamental geospatial data agencies often enable geospatial analysis through services and licensing arrangements, and perhaps also through value-added service partners.

Most innovation, autonomous operations and knowledge services will be delivered by industry. These innovations will be at much faster rate than governments to understand it's implications or act, therefore giving industry an increasing leadership role. With leadership comes responsibility, both towards citizens and the planet, and a clear need to work with governments to help best policy development and appropriate skills.

Many companies provide geospatial technologies, data, services and analytics, often referred to within the ecosystem as the 'geospatial sector'. But there is no such formally recognized sector - it is just too small to be considered as such. That does not dilute the importance of geospatial knowledge but it must be recognized that geospatial knowledge leadership is increasingly from companies that do not see themselves as part of the 'geospatial sector' - from Intel to Grab. For these companies, using location is just a part of their much bigger business knowledge, data and digital technology ecosystem. For this reason, GKI advocates that the 'geospatial sector' and wider digital ecosystem need to coalesce, growing and partnering into wider data and knowledge services whilst seeking improved user experiences and reaching across industry sectors for new customers and partnerships.[44]

Outcomes:

- Increased use of geospatial capabilities across all industry sectors, with business processes adjusted to gain maximum value from geospatial knowledge.

- Recognizing that the industry geospatial knowledge ecosystem is broad and growing, professional associations will grow into this space.

- Growth of a data-economy through location.

The GKI Program, Year 2, will work with a number of key industry sectors to create a greater understanding of its relevance and

Geospatial Knowledge: Traffic congestion has increased globally during the last decade. As part of its smart mobility mission, TomTom monitors real time traffic flow so that drivers and, in the future, automated vehicles know the best route. But aggregated data has wider use too, giving city planners and environmental teams insights to improve matters. And the most congested city? TomTom reports that the southern Indian city of Bengaluru takes the top spot, with drivers expecting to spend an average of 71% extra travel time stuck in traffic.[45]

value to industry, and develop pathways on 'how' GKI can deliver within that sector to the future economy and society.

4.1 Growing the Data Economy. The data economy is booming, led by industry. Through applications and sensors, businesses are collecting and using geospatial data for business objectives and sometimes offering it to wider digital value chains. Industry also creates geospatial data as a 'by-product' with no obvious value, especially through sensors and automation.[46] These can be opened up, including through co-creation discussed in Element 3. Other stakeholders in the ecosystem may find value too, provided arrangements are in place to help balance rewards across complex data and application value chains, where such 'by-products' could generate value.

- **Recommendation:** Businesses should open-up their geospatial data more widely, both under open license and on a value-sharing basis.

- **Recommendation:** Data trusts are being considered in some jurisdictions to help ensure fair reward across value chains. Government digital leads could investigate the barriers and opportunities for industry to provide such services.

4.2 Growing the Knowledge Economy. The need for knowledge is driving new geospatial applications, such as geo-fencing, and analytics companies are bringing timely 'first to know' foresight and prediction, for example, in the finance sector. Timely here refers to the foresights provided in minutes and seconds. In automation, this timeliness is measured in milliseconds. This will see industry becoming increasingly 'data source and algorithm' agnostic in meeting different knowledge use cases on time - indeed single data sources could be increasingly risky. Businesses will continue to adapt and emerge to support this model, aggregating data, integrating data, extracting knowledge from data, giving assurance to knowledge. The knowledge economy is booming.

- **Recommendation:** Geospatial data-rich businesses such as geospatial information companies, should seek growth through delivering generalized and bespoke geospatial knowledge services as an addition to data services.

4.3 Private Investment. Industry direct investment in geospatial capabilities is increasing as data and knowledge are valued as an asset. Major Investment is more likely where disruption can occur, such as, with collaborations that integrate new technologies to meet market gaps. If proof is needed then consider the hundreds of billions invested into Earth Observation and the associated AI that is deriving the downstream value. Space has a natural appeal, but if venture capital will invest in space where derived data and knowledge are the revenue source, then logically they should also do so in similar geospatial knowledge industries.

