UN-GGIM

UNITED NATIONS
COMMITTEE OF EXPERTS ON
GLOBAL GEOSPATIAL
INFORMATION MANAGEMENT

Future trends in geospatial information management: the five to ten year vision

THIRD EDITION

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This document was produced by Ordnance Survey of Great Britain at the request of the United Nations Committee of Experts on Global Geospatial Information Management.

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UN-GGIM | United Nations Committee of Experts on Global Geospatial Information Management

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Acknowledgements and disclaimers

This report has been authored on behalf of the United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM) by Christin Walter of Ordnance Survey, Great Britain's national mapping agency. However, the content is based primarily on the First and Second Editions of the Future Trends report, contributions received in written form and the views expressed during the discussion fora held in June and August 2019. Hence the content does not necessarily reflect the views of the author or the employer. While different, and at times conflicting, views were expressed by contributors, consensus on a number of major trends and themes were forthcoming.

A full list of those who have contributed can be found at the end of the report. We are grateful to every person and organisation for giving their time, either to provide written contributions, attending the discussion fora, or taking part in individual evidence gathering sessions, and allowing us to use their collective inputs in this report.

The report, which was written before the global COVID-19 pandemic, was updated where possible to reflect the impact and consequences of this unprecedented crisis. As we continue to experience this ongoing public health emergency, the report does not aim to draw conclusions about the potential long-term effects on global geospatial information management.

Foreword

In these days of global pandemic the value of geospatial is more apparent than ever.

The Covid-19 pandemic has reinforced that, as with the SDGs, many countries continue to face challenges in collecting, managing, and using timely and reliable data with the required enabling geospatial technologies to measure and track what is happening where, when, and how.

Our geospatial infrastructure has been called on to help understand the economic, social and environmental impacts of the global response to Covid-19. Spatial data analytics, geographic visualisation, and machine learning techniques using aerial and satellite data have proved to be critical in supporting the essential components of disease prediction, spread, prevention, and response.

This report looks in-depth at the challenges and opportunities that will impact how we collect, manage and use geospatial information over the next five to ten years. Commissioned by the United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM), this third edition of the Future Trends complements the Integrated Geospatial Information Framework (IGIF).

The IGIF is intended to be dynamic, responding to changes in the external environment, and this Future Trends report helps to show where those changes are most likely to occur, enabling the Framework to keep pace and adapt.

But the events of 2020 have made it clear that our global community is more complex and interconnected than ever. None of the trends identified in this report should be considered in isolation. Digital transformation, disruption and change in the geospatial industry are a given, but we must be prepared for the reality that our challenges will be shaped by multiple trends acting and interacting across our societies, economies and environment.

Every nation will experience a transformation in their response; the report tries to recognise that every nation is starting from a different place; with different experiences, policy contexts, digital technology development, and levels of geospatial maturity. The use and affordability of technology, as well as analytical methods, have the potential to reduce the geospatial digital divide over the next decade, with discontinuous change creating opportunities for many nations to leapfrog into the future and make rapid progress.

But this is not a futurology report or an inspection of market forces. Instead, this Future Trends report provides a consensus view from across the entire geospatial community landscape. The strength of our community is in its collective discussion and debate. We enthusiastically share insight for the benefit of all, and hope that through sharing best practice, we reach a deeper understanding ourselves.

Covid-19 has accelerated many of the trends highlighted in the report, such as the critical role that data analytics will play in our public and private sectors, and has illustrated the critical role that we, as geospatial leaders, will play in the global conversation around trust and ethics. As a community, we must consider the implications of the proliferation of location data on the global market, our countries, and our citizens.

Overall, 124 UN Member States, organisations and relevant expert stakeholders from all over the world have contributed to this revision. We thank you all for your contributions to this third edition of the Future Trends report, and hope that you will recognise your words and your wisdom enclosed. We look forward to tackling future global challenges and realising our shared opportunities over the coming years as we consider our common geospatial future.

Stefan Schweinfest
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Executive Summary

This 2020 edition of the Future Trends report marks the beginning of a highly important decade for both sustainable development and geospatial information management. It is characterised by three significant global milestones, namely the beginning of the 'decade of action' for the 2030 Agenda for Sustainable Development, the start of the Decade of Ocean Science for Sustainable Development, and the 10th anniversary of the United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM).

The effects of climate change have become the 'defining issue of our time'.[1] Today, the way in which our society is organised amplifies the structural threats that climate change and the emergence of new infectious diseases have upon the world. The COVID-19 pandemic is a striking example of this. Over the last two decades, outbreaks of infectious disease have emerged every two to three years. While the resilience of society overall has decreased, and our dependency on globalisation has increased, the potential disruptions caused to society and the economy are resulting in unprecedented impacts. It is often impossible to predict the next incident but understanding the pattern of recurring risks and investing in the capabilities (infrastructure, skills, and technology) to mitigate and respond to these perceived events increases our level of preparedness. Governments and institutions can make the necessary investments in the many components of preparedness - of which geospatial information is key.

In the 1990s, Bill Gates reflected that

"we always overestimate the change that will occur in the next two years and underestimate the change that will occur in the next ten."

Although still valid, little did anyone suspect that the pace of change experienced today would challenge our ability to adapt. Even though this report aims to anticipate the trends that will influence geospatial information management over the next five to ten years, it also recognises that this goal will be increasingly unrealistic to achieve as the lifecycle of technology and business practice innovation becomes even shorter.

Like never before, the geospatial industry is affected by a variety of outside influences that determine how and in what direction the industry is likely to develop. Climate change, a shift in people's values and attitudes, public health concerns, and population change related to urbanisation are topics of concern to all nations. Balancing situation-appropriate responses to these issues shows the important role the geospatial industry plays in providing data-driven analysis to support decision-making.

For the past three decades, digital data has increasingly become the basis on which governments, organisations and businesses alike base their decisions. Today, the volume, size, speed, diversity and complexity in which geospatial data is generated requires change: to the processes currently used by governments and businesses across the world, and to workforces that are capable of searching, analysing, merging and harmonising these large amounts of data.

Technology, in particular, plays a prime role in disrupting the geospatial industry. Ranging from increasing levels of automation to the Internet of Things, Big Data, Artificial Intelligence, immersive technology and the rise of Digital Twins, the speed at which innovation occurs represents great opportunities and challenges to those trying to prioritise efforts. The private sector and national agencies alike are impacted by this unprecedented level of disruption. Among the variety of technological trends, there is general consensus across the industry that automation, Artificial Intelligence, and connectivity through 5G will have the greatest disruptive impact over the short to medium-term.

Geospatial information and technologies have become a ubiquitous part of everyday services and is central to the business models of many of the digital disruptors that have become prominent in the 2010s. The rise of smartphones, tablets, and other mobile devices has contributed significantly to people's expectation of the use of geospatial applications. User demand for increasing accuracy, currency, and detail is growing and processing will require more automated data capture and feature extraction to keep pace with those requirements.

Technological developments, the nature of machine-led decision-making in autonomous mobility, and other applications that require multi-stakeholder partnerships are creating new challenges in a world that will increasingly be managed virtually. In the context of trends, cybersecurity, data privacy, ethics, trust and licensing will increase in relevance as interdisciplinary collaborations, and are now at the forefront. Government-led geospatial infrastructures will need to take account of and consider responses to these emerging legal and policy top trends.

Governments continue to remain highly relevant in the geospatial industry by providing high quality, reliable, trusted and maintained geospatial information for a wide range of applications from national resilience to the effective administration of property, resources and land use extended to other relevant areas such as health, education, urban planning, and others.