- **Recommendation:** Geospatial knowledge businesses, particularly those with global attraction, should be prepared to seek substantial private investment to 'be first to the global market'.

4.4 Diversity. To be ahead of competition organizations need talented people. But there is massive demand across the tech industry for the same talent and so organizations must be diverse and engage with wide variety of stakeholders.[47] Diversity across organization leadership and technologist will be the norm, across age, sex, (dis)ability[48], race or religion. Geospatial knowledge industries are attractive to younger people, simply because geospatial knowledge has the power for social and environmental good, and so are well placed to recruit and promote talent from all walks of life.

- **Recommendation:** Technology businesses, including geospatial, should work collaboratively to recruit talent from all sections of society.

4.5 Global Village. Businesses are competitive and look at value from a 'bottom line' perspective. However, other measures are gaining in importance and sustainability is a factor in investment decisions; Environmental, Social and Governance (ESG) requirements on business increasingly influence investment decisions. There are several ways business can use geospatial knowledge to gain ESG credibility, from environmental monitoring of activities to providing open data to supporting less-developed nations and/or communities. Conversely, use of bespoke standards that prevent interoperability could act against ESG credibility. Global services, marketplaces, knowledge providers and social media all create and consume local geospatial knowledge and can open opportunities. However, industry and regulators need to ensure that this does not disadvantage local businesses or the digital divide will cause even greater economic divide.[49]

- **Recommendation:** 4IR businesses utilize geospatial knowledge in innovative ways to demonstrate ESG credentials, whether local or global. This will require geospatial agencies and geospatial businesses to 'lead the way' and explore and publicize this approach.

Element 5: Applications, Analytics and Modelling

Data integration, analytics, modeling and applications are the engines of digital growth, whether for increased automation, knowledge-on-demand, or improved decision-making. Automated access is required for many forms of data and analytics to find and select the right combination and provide the knowledge necessary for that question or use-case.

The growth of AI over the decades is now seeing widespread use in the geospatial ecosystem - turning data to information, information to knowledge, and driving new businesses to exploit them. However, both geospatial experts and amateurs need to access location-based knowledge.[50] Mirroring the availability of data, many algorithms and applications will be accessible on the web, open or with transaction/license charges. These can be combined with data to deliver a particular answer or the knowledge sought. There are known and unknown opportunities and limitations to AI and all algorithms, and understanding the veracity of derived knowledge remains critical for users.

Global government policies will play a part in safety, access and trust by fostering accessible AI ecosystems with digital infrastructure, and technologies and mechanisms to share data and knowledge.[51] This includes GKI.

Outcomes:

- Widespread use of geospatial tools, data and knowledge within consumer applications.
- Trust in geospatial derived knowledge for the human or automated use it is to be put through Transparency in the geospatial models and assumptions in algorithms.
- Geospatial knowledge that provides prediction and foresight, not hindsight

5.1 Consumer Applications. There are 5.7 billion unique mobile subscribers in the world, over half of them in Asia-Pacific. Consumer apps will move from hard-coded analytics to knowledge inferencing, able to interpret questions and geospatial context, retrieve

Geospatial Knowledge: The US analytics company SpaceKnow provides actionable intelligence by fusing satellite imagery data with advanced statistics, machine learning, and industry expertise. It is developing provider/data agnostic AI tools to be able to provide faster turnaround by using data from different satellite sources, including 24/7 synthetic aperture radar data that is ideally suited for AI. In this way it can gain an edge in a world where sometimes 'first to know' matters, for example in the finance industry.[52]

Geospatial Knowledge: For consumers, L'Oréal offers a smart skincare at-home assistant called Perso – a hardware and software system that creates personalized skincare formulas using AI technology. This includes geo-location data to assess local environmental conditions that can influence the state of the user's skin — including weather, temperature, pollen, UV index, and humidity.[53]

trusted geospatial information and analytical resources, process the query, portray the answer, and enable feedback. Location is part of this and thus consumer applications could gain insights that may impinge on the privacy and rights of individuals - for example, giving information on the inhabitants of a particular property. Even before legislation, industry codes of practice will start to impact geolocation aspects of applications, especially where applications are collecting location in the background.

- **Recommendation:** The use of location in applications should be subject to industry guidelines and standards based on clear impact-based legislation described in Element 1 and under the principle that an individual's location is private unless permission to use it is given.

- R**ecommendation:** Specific applications use location to provide knowledge and assist decision-making but generic search engines do not; search engine developers should continue to seek the integration of true geospatial knowledge capabilities within search engines, personal assistants, etc.

5.2 Predictive Analytics, Modeling and Simulation. Prediction through analytics and the modeling of different options is critical in decision-making, yet can be illusive. With the evolution of AI and advanced computing, algorithms are becoming more and more complex, and understanding the underlined principles at work, based on the outputs, is much more difficult. Earlier, decision support systems were programed in a rule-based way and the rules that were applied would together offer the necessary explanation. But for modern large-scale neural networks, a vast range of factors, inputs, and exceptions make veracity of the attained knowledge less certain. Trust is therefore key in AI today, achieved partly through diverse programming teams, partly through greater openness, peer review and user-feedback and partly through training. Equally, excessive analytics fragmentation should reduce, and the benefits of replication, adaptation, modification, and expansion will lead to a more modular approach. Geospatial modules will be included in this.

- **Recommendation:** Geospatial data, information, knowledge and algorithms should be findable, accessible, machine readable with declared veracity and include archived data from previous eras to help understand change and enable better prediction.

- **Recommendation:** Data science, geospatial and similar professionals should seek greater understanding of all predictive approaches, not just GIS, and understand the strengths and weaknesses of each; government entities and businesses should build diverse analytical teams combining different skills.

5.3 Automation. Industry is leading automation and the associated data and analytics. Direct human intuition has always played a major part in decision-making, providing the user who understands the wider context a chance to accept or reject derived information and knowledge and to rank its validity for the use-case concerned, based upon experience. With automation, the only human 'in the loop' is the programer, with associated bias. Measures such as multiple systems with differing sensors, technologies and analytics can improve operation and safety but such automated systems still need to be tested. This leads to fresh challenges and, equally, opportunities. Real, simulated or hybrid geospatial data can assist AI training, and digital systems can be tested in a virtual environment rather than 'on the road'. Even with 5G, the cloud, and a networked IoT, in a rapid 'sensor to decision' regime, edge computing will prove essential and absolute position is likely to be less important than relative position. This will lead to different real-time geospatial analytics solutions, to the 'absolute position' employed in traditional geospatial applications, although the two will overlap.

- **Recommendation:** Governments work with industry to understand the necessary location regulations, processes and common geospatial data requirements to ensure safe operation across different fleets of unmanned vehicle systems operating on roads or in the air.

- **Recommendation:** Governments assess the utility of, and develop, virtual testing facilities for safety critical automated digital systems, including a virtual geospatial environment.

5.4 Knowledge Visualization. The representation of geospatial knowledge is expanding from 'maps' to include real-time storyboards, augmented reality and virtual models or any form needed by human or machine. Geospatial businesses will engage with and enable these new cartographies. Virtual reality and its derivations are becoming a component of all walks of life, from biological sciences to city government engagement with citizens, from education through tourism to mission rehearsal, and clearly entertainment. Immersive 4D modeling allows decision-makers to experience options. Forecasts project massive growth in both AR and VR headset sales in the coming years, with both technologies combined expected to sell over 26 million units per year by 2023.[54] We can expect the development of new or adapted use-cases to develop rapidly over the decade. Requirements for constantly updated geospatial data will expand.

- **Recommendation:** As such technologies are built, open standards should be developed and agreed upon, which allow visualization devices to be data agnostic.

- **Recommendation:** Foundation data providers should work with research establishments and industry to identify potential new use-cases for different national data.