The next five to ten years will see significant developments in the maturity and application of already well-established technologies across the geospatial industry. Among others, Artificial Intelligence, sensor technology, and the Internet of Things will drastically change how data is collected, managed and maintained. Developed nations, developing nations, and small island developing states alike will reap the benefits of more affordable drone and satellite technologies equipped with image classification capabilities as valid alternative data sources. This will address the incredible inequality observed today in nations around the world. The use of technology and analytical methods has the potential to reduce the geospatial digital divide over the decade to come.[2]

The report provides a consensus view of the developments and future direction for geospatial information management over the next decade. We wish to thank all those who have contributed to the development of this report and provided their expertise and professional insights.

The first chapter of the report provides a high-level analysis of the top global geospatial drivers and trends that are predicted to have the greatest impact on geospatial information management over the next five to ten years. Recognising that change in the industry is driven by a set of diverse drivers and trends, the report sets out five top forces: Technological advances, the rise of new data sources, the changing user requirements, industry changes, and the regulatory and policy environment. The chapters that follow provide updates, where relevant, on the trends identified in the previous two editions. It concludes by producing a brief overview of the topics covered by all Future Trends reports since the publication of the first edition in 2013.

Introduction

The first and second editions of the report *Future trends in geospatial information management: the five to ten year vision* have proved to be important reference documents for the global geospatial community. They are considered an important output for the UN-GGIM Committee of Experts and have provided a consensus view for the professional geospatial community to keep abreast of new trends in geospatial information, particularly in assessing the impact of geospatial technologies.[3]

This third edition Future Trends report, prepared through a global consensus process is expected to be presented to the Committee of Experts for adoption at its tenth session in August 2020.

As well as exploring emerging themes, this third edition highlights changes to the trends identified in the previous two reports, showing how geospatial information and technology underpin national governments, and documenting the increasing role that geospatial information will play as part of the 2030 Agenda for Sustainable Development.

Many of the chapters in this report touch on the 'state of the art' developments in geospatial information management that are mainly of interest to developed nations and major economic centres including topics like Big Data analytics, Artificial Intelligence, automated feature extraction and change detection. The report aims, wherever possible, to highlight exceptions and challenges faced by developing nations and rural populations as well as show the opportunities related to technological advances and analytical methods to ensure no one will be left behind.

The report seeks to achieve two aims, to highlight the latest trends in geospatial information management, and to provide a high-level overview of how these trends have developed since the publication of the first and second editions of the Future Trends report. It includes a separate chapter illustrating the top global drivers and trends likely to impact the industry over the coming five to ten years. It aims to show how evidence-based decision-making benefits and promotes economic development and increases sustainability and resilience by applying geospatial thinking and adopting geospatial data and technology innovatively at the local and national level.

The role of geospatial information in achieving the 2030 Agenda for Sustainable Development

The year 2030 marks a milestone in the evolution of the global effort to steward the progress towards economic, environmental and social dimensions of sustainability. One of the most critical conditions for the fulfilment of the ambitions expressed in the 2030 Agenda for Sustainable Development is the effective and efficient use of dynamic and disaggregated data for decision-making, the delivery of services, citizen empowerment, entrepreneurship, competitiveness and innovation, and to contribute to the achievement and monitoring of the Sustainable Development Goals (SDGs) and their objectives.

Most notably, the 2030 Agenda recognises the value that geospatial information provides to enable informed, data-driven decision-making. The importance of geographic information is clearly highlighted by SDG Goal 17 on 'Strengthen the means of implementation and revitalise the global partnership for sustainable development'. It states that *"by 2020, enhance capacity building support to developing countries, including for Least Developed Countries (LDCs) and Small Island Developing States (SIDS), to increase significantly the availability of high-quality, timely and reliable data disaggregated by income, gender, age, race, ethnicity, migratory status, disability, geographic location and other characteristics relevant in national contexts."* It recognises the importance of geospatial information for sustainable development monitoring and accountability, and highlights the need for timely and reliable information to build accountable actions and evidenced-based decisions.

In the recent past a 'spatial data infrastructure' (SDI) has been considered to be a helpful way of organising data to support activities such as those required to deliver the 2030 Agenda. However, there is now a paradigm shift from a Spatial Data

Infrastructure (SDI) to 'knowledge infrastructure'. that can be used for data integration, analysis, modeling, aggregation, fusion, communication, and for organising and delivering data across disciplines and organisations.

As we undergo almost continuous digital transformation and disruption, three key factors now challenge the limitations of a traditional SDI. The first is the recent and growing availability of more diverse data and data types and needs that are now more relevant and dependent on geospatial data than were originally considered. The second limitation is the growing demand for data integration, fusion and analysis. The third is that the main focus of SDIs has just been geospatial data.

Together with the World Bank, the Committee of Experts has launched the Integrated Geospatial Information Framework (IGIF) to help support governments to develop and enhance their own geospatial information management. A 'knowledge infrastructure', the IGIF builds on previous efforts in planning and implementing SDI and NSDIs. These implementations have historically focused on the collection of data and the implementation of technologies. In contrast, the IGIF additionally focuses on the governance, policy, financial, capacity and engagement processes necessary to collect, maintain, integrate and share geospatial information, through all levels of government and society, in a modern and enabling technology environment.

The Framework will assist countries to move towards e-economies, improve services to citizens, build capacity for using geospatial technology, enhance informed government decision-making processes, and take practical actions to achieve a digital transformation in the implementation of national strategic priorities and the 2030 Agenda for Sustainable Development. The Framework can be understood as a foundation for bridging the geospatial digital divide, securing socio-economic prosperity, and to leaving no one behind. The third edition of Future Trends will complement the IGIF helping to ensure that the Framework integrates and takes advantage of the latest innovation and trends. An indication of where the trends will impact on the Framework Pathways is provided in Section 1.8, noting that at the time of writing, the IGIF Implementation Guide has yet to be approved and endorsed by the Committee of Experts.

Delivering value through geospatial information

Geospatial information and Earth observation data combined with environmental, socio-economic and other statistical data provide a unique input to governments in their policy preparation, monitoring and evaluation. This data, along with digital developments and industry innovations, mentioned elsewhere in this report, will play a large role in global stewardship, enabling timely, more accurate and trustworthy information to be made available to decision makers to inform decisions, monitor progress and assess the impact of interventions as well as for future planning.