5.5 Assurance. Data integration and aggregation processes are known to generate uncertainty[55] and machine cognition models will need to declare assumptions/beliefs and decision-making principles. In turn, a greater openness in data quality and provenance will be required by industry and model validity will be exposed to humans and machines to enable users to understand the quality of derived knowledge. Models also need to be clear in their ability to respond to local conditions, and be exportable to other regions - be "glo-cal". And in the same way we consider 'data life-cycles', AI and advanced analytics should be regarded similarly so that unsafe models do not litter the internet.

- **Recommendation:** Companies and governments should publish their assumptions and other veracity information on analytics, applications, etc. In addition, they should ensure full feedback to monitor the success of solution in their operation and thus further develop veracity. Regulation will be required by the government to ensure this happens.

Element 6: Geospatial Dimension to the Digital Infrastructure

The common thread in many use-cases in this Paper is that data with associated location from multiple sources is integrated and analyzed using advanced analytics, often on the Cloud.

GKI seeks that geolocation, geospatial data and associated analytics are fully part of the wider digital ecosystem, sitting on the same global digital infrastructure. Geolocation, geospatial information, expertise, technologies and analytics are an important element of this global digital infrastructure, which must continue to evolve with location, geospatial data and geospatially enabled analytics at its core. In doing so, location becomes a powerful means to derive knowledge, from across data and application sources sitting in the Cloud.

Outcome:

- From individual companies to global institutions, location becomes a fundamental attribute within data, information and applications, and a core element of organizational data infrastructures and business processes.
- Geospatial technologies and standards are seamlessly integrated into web, business and government systems and enterprises.
- National digital policies and strategies incorporate geospatial as an underpinning consideration rather than separate geospatial strategies.

Geospatial Knowledge: The value of location is increasingly being recognized in the digital ecosystem. Intel, extensively known for computer chips, seeks to 'unleash the potential of data'. Two subsidiaries demonstrate that these are not just 'vision' words. Mobileye's advanced driver-assistance systems are improving safety in 60 million vehicles globally, with sensors and onboard processing allowing autonomous operations. One output is real-time detailed mapping data of use to mapping agencies. Further, in 2020, Intel acquired Moovit, a global mobility-as-a-service company, bringing it closer to achieving its plan to become a complete mobility provider, including robo-taxi services, which is forecast to be an estimated $160 billion opportunity by 2030.[56]

Geospatial Knowledge: Location is one aspect of epidemiology, but so much other knowledge and data contribute too. Covid-19 responses have seen wider exposure to geospatial capabilities. Analytics companies noted concerns in Wuhan before the Chinese Government publicly declared them, based on location-tagged data. Testing results helped nations to establish local measures and trace potential carriers based on location. Social media data and facial recognition were also used in some countries to help track individuals.

6.1 Digital Infrastructure. The global digital infrastructure is not specific to any form of data or application, and is carried on the internet, on local systems, in the Cloud and with a set of established protocols and standards. Whilst it is complex compared to most forms of data, geospatial data, information, applications and knowledge should seek to use this same infrastructure.

- **Recommendation:** Geospatial data, analytics, knowledge should be findable and accessible on the wider global digital infrastructure.

- **Recommendation:** Governments and industry should work towards delivering a mainstream web-based approach to geospatial resources and location, as recommended by the Joint W3C/OGC working group in 2017.[57]

6.2 Knowledge on Demand. Existing geospatial infrastructures have largely relied on human intervention to search and find existing geospatially referenced knowledge, foundation geospatial data and wider spatially referenced datasets. Focus should switch to automation in achieving this, along with an ability to identify the best applications and algorithms. Amongst other requirements, to fully enable knowledge on demand, Semantic Web/Web 3.0 is essential.[58] Practices such as globally unique persistent HTTP URIs for Spatial Things, spatial data indexable by search engines, APIs and linked data will all help build knowledge on demand.

- **Recommendation:** W3C and OGC collaboratively progress the 2017 recommendations, articulate a benefits case and elevate the discussion to geospatial executive level.

6.3 Integrated Standards. GKI sits on the web and thus collaboration by geospatial standards bodies with wider web standards organizations, such as with W3C, is critical.[59] Nations and organizations will implement IHO, ISO and OGC collaborative Tier 3 and Tier 4 standards.[60] Open standards on geospatial information licenses and data quality and provenance will be in place, enabling machines/machine transactions. Standards organizations will also tackle emerging issues, such as, vertical geo-referencing.

- **Recommendation:** Government agencies should adopt open standards across the digital domain, including geospatial.

- **Recommendation:** Geospatial standards bodies should align closely with wider digital infrastructure standards and developments, and the data science industry, to maximize the ability of geospatial information and algorithms to contribute to knowledge on demand.

- **Recommendation:** Geospatial standards bodies should work with allied foundation data providers and wider specific user-domain groups to help wider data integration through location. Examples could include health, fisheries, socio-economic, and automotive sectors.

6.4 Real Time Data Processing. Increasing number of real time feeds from sensors and the IoT will provide ‘streaming’ Big Data with location. Real-time processing, potentially combining Edge Computing, AI and the Cloud, will extract features and locations of value for a range of uses, from networked traffic obstruction warnings to, where permissible, the tracking of suspected terrorists. This is real time knowledge incorporating location related to, but broader than, Element 2’s intent to get near-real-time foundation data updates.

- **Recommendation**: Whereas in the past time-consuming post-processing would have been required, businesses and organizations focused on sensors can now seek to create valuable geo-located data and insights, adding new services.

6.4 People. Tech industries, which clearly encompass geospatial knowledge companies, will be learning organizations – continually upskilling staff to prepare for tomorrow's roles and encouraging innovation top to bottom. Geospatial knowledge competencies will be agreed upon between the education sector, national professional bodies and industry associations, with clear paths for recognition and development in the way surveyors, engineers and even data science professionals have established.

- **Recommendation:** Geospatial professional development is essential in a rapidly evolving digital ecosystem. Industry, existing professional organizations and government should work together to ensure this is delivered.

- **Recommendation:** Digital and data education and professional development organizations should collaborate with the geospatial ecosystem to support the development of spatial aspects of wider data and software development competencies.

- **Recommendation:** Changes to working practices brought about by Covid should be embraced to enable geospatial professionals across all nations to better interact, and for professionals in poorer nations to develop skills through education, training and participation in fora such as UN GGIM or standards working groups.

6.5 Open Positioning Infrastructure. Whilst governments have a role in national position, navigation and time policy and strategy (covered in Element 1), open positioning infrastructures benefit all. Further positioning infrastructures will not be government owned. It will be established by private industry and accessible to everyone. An ambulance crew trying to find the right store in an indoor shopping complex should not be hampered by positioning incompatibility.

- **Recommendation:** Private sector positioning infrastructures should meet open standards and be accessible to all.

6.6 Value Measurement. Data-driven innovation, new business models and analytics are changing the workings of science, governments, cities, and industry.[61] The relative advantage of geospatial investment will be recognized and quantified by governments and business. Governments and businesses will establish mechanisms to value the outputs of this investment to the national economy and business outcomes as part of wider data and knowledge value measurement.

- **Recommendation:** Governments introduce programs to understand and monitor the value derived by government and the economy from different segments of the national knowledge and data ecosystem, including geo-located data and foundation data, to inform investment decisions. Businesses should do similar i.e., understand the value derived from data.