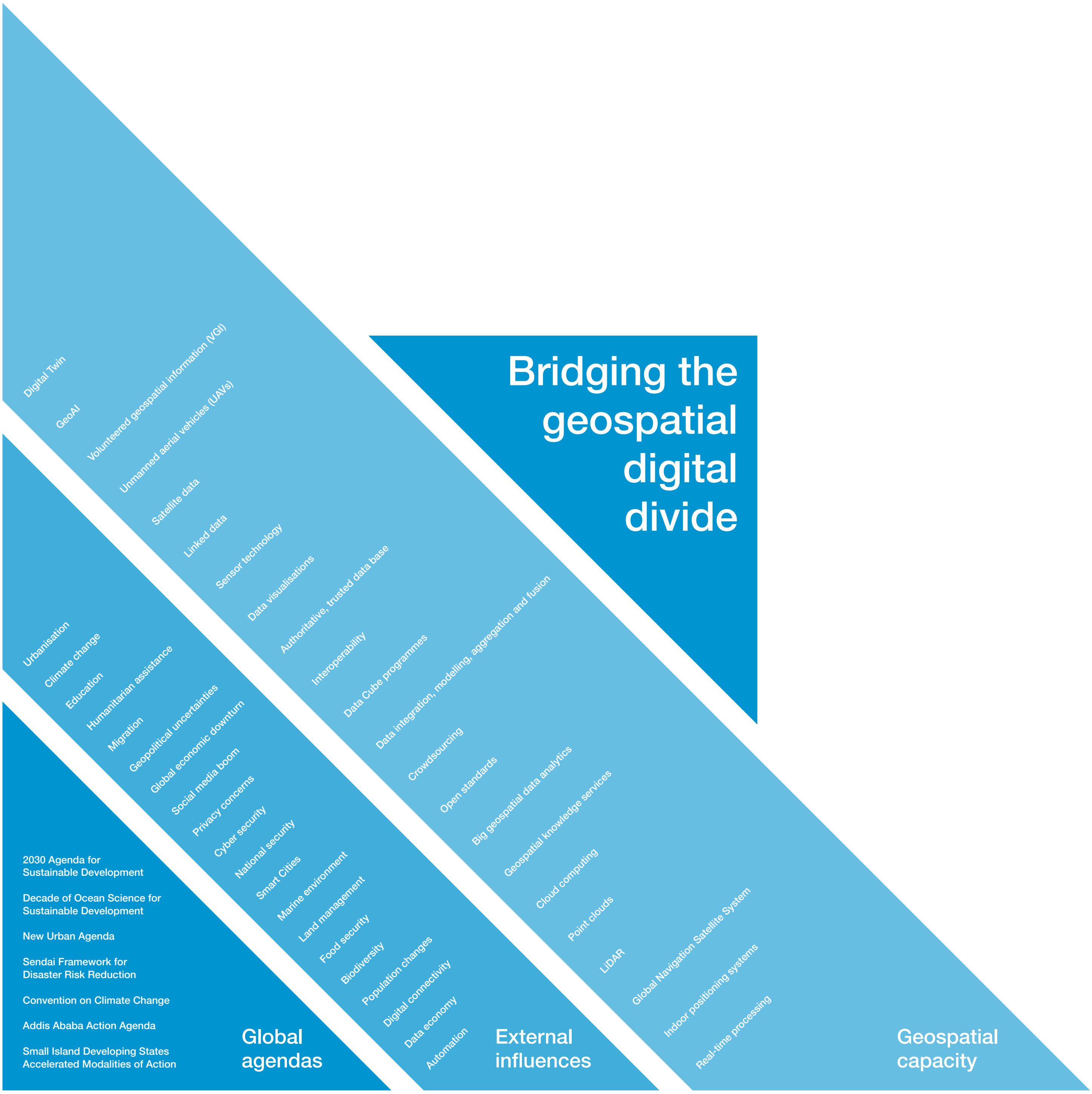
Since the publication of the last Future Trends report, a significant increase in the use of geospatial information and technologies has been observed across a variety of sectors, especially in the health sector. For instance, geospatial information plays a vital role in the 'Framework for a Public Health Emergency Operations Centre' as published by the World Health Organization.[4] As such, geospatial data and technologies are seen as the backbone in response to and recovery from emergency incidents, and also as part of the process for spatial risk assessments. Similarly, UNICEF has published a guidance document on the use of geospatial data and technologies in immunisation programmes with specific implementation guidance for countries such as Kenya and Myanmar.[5] These examples clearly highlight that geospatial information not only supports the development, implementation and monitoring of programmes across the world, but sits at the heart of achieving the 2030 Agenda for Sustainable Development.

Recent emergency incidents, such as the Ebola outbreak in Western Africa and the global Covid-19 pandemic, have significantly prompted large scale projects aiming to improve the opportunity, availability, quality and accessibility of geospatial data in support of sustainable development. For example, the Geo-Referenced Infrastructure and Demographic Data for Development (GRID3) project funded by the Bill and Melinda Gates Foundation and UK Aid which is being implemented in the Democratic Republic of Congo, Mozambique, Nigeria and Zambia.

In the digital age, geospatial information and technologies play a crucial role in leveraging the potential of the 'Fourth Industrial Revolution' to help solve global challenges. A recent UN report found that the world's LDCs are narrowing the digital divide by enabling access to mobile-cellular network and mobile broadband coverage.[6] However, what remains unclear is whether the development and adoption of digital technologies is evenly distributed within countries or whether parts of the population are excluded from these advances based on their geographic, socio-demographic and socio-economic status. Persistent digital divides impact on a nation's economic development, educational capacity, employment opportunities and social inclusion.

Digital transformation has been instrumental in democratising mapping information, making geospatial technology available to the individual by way of location-enabled devices. In an increasingly interconnected world, geospatial information has become integrated into everyday life. This can be seen through the daily use of smartphones and location-based services, to the growth in developments in self-driving cars, the Internet of Things, and satellite sensors. Taking advantage of this growing volume of location-based information, geospatial has become a game changer for local and national governments alike.

However, many developing nations continue to lack the infrastructure and trusted data to make informed business and government decisions. Governments at all levels require authoritative sources of fit-for-purpose data on the nation, its environment, assets, people, and its physical and social infrastructure to inform robust evidence-based decision-making and to encourage economic development, entrepreneurial activity, transparency, protection of privacy or national security.



Bridging the geospatial digital divide
Digital Twin
GeoAI
Volunteered geospatial information (VGI)
Unmanned aerial vehicles (UAVs)
Satellite data
Linked data
Sensor technology
Data visualisations
Authoritative, trusted data base
Interoperability
Data Cube programmes
Data integration, modelling, aggregation and fusion
Crowdsourcing
Open standards
Big geospatial data analytics
Geospatial knowledge services
Cloud computing
Point clouds
LiDAR
Global Navigation Satellite System
Indoor positioning systems
Real-time processing
Geospatial capacity
Urbanisation
Climate change
Education
Humanitarian assistance
Migration
Geopolitical uncertainties
Global economic downturn
Social media boom
Privacy concerns
Cyber security
National security
Smart Cities
Marine environment
Land management
Food security
Biodiversity
Population changes
Digital connectivity
Data economy
Automation
External influences
2030 Agenda for Sustainable Development
Decade of Ocean Science for Sustainable Development
New Urban Agenda
Sendai Framework for Disaster Risk Reduction
Convention on Climate Change
Addis Ababa Action Agenda
Small Island Developing States Accelerated Modalities of Action
Global agendas

1. Drivers and trends in geospatial information management

The advent of the Fourth Industrial Revolution, digital transformation, and the disruptions that have come with them have changed many business practices, provided new technological applications, and have brought about a data revolution, impacting both the cultural, social and economic realm. Ultimately, creating a world that is becoming increasingly interconnected.[7]

As the data ecosystem becomes more complex, the notion that 80 per cent of information has a spatial component increases the relevance of the 'where'.[8] The geospatial industry is as much influenced by these developments as any other sector which shows that operating in an industry 'bubble' will erode the competitive advantage of the organisations functioning within it.

The view of 'everything happens somewhere' will drive many of the changes in the global economy as geospatial enters the mainstream. Developments in location-based applications offered by non-geospatial businesses have transformed how services are consumed, and the rise of autonomous systems has shaped the increasing need for near real-time information. The next five to ten years will see an unprecedented change in the way in which geospatial information will shape and be shaped by the global economy.

1.1 Setting the scene: The geospatial industry in the global economy

1.1.1 The pace of change and the vastly dynamic, global environment in which the geospatial industry operates has a significant impact on the need for current high-quality geospatial information for national resilience and effective administration, to name but a few.

1.1.2 Assessing the trends that are likely to have the greatest impact on geospatial information management, the report sets out several patterns of political, economic, social, cultural, technological, and environmental change that will influence the state of the global geospatial industry in the coming years.

1.1.3 **Global pandemic** – The COVID-19 pandemic has emerged as an unprecedented crisis that has gradually affected all people in all countries with global impacts and consequences. The effects of the crisis highlight the interconnectedness between public health, society, economy, and environment. National governments around the world are utilising geospatial information to manage this unprecedented public health emergency.

1.1.4 **Political realities** – Geopolitical uncertainty is on the rise and is anticipated to remain a source of risk for large and emerging economies alike. One of the main factors that has arisen over the past five years has been the re-emergence of country-level economic policies towards increased protectionism which primarily affects trade and the financial markets. Considering the already existing public finance pressures, government organisations across the world will continue to have to demonstrate value for money to safeguard their funding arrangements.

1.1.5 Taking account of the upsurge in platform business models, the evolution of sensor networks and the social media boom, regulators seek to balance innovation and consumer protection in the digital era. National governments and supranational organisations are projected to put in place policies and guidance to secure the personal privacy of the individual without hampering innovation over the long-term.

1.1.6 **Economic outlook** – Global economic growth had slowed in 2019, and collapsed in 2020 as a result of the substantial negative impact of the COVID-19 crisis. It will take years to recover from the current economic recession. This economic downturn has been accelerated due to the COVID-19 pandemic and predictions show that this development will have a long-lasting impact around the world. Nonetheless, the changing dynamics in global economic growth towards emerging and frontier markets are expected to fuel the global economy in the longer term.

1.1.7 It is expected that large cities will continue to be the major drivers of any growth in national GDP. The speed of urbanisation and the recognition that managing the consequences and realising the opportunities requires disaggregated geospatial data is leading to a propensity of city municipalities to buy in high-quality geospatial services and insights rather than develop the capability in-house from scratch.

1.1.8 **Population change and shift in values** – Populations across the globe continue to become more urbanised with an estimated 730 million people living in cities by 2030, leading towards requirements for improved physical, economic, social, and environmental infrastructure both within cities and between cities.[9] It is projected that by 2030, there will be 38 megacities with populations of over 10 million and rising. This new infrastructure will need to be capable of handling a society that continues to age with estimations showing that the number of people aged 60 years or over is projected to grow globally.[10] Population trends relating to urbanisation, ageing and migration – combined with economic and technological changes – have led to a demographic shift that reshapes the values, attitudes and necessities of future generations.

1.1.9 Today, the smartphone has become a ubiquitous part of people's daily lives with two-thirds of the world's households owning a smartphone device. Improvements in connectivity have promoted the use of Apps and increased the amount of data produced and consumed. Speed, convenience, and instant access to information are driving expectations around seamless and integrated user experiences.

1.1.10 **Technological developments** – Digital connectivity underpins most of the technological advances today, and mobile internet access has enabled many emerging economies to leapfrog fixed-line network infrastructure. Reliable digital connectivity enables advancements in Artificial Intelligence, immersive technologies, and the Internet of Things to transform how the geospatial industry captures, creates, maintains, manages and offers data over the next decade and beyond. Moreover, future business opportunities around Big Data, analytics, machine learning, platform economies, digital ecosystems and smart cities are significant and geospatial information are the underpinning component of these offers.

1.1.11 As the number of digital devices increases - from smartphones and watches to autonomous vehicles connected to the Internet of Things - the volume, value, variability, variety, velocity, and veracity of data will continue to grow exponentially. However, the exact impact of technological developments, integrated applications, and data abundance on the geospatial industry and the global economy remains unclear; it can be expected that data collection and data analysis will drive capacity-building and evidence-based decision-making over the next decade.

1.1.12 **Environmental pressures** – The impacts of climate change continue to devastate lives, communities and economies all over the world, as international migration becomes increasingly linked to climate-induced factors. However, with population growth, rapid urbanisation and further industrialisation, the demand for natural resources especially water and food production continue to grow and increase environmental problems such as air pollution and waste; ultimately, creating further environmental pressures and threatening resource security. The most visible effects include changing weather patterns, sea-level increase and water stress, deforestation, reduced crop yield and biodiversity loss. Geospatial information and technology have been applied to all these scenarios to combat, monitor and mitigate the impact of those factors and may receive a boost due to the upcoming negotiation of a post-2020 Biodiversity framework.

1.1.13 Many governments and businesses, in particular the insurance sector, are already investing significantly in mitigating and preparing for the effects of climate change. Insurance businesses are attempting to account for climate change in their financial risk portfolios, and it is anticipated that national and local governments as well as international donor community will increasingly invest in the preparation for and planning of disaster mitigation and response. Both geospatial data and analytics capabilities will be required on a greater scale to support these efforts.[11]

1.2 Top geospatial drivers and trends: Assessing the five to ten year vision

1.2.1 In light of the Fourth Industrial Revolution, geospatial information management is increasingly influenced by global mega-trends like urbanisation, population growth, and digitisation that are contributing to the long-lasting impact of these developments. Many aspects of geospatial information have become mainstream. As technological developments break down barriers, many of the specialised skills are no longer industry-specific; and, the emergence of vast data ecosystems provide opportunities to develop new solutions to engage with users. To keep abreast of trends in geospatial information, the regular revision and assessment of their implications remain relevant.

1.2.2 Drawing on the information received throughout the consultation process and the views expressed during the discussion fora, the report has identified the top trends that are likely to affect geospatial information management over the upcoming decade. The trends have been divided into five overarching industry drivers as shown below in Table 1. The report provides a consensus view for the professional geospatial community with the aim to forecast how these drivers are expected to evolve over the next five to ten years. However, the table is not exhaustive and more detail on the trends discussed in this section as well as further industry developments are highlighted in the chapters that follow.

1.2.3 This assessment of drivers and trends enables countries to choose the trends that are likely to have the greatest impact on their future development. This prioritisation of trends will allow for the development of national strategies that focus on the successful implementation of the trends. Each trend will have a different level of impact on geospatial information management as some trends will not affect every geographic region or industry segment equally. Thus, the trends have been mapped on a matrix to highlight the level of predictability on one axis and the potential impact on the other. The matrix intends to provide an overview of the effect each of the top trends is likely to have on the industry (Graphic 1). The impact and level of predictability is based on the analysis of the expert contributions received and documents provided.

1.2.4 Overall, this high-level analysis shows that despite being driven by technological developments and the availability of new data sources and analytical methods, the industry is influenced by a much broader set of drivers. It appears certain that a data-driven society will fuel innovation which is central to growth within organisations and nations. Such innovation will be underpinned by developments in the areas of connectivity, interoperability of data and metadata, sensor networks, data processing and analytics, and cloud computing.

1.2.5 Other trends highlight the wider impact on society, business, and policy. Nonetheless, in terms of impact and predictability, no one single geospatial driver is advancing change in the global geospatial information management landscape. It is the combination of all the trends across the five industry drivers that are shaping the transformation of the industry over the next five to ten years.

Table 1. Geospatial Drivers and Trends

Trends

Drivers: Rise of new data sources & analytical methods

- Relevance of ***data integration and interoperability*** increase
- Products and solutions produced from ***multiple data sources*** becoming the norm
- ***New opportunities for data gathering***, i.e. autonomous vehicles
- ***Crowdsourcing and VGI*** become established ways of data collection
- ***High-resolution high-revisit Earth Observation*** data become valid alternative to aerial imagery
- ***Big Data processing*** has become a normal path of geospatial data processing
- Integration of multiple data sources requires ***licensing harmonisation***
- ***Digital platforms*** provide access to data at scale
- ***Linked Data*** enables knowledge-on-demand

Drivers: Technological advancements

- ***Ubiquitous connectivity*** enables deployment of new tech
- ***Digital infrastructure*** through sensors and IoT
- Interconnecting modes of transport through ***intelligent mobility***
- ***Digital Twins*** for modelling, simulation and prediction
- Wide uptake of ***edge computing*** to enable intelligent mobility, the IoT, and smart cities
- ***Visualisations and immersive technology*** widely used to enhance customer experience and decision making
- ***Machine learning, deep learning, and AI*** disrupt geospatial production
- ***Data cubes*** can deliver analysis ready data
- ***Quantum computing*** enables intensive processing

Drivers: Evolution of user requirements

- Rise of products and services specifically designed for the ***urban environment***
- Demand for ***real-time information*** provision
- ***Digital divide and exclusion*** continue to hold back universal digital transformation
- Seamless experience between ***outdoor and indoor mapping*** becomes an expectation
- Viable integrated ***Smart City*** solutions becoming wide spread

Drivers: Industry structural shift

- Increased ***diversity at work*** in technology, science, and innovation
- ***Talent and consumer shift*** - changing values and attitudes
- ***Incubator spaces*** enable innovation to enter markets swiftly
- ***Regeneration of business ecosystem*** through the rise of non-geospatial start-ups
- ***New collaboration agreements*** with industries outside of geospatial emerge

Drivers: Legislative environment

- ***Digital ethics and privacy*** addressed by national and international initiatives
- ***Cybersecurity*** conversations increase in tandem with increase in digital devices
- ***Pace of digital and tech change*** puts pressure on national institutions to address policy and legislative shortcomings
- ***Pressure on government institutions*** to be more tech and digital savvy

Drivers

Graphic 1.

Five drivers will advance change in the global geospatial information management landscape over the next 5 to 10 years

1.3 Technological advancements

1.3.1 Innovation has driven many technological developments in recent years. In particular, disruption in geospatial information management is driven by automation, Artificial Intelligence, sensor technology, and the Internet of Things. In addition, advances in technology such as high-performance cloud computing, ubiquitous high-speed connectivity, new sensor networks and sensor platforms, geospatial analytics, and autonomous smart machines have created a shift towards a more machine-centric world. This machine-to-machine world is about location-based computing and outcomes in an essentially “mapless” environment.

1.3.2 These developments have fuelled and will continue to fuel an explosion in the volume and currency of data, driving down the cost of data capture. With new developments in intelligent transport systems (ITS) and the growth of Big Data and Big Data mining, there has been a significant increase in the demand for geospatial information, particularly highly detailed, (near) real-time data. Aside, developments in BIM enable urban planners to monitor the building information, facilities, infrastructure, and indoor environment to enable seamless indoor-outdoor mapping, modeling, and data handling.

1.3.3 5G is seen to be one of the most influential changes in recent years. It is expected that 5G will bring about an increase in the capacity for information exchange. This includes higher data exchange speed in latency time or time required to establish the connection between user and server, in addition to the frequency allowing broadband to be about 1000 times faster per unit.

1.3.4 In the last few years, a substantial rise in Digital Twin projects across North America, Asia, Australia and Europe has been observed. Aiming to improve the efficiency of urban planning and management, enabling informed decision-making, and gaining insight from multiple datasets are central drivers for city municipalities, the application of this technology will continue to spread across the world. Aside, developments in BIM enable urban planners to monitor the building information, facilities, infrastructure, and indoor environment to enable seamless indoor-outdoor mapping, modeling, and data handling.

1.3.5 Although quantum computing is still in the research and development (R&D) stage of its development, geospatial industry experts anticipate the technology to have great impact on intensive processing. Early applications show promising results in areas of connected and autonomous vehicles (CAVs).

1.4 Rise of new data sources & analytical methods

1.4.1 It is anticipated that mobile data collection, crowdsourcing, and social media are likely to have the greatest impact over the coming decade. These forms of data collection will enable accurate, (near) real-time applications that are increasingly demanded by various users of geospatial data.

1.4.2 The availability of low-cost, high-quality, high-frequency Earth observation satellite data has contributed to the ever-increasing volumes of data. Combined with Artificial Intelligence and computational capabilities, developed and developing nations will witness productivity increases in the processes of data obtaining, maintenance, and management.

1.4.3 This variety of data licences represent a real barrier to interoperability and solution development based on different data sources. Integrating different datasets when the terms of the licences differ remains a significant challenge. Over the next decade, the industry anticipates the developments in licensing harmonisations towards a set of simple, standard and concise licences.

1.5 Industry structural shift

1.5.1 Geospatial information management has undergone significant disruptive change in terms of map generation technologies, use cases, business models, and user requirements. Expertise in consolidating large numbers of data sources, understanding of mapping requirements, and new toolsets developed to automate map creation will be critical for the future. In addition, on-demand mapping, generalisation and topological reconstruction will be more focused.

1.5.2 Driven by the automotive industry and telecommunication, high-definition maps are crucial for the introduction of widespread ITS. Developments show that GPS-assisted tracking systems may be used for car tracking, traffic control and monitoring for alternative road selection on demand. This technology can assist moving object modeling and mitigate the number or severity of car accident and fatalities. Consequently, the automotive industry has been identified as one of the future markets of choice for many geospatial businesses that are offering data and solutions through partnerships and R&D collaborations with vehicle manufacturers and academia. Car-generated data offers much opportunity and is predicted to be one of the fastest growing markets of the future.

1.5.3 In terms of skillsets, automation and Artificial Intelligence applications will enable employees to be freed up from monotonous tasks that machines take over enabling the workforce to upskill or reskill to perform higher value tasks.

1.6 Evolution of user requirements

1.6.1 The internet, mobile devices and the growing number of location-based services means that an increasing number of users have constant and direct contact with geospatial information. Demand for near real-time data is driven by the expectation of instant and frictionless access to information on mobile devices.

1.6.2 City municipalities have emerged as a highly engaged user of geospatial information, particularly since the rise of smart city solutions and Digital Twin technology have become available. Early examples of digital representations of city infrastructure have enabled municipalities to monitor and simulate scenarios related to climate change and flooding events while mitigating risks and increasing infrastructure resilience

1.6.3 This focus on the urban environment will continue to drive the development of viable integrated smart city solutions across the world.

1.7 Legislative environment

1.7.1 The increasing number of connected devices and data volumes have also started to raise questions around data privacy and cybersecurity which may lead to calls for changes to the legislative or regulatory environment to be addressed in some way.

1.7.2 The Cambridge Analytica and Facebook data scandal in 2018, has led to calls for tighter data privacy regulations and data ethics frameworks. National governments and international institutions alike have created guidelines on ethical considerations when using geospatial data and technologies.

1.7.3 There is evidence that the immediate reaction to disruption is often to introduce legislation to address perceived risk before the potential benefits are understood and a balanced approach to the legislation can be developed.

1.8 The impact of the trends on the Integrated Geospatial Information Framework

1.8.1 The third edition of the Future Trends report complements the IGIF. It helps to ensure that the Framework integrates and takes advantage of the latest innovations and trends.

1.8.2 Table 2 below cross-references the top trends against the nine strategic pathways of the IGIF. Based on the distribution and crossovers, it could be argued that priority should be given to those pathways that are likely to see the most amount of change.

1.8.3 Unsurprisingly, the *Innovation* and *Data* pathways, accompanied by the Standards pathway, received the most coverage in the impact assessment table (Table 2). Nonetheless, it is notable that all trends relate in some way to each of the individual pathways.

1.8.4 For instance, the *Capacity* and *Education* pathway will be impacted by all trends to a greater or lesser extent. The geospatial industry, in collaboration with academia, will need to ensure that all trends are considered to develop capacity and improve education programmes that will enable the industry to remain relevant in the global economy.

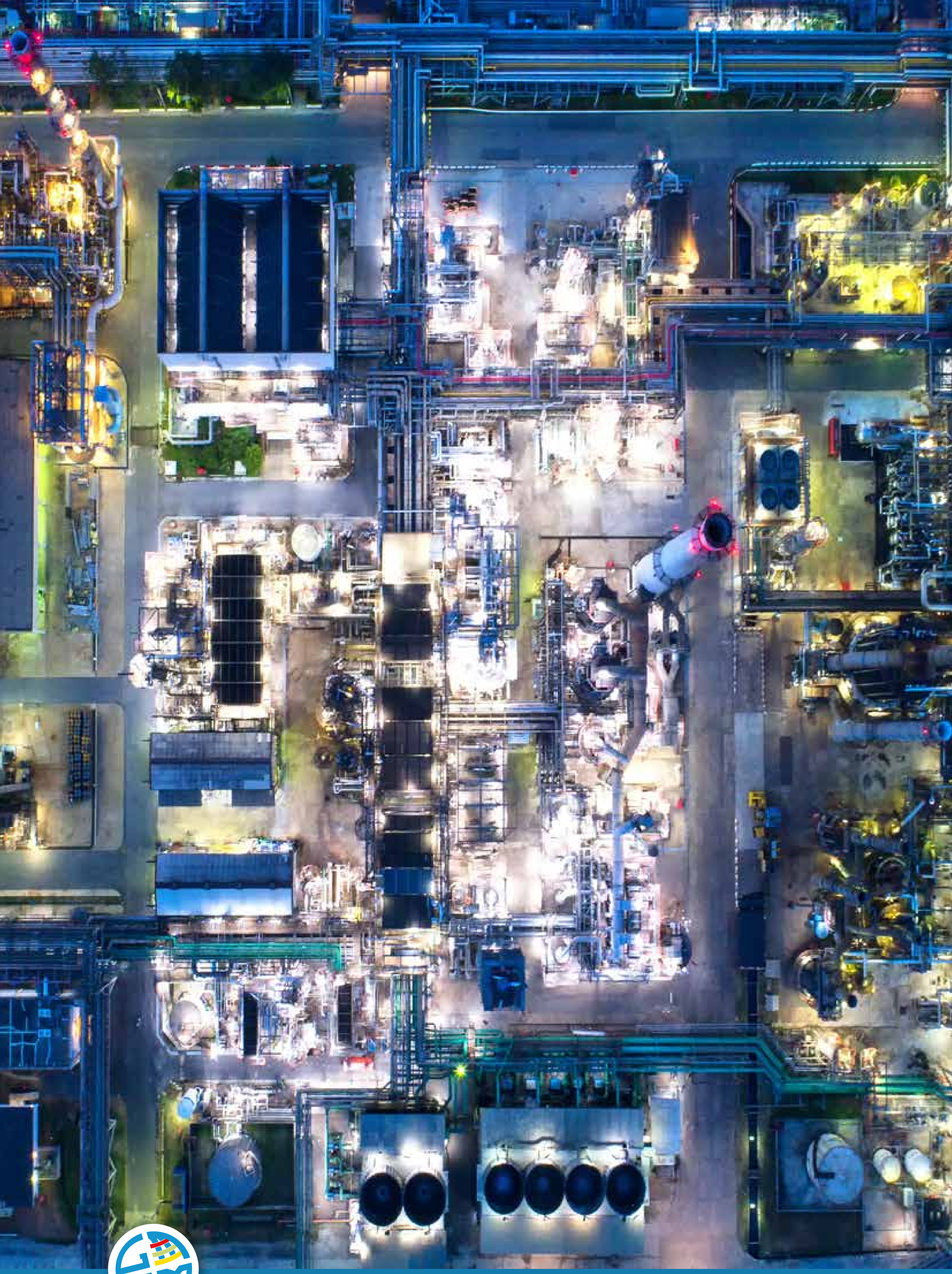
1.8.5 Another pathway that will see significant transformation is the Policy and Legal pathway. In relation to technological advances, developments such as edge computing and machine learning are likely to become legal issues and will be a new area of concern for the geospatial sector. In particular, the areas of cyber security, privacy and data sensitivity will need to be addressed as machine-to-machine processing will trigger new intelligent data that has the potential to expose sensitive information or assets. Recent examples of fitness apps exposing patterns of behaviours highlight the criticality of keeping abreast of the impact of innovation.

1.8.6 Ultimately, decision makers, institutions, and organisations working on a national approach will inevitably be tracking and studying the dynamic developments in the above. As an integrated framework, the IGIF provides strategic pathways and offers a new mechanism for countries to build upon to further strengthen geospatial information management and guide their transformational change.

Table 2. Trends - IGIF Pathways impact assessment

Key Trends (IGIF Pathways)	Governance & Institutions	Policy & Legal	Financial	Data	Innovation	Standards	Partnerships	Capacity & Education	Communication & Engagement
Technological advancements									
Ubiquitous connectivity enables deployment of new tech				●	●			○	
Digital infrastructure through sensors and the IoT	○			●	●	●			
Interconnecting transport through ***intelligent mobility***				●	●	●			
Digital Twins for modelling, simulation and prediction				●	●	●			
Edge computing for intelligent mobility, IoT, smart cities		●		●	●	●			
Immersive tech and visualisation for decision making				●	●			○	
Machine & deep learning, AI disrupt geospatial production				●	●	●		○	
Data cubes can deliver analysis ready data				●	●	●		○	
Quantum computing enables intensive processing				●	●	●		○	
Rise of new data sources & analytical methods									
Relevance of ***data integration and interoperability*** increase	○			●		●			●
Products/solutions from ***multiple data sources*** the norm		○		●		●			
New opportunities for data gathering; autonomous vehicles				●	●	●	●	○	
Crowdsourcing and VGI become ways of data collection	○			●	●		●	○	
High-res-revisit Earth Obs data valid alt to aerial imagery				●	●				
Big Data processing normal for geospatial data processing				●	●	○			
Integration multi data sources needs ***licensing harmonisation***		●		●		○			
Digital platforms provide access to data at scale		●		●	●		●		
Linked Data enables knowledge-on-demand	●	●		●	●	●			
Industry structural shift									
Increased ***diversity at work*** in STEM								○	●
Talent and consumer shift - changing values and attitudes					○			●	○
Incubator spaces enable innovation to enter markets swiftly			○	○	○		●	○	
Regen of business ecosystem; rise non-geospatial start-ups					●		●		
New collab agreements industries non-geospatial emerge							●		○
Evolution of user requirements									
Rise of products/services designed for ***urban environment***			○	○	○				
Demand for ***real-time information*** provision		○		●	●	●	○		
Digital divide/exclusion slows universal digital transformation	○				○			○	
Seamless experience between ***out/indoor mapping*** expected				●	●	●			
Viable integrated ***Smart City*** solutions become widely spread			○		●		○		
Legislative environment									
Digital ethics/privacy fixed by nat/international initiatives	○	●		○	○		○	○	○
Cybersecurity/digital devices conversations increase in tandem		●							
Digital/tech change; address policy/legislative shortcomings		●			●				
Government institutions to be more tech/digital savvy	●	●	○		●			○	○

● Major level of impact ○ Minor level of impact



2. The digital infrastructure of the future

The digital data infrastructure is becoming as relevant as the features of the physical environment, but it is the densely populated and resource intensive areas - cities - where the greatest drive towards utilising this infrastructure can be experienced.

Highlights:

- Advances in next-generation mobile communication technology allow for speeds of up to one gigabyte per second, revolutionising data exchange;
- Digital Twins and data exchange enhance and optimise the real-world by monitoring and simulating scenarios to mitigate risks and increase resilience, and may also allow real-time information intervention;
- Visualisations and immersive technology enhance the way in which people interact with the environment and will increasingly inform decision-making alongside other use cases;
- Edge computing enables reliability, mitigates risk and facilitates situational awareness of autonomous systems; and,
- Data and semantic interoperability are key challenges that need to be overcome through the application of common standards.

2.1 Ubiquitous connectivity

2.1.1 Connectivity has been described as the most critical enabler of digital transformation over the next 10 years. The advent of fifth generation (5G) mobile communication and its ability for large amounts of data to be transmitted at higher speed is likely to change how the geospatial industry operates and would enable a raft of emerging technologies to reach maturity. These include the ever-increasing number of connected devices, CAVs, Artificial Intelligence, immersive technologies, as well as Digital Twins. It is the ubiquitous connectivity, through ultra-fast speeds and low latency, which will facilitate near real-time massive machine-type communication between intelligent machines without human input. It is expected that as deployment reaches its technological and commercial maturity, the impact of 5G will improve the productivity, efficiency and effectiveness of companies and public administrations.

2.1.2 Interestingly, the deployment of 5G is also a prime example of the relevance of location intelligence in enabling emerging technologies. By creating a dynamic 3D digital map of the physical environment – the ‘Digital Twin’ concept will be discussed later in this chapter – and incorporating additional high-resolution features such as street furniture, building material, vegetation and weather conditions, spatial planning can be conducted effectively allowing for 5G small cell technology to be deployed economically.

2.1.3 Nonetheless, one of the biggest remaining barriers to the implementation of 5G is the speed of its deployment. Due to high investment requirements, Return on Investment (ROI) uncertainties, and ongoing standardisation, the timeframe for wide-scale 5G deployment falls some time into the 2020s but will largely depend on the willingness of national governments and telecommunication providers to deliver the necessary infrastructure.

2.1.4 Despite its benefits, connectivity is unlikely to spread equally around the world. The digital divide and digital exclusion remain key factors in holding back ubiquitous global digital transformation. Although the capability of existing digital technology has improved and the number of connected devices have grown exponentially over the last decade, remote communities continue to lack access to digital devices, reliable Information and Communication Technology (ICT) and/or the digital skills to reap the benefits of this digital transformation. This trend can be observed in high, middle, and low-income countries as funding is mostly linked to the urbanised economic centres of a nation. Those living on the periphery will continue to experience the impact of lacking access to digital means on public services, economic and employment opportunities, and political empowerment.

2.2 Conceptualisation and realisation of Digital Twins

2.2.1 The last edition of the Future Trends report thoroughly introduced the concept of smart cities and the Internet of Things as a result of the increasing pace of urbanisation. Although the meaning of 'smart' still comes in various guises, it can be viewed as a proxy for several elements described throughout this report namely as a data-driven society, citizen centricity, technology enablement, digital ecosystems, place-based decision making, economic growth, sustainability, resilience and public security.

2.2.2 Ongoing urbanisation is likely to have a major impact on cities across the world. These include, the need to plan and build new infrastructure or to effectively manage the existing infrastructure to support an expanding population; the need to utilise existing resources, infrastructure, and services in a more resilient and sustainable way to support increased demand and maximise ROI; and, the need to apply authoritative data to support effective decision-making. As noted earlier in the report, data-driven societies, data-driven innovation, and data-driven decision-making will be central to the operational overhaul of the urban environment.

2.2.3 Today, sensor networks are increasingly common in cities providing near real-time information on temperature, moisture, noise and pollution levels, enhancing efficiencies and enabling data-driven decision-making by both public and private stakeholders. Real-time information applications already assist many municipalities in their decision-making processes and there is an ever-growing need for status updates on one or more devices to be as timely as possible. However, there are limitation of sensor networks regarding the energy required, their coverage, and the sensors localisation optimisation. As digitalisation improves, real-time information will assist more organisations in their everyday processes, particularly those responding to emergency events, such as disasters and disease outbreaks, such as the COVID-19 pandemic. The ability for smart city services to be built upon high-quality geospatial base data which is required to plan, build, operate and maintain assets will enable many future high-value services to be developed to enable smart cities.

2.2.4 The concept of the city Digital Twin is progressing rapidly, and it is almost impossible for effective urban planning to take place without the availability of sensors, image capture and processing, and data analysis technology. Essentially, a Digital Twin is a digital representation of a physical asset that enables users to visualise it, check the asset's status, perform analysis and generate insights in order to predict and optimise its performance. In comparison to static 3D models, Digital Twins are directly linked to multiple data sources and receive updates continuously. Early examples of digital representations of city infrastructure have enabled municipalities to monitor and simulate scenarios related to climate change and flooding events while mitigating risks and increasing infrastructure resilience.

2.2.5 Digital Twins are set to enable an asset-centric approach helping to model, simulate and predict the performance of assets, systems and processes within the urban environment and when fully integrated should provide autonomous operations and maintenance. Described as the highest form of Digital Twin maturity, the technology will enable complete self-governance and offer transparency by minimising cost, improving productivity, lowering environmental impact, reducing operational risk and improving operational reliability.

2.2.6 Although belonging to different domains, Geographic Information System (GIS) and Building Information Modeling (BIM) will likely converge as users are increasingly expecting a seamless experience between indoor and outdoor mapping. The Second edition of the Future Trends report touched upon the integration between outdoor and indoor positioning. It referred to the issue of traditional mapping providers stopping mapping and several industries are likely to be impacted by developing a seamless indoor-outdoor experience. Nonetheless, the challenges in bringing those different domains together continues and are described later in this chapter.

2.2.7 Over the long-term, advances to Digital Twin technology is expected to enable machines to design, build and operate its real-world equivalent in a highly efficient and effective way. Machines will be able to process and analyse vast quantities of data gaining insight and understanding that goes beyond the human capability. Thus, machines will automatically run unlimited diagnostics and models against the Digital Twin to enhance and optimise the real world. Looking beyond the next five to ten years, humans and machines are likely to co-exist, interoperate, and collaborate to solve real world problems, such as flooding events, water shortage and efficient agriculture.

2.2.8 This will mean a paradigm shift in the way geospatial data and metadata are collected, managed, represented and exploited. It can be expected that data capture will almost exclusively be driven by interconnected devices, while smart software will dominate the data exploitation space. Existing examples of digital representations of urban environments have shown that the future of smart cities will be significantly less effective without the digital representation and related context of geography, whether that is to support future domains such as BIM, digital asset management, 3D land and property cadastre, utility services, intelligent transport systems, integrated mobility, defence and intelligence, public safety, or security.

2.3 Intelligent transport systems and edge computing

2.3.1 One of the areas in the smart city and Digital Twin domain that has received significant attention and investment by public and private bodies is the enablement of ITS. Arguably, the geospatial industry needs to answer three significant questions: (1) How will this development change the mapping requirements that users of ITS are likely to experience?; (2) How can geospatial technologies enable ITS?; and, (3) How can the geospatial industry consume and use the data that is collected by ITS? Over the long-term it is likely that mobility plans based on geospatial information may be implemented.

2.3.2 There are opposing views on the requirements for the development of ITS and automated driving. While the automotive industry conducts extensive trails of automated navigation based on the built-in car sensors, some argue that a digitally connected navigable road network that holds information on street-level features like lamp posts, pedestrian crossings and road markings with resolution better than 5cm will be required. Due to the predicted mixture of vehicles operating at different autonomy levels, it is considered that real-time information updates will be crucial to allow CAVs to observe temporary objects and obstacles in the road.

2.3.3 Today, trusted geospatial data enables the acceleration of the development, deployment and safety of CAVs. Location data for planning and testing in a synthetic environment also provides geo-references in places where full connectivity and sensor feeds cannot be guaranteed. By the end of the 2020s, it is anticipated that the sensor technology inherent in CAVs will be sufficient to fully operate independently. When fully connected to other vehicles (V2V), to infrastructure (V2I), or to the surrounding 'smart' environment (V2X), CAVs may not require any additional location data to safely navigate on public roads.[12]

2.3.4 With many global players working on CAVs, several descriptions for routing and road attributes have arisen which do not always match. To ensure interoperability of systems and designs, common terminology and standards must be developed when modeling, testing and ultimately vehicle-proving on public roads and footpaths is to take place safely. Consistent definitions for road geometry are required. A simple but illustrative linguistic example is the use of the term sidewalk in the US and pavement in the UK.

The collaboration and involvement of relevant national and international standards bodies will be vital for defining and maintaining a set of common terms.[13]

2.3.5 But the CAV concept is not limited to land traffic. Autonomous sensor carrier help to survey the seas and oceans, to inspect underwater cables and pipelines and search for underwater obstacles. It can be foreseen that autonomous short track shipping along coasts will be introduced within this decade. The requirements in density, accuracy and up-to-dateness of information are not as strict as for land operations. However, to maintain the required quality level of geospatial information under the harsh marine conditions and the sole reliance on satellite-based communication needs further improvement along the whole chain of information gathering, processing and dissemination. Special regard is to be placed to the crossover from marine-based charting and land-based Mapping as one continuous surface. Automatic berthing, charging and discharging of cargo depends on smart combination of sensor technologies and geospatial information such as mapping requirements for seabed topography and machine interpretable quality indicators.

2.3.6 The emergence of CAVs has brought about a focus on the so-called mission-critical environments in which the inherent latency in connecting to a centralised cloud computing system would render any ITS unsafe. Overall, this is leading to a shift from a centralised structure to distributed systems – or short, a shift from the cloud to the edge. This means that real-time data processing and the execution of the service will happen locally on the device (and for CAVs and other applications on nearby edge nodes/servers to reduce latency), while the different variations of Artificial Intelligence will continue to run in the cloud.[14]

2.3.7 Applications that extract moving objects in street view for navigation, autonomous decision-making and safety will have the ability to perceive the environment around itself. Therefore, any autonomous system will require to process the data it captures locally which makes edge computing a mission-critical enabling technology for successful ITS. Put simply, Artificial Intelligence refers to a variety of algorithmically trained computing models such as machine learning, natural language processing, robotics, and computer vision that are being applied to various geospatial applications ranging from object recognition to real-time motion detection. Although the next chapter will address Artificial Intelligence and machine learning more thoroughly, it is notable that in the case of CAVs navigation and object recognition data need to be processed locally as latency, distance and the unpredictability of connectivity would prohibit safety and autonomous decision-making if conducted in the cloud.

2.3.8 To enable reliability and efficient data processing, a cloud-edge feedback loop has been proposed to consistently feed data captured by sensors about the physical world into the digital model. As the data is analysed and insight is gained, immediate data-driven actions can be taken reducing the time and improving outcomes which are at the heart of enabling smart change.[15]

2.4 Visualisation technology and immersive experience

2.4.1 Geospatial technology has always been able to visualise complex data relationships. Yet, new immersive technologies are revolutionising how users interact with digital information by enabling real-time 3D representations and immersing the user in digitally generated or enhanced realities. The two most widely used immersive technologies are virtual reality (VR) – a fully computer-generated simulation of a 3D environment – and augmented reality (AR) – a reality-based environment that is overlayered with computer-generated effects, display or text that enhances the users' real-world experience. These technologies enable the user to interact with simulations and visually relate to the information sensors provide. Examples include the merging of the real world and computer-generated virtual layers which can be used to visualise existing structures alongside planned ones.

2.4.2 The combination of geospatial data, virtual reality software and other datasets makes it possible to experience a built environment before it has been constructed. As advances towards creating Digital Twins are made, this new functionality would be likely to enable a virtual representation of a place or building that can be navigated via a VR headset.

2.4.3 The application of AR has seen the most progress in recent years as the likes of Google and Microsoft are extensively investing in the AR headset technology. It is anticipated that from the early 2020s this type of eyewear will start to move into the mainstream as the cost of the technology decreases and the first application industries utilise these headsets. For instance, the Architecture, Construction and Engineering (AEC) industry are likely to be one of the first sectors to start visualising building plans holographically on site.

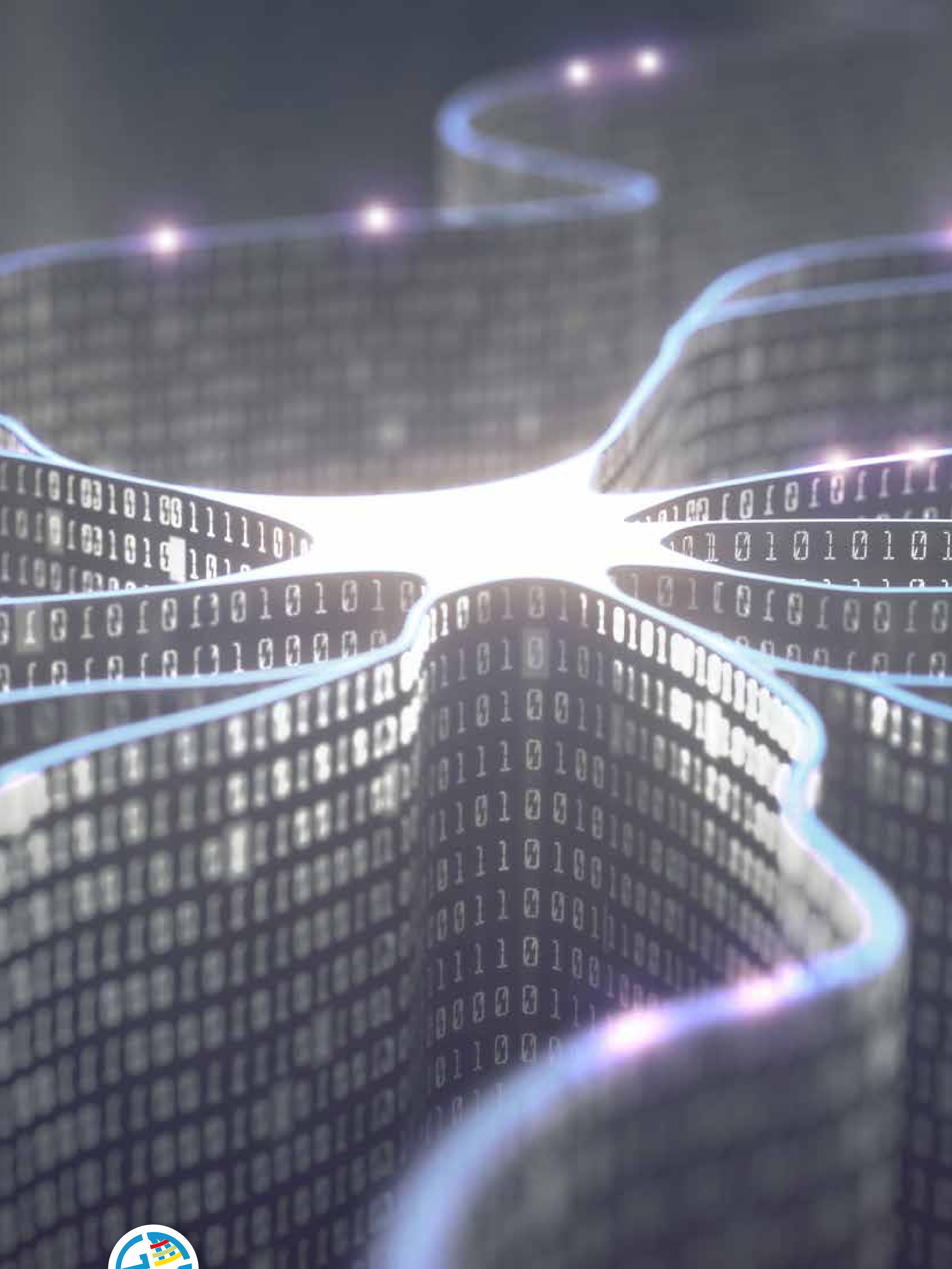
2.5 Building collaboration with standards

2.5.1 Enabling effective collaboration between the stakeholders responsible for different aspects of the urban lifecycle will require reworking how those stakeholder groups share data, exchange data, and build systems together. Spatial visualisation and data integration techniques are being developed and combined with other technologies - such as Artificial Intelligence and machine learning - so that systems are capable of ensuring the right information gets to the right people, at the right time, and crucially in the right format. However, some key challenges in the development of such systems remain.

2.5.2 The concepts and language used by stakeholders to describe the features and processes relevant to the domain has an impact on aspects such as the semantic structures – for instance ontologies and taxonomies – used to give meaning to the data, as well as the design and implementation of the tools for creating and storing data.[16] Between different stakeholders and especially between different domains, even small differences can result in significant difficulties making data sharing or exchanging