Relationship with UN IGIF

The United Nations Integrated Geospatial Information Framework (UN IGIF) is a globally adopted multi-dimensional Framework aimed at strengthening national geospatial information management arrangements in countries - developing countries in particular. It comprises an overarching strategy, implementation guidance, and action plans at the country level. At the strategic level, the UN IGIF contains a vision, mission, strategic drivers, 7 principles, 8 goals, 9 strategic pathways, and many defined benefits. However, through the Implementation Guide, anchored by the 9 strategic pathways and influenced by governance, technology and people, the UN IGIF provides the detailed guidance towards 'integrating' geospatial information with any other meaningful data to provide understanding and benefit from a country's national development priorities and

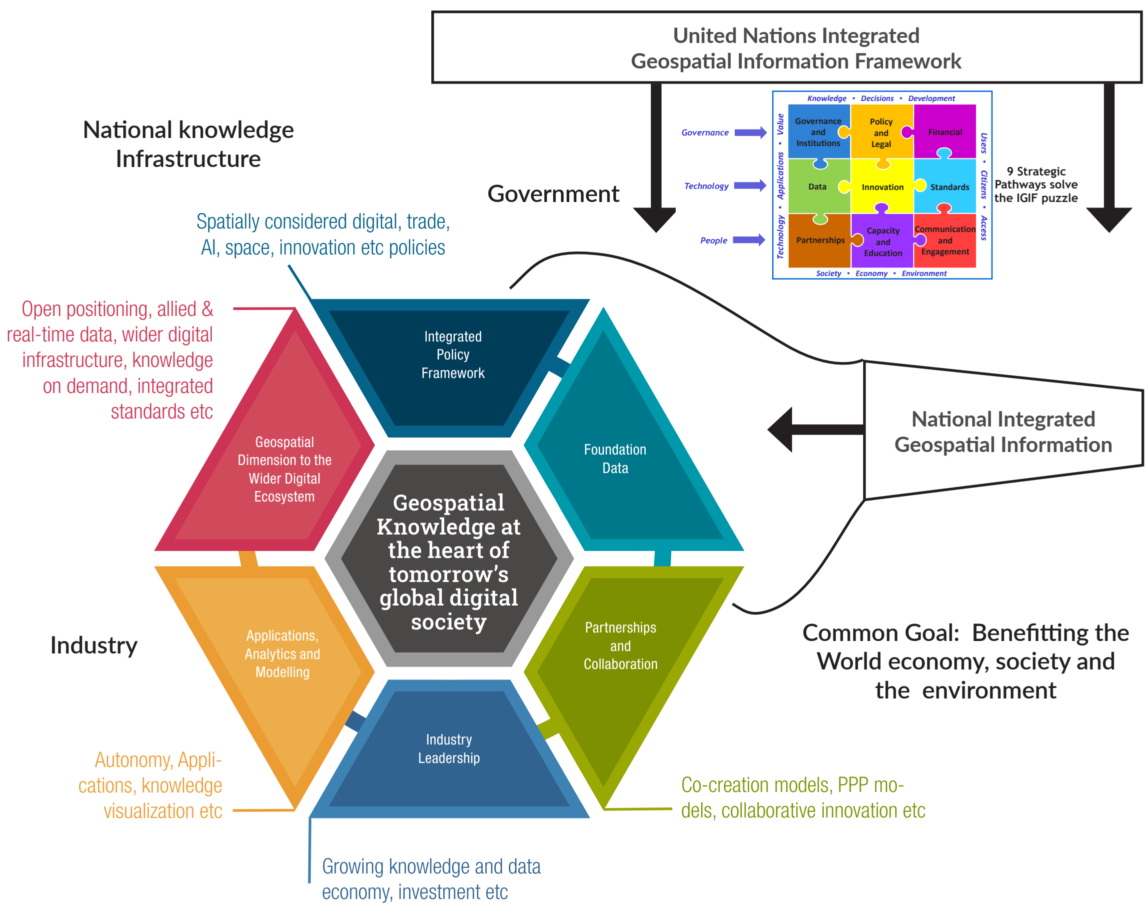


Figure 6. GKI's Relationship with UN IGIF
(The IGIF supports national governments implement geospatial information management. This is one vital element of GKI, which is more broadly concerned with location as part of the wider digital, or knowledge, infrastructure across government and industry.)

Source: Geospatial World

the SDGs. That said, as a "framework" (not infrastructure) it also recognizes, complements and supports the implementation of NSDIs and other geospatial infrastructures such as the GKI.

Figure 6 demonstrates the relationship, although for simplicity it does not reflect that the arrows are two-way, with feedback and opportunities all the way back through the chain to the UN IGIF itself. Through its nine strategic pathways, the UN IGIF guides nations towards integrated geospatial information management. This includes the delivery of trusted authoritative fundamental geospatial data. Geospatial policies are important in this, as are partnerships, although in GKI the focus is on integrated digital polices that are enabled by location, and a wider range of partnerships. The UN IGIF sits very firmly with Governments, whereas GKI focuses to a large extent on industry and wider government digital policy makers. In so doing, it intends to place geospatial knowledge at the heart of tomorrow’s sustainable digital society, represented in the diagram by the national knowledge infrastructure and a cooperative effort by government and industry.

As part of emerging ‘knowledge infrastructure’ conceptual thinking, the GKI seeks to bring a geospatial dimension to the wider digital ecosystem. While GKI is anchored by geospatial, it engages with a broader range of industry sectors. Thus, as nations implement the UN IGIF, GKI can also help in delivering integrated geospatial information management. GKI offers new approaches to support the delivery of geospatial information, which, where proved successful, may lead to future amendments of the UN IGIF. Equally, GKI reaches into the wider industry and digital ecosystems, helping to expose the benefits of geospatial information, understand future requirements, generate new partnerships, and appropriately influence emerging digital policies.

Geospatial Knowledge Infrastructure Concept Development: 2021–2023

Geospatial Knowledge Infrastructure (GKI) integrates digital economies, societies and citizens with geospatial approaches, data and technologies. In so doing it delivers the location-based knowledge, services and automation expected in the 4IR age. GKI concepts are being developed as part of a three-year program that seeks to project value, enhance adoption and evolve the understanding of geospatial knowledge for social, economic and environmental development in the digital age. The objectives of the program are to:

- To define and project GKI and its value proposition
- Forecast GKI's relevance and connectivity with the fundamentals of the next generation
- economy and society
- Evolve collaborative GKI industry, policy and technical models
- Redefining the role of stakeholders in GKI: Government, industry and civil society
- Develop National GKI 'strategy/readiness' reports and roadmaps
- Connect GKI with global development agendas.

The first phase of the program has focused on introducing the GKI concept and developing an initial GKI conceptual perspective. This has been achieved through global consultations across the more-traditional geospatial ecosystem, governments, geospatial industry, and civil society. Individuals from 1000+ organizations across 108 countries have contributed thinking through roundtables and a global GKI summit in February 2021 which attracted 2119 participants. Due to the impact of Covid on geospatial agency leadership training that was scheduled in 2020, the training will now be held in October 2021 at the Geospatial World Forum in Amsterdam.

This Paper has been developed during the first phase of the program. It is a geocentric view but provides the basis for an infrastructure that integrates government, industry and academic geospatial capabilities with the wider digital drive to better the world economy, society and environment.

The second phase, commencing in May 2021, moves the debate into wider industry. Seven different sectors are being selected for engagement to help build GKI models. This will help create a greater understanding of the relevance and value of GKI to industry and develop pathways on 'how' GKI can deliver within that sector of the future economy and society. Building on Phase One, this engagement will also allow the collaboration and partnerships element to be refined further. Importantly, a blueprint for a GKI technical architecture will be developed for all stakeholders, based upon the wider digital infrastructure and supporting the drive for 'knowledge-on-demand'. This white paper will be revised at the end of Year Two to reflect findings and a second global GKI summit will be held.

The third phase of the program will take the learnings of the previous two phases and engage with government digital leads. Ultimately, integrated digital, social and industrial policies will be needed to ensure maximum value of location to the wider digital, autonomous and knowledge ecosystems. This is currently intended to include working with six national/city governments to develop GKI adoption strategies, so that concepts to 'join' the geospatial and wider digital knowledge infrastructures can be properly tested and developed.

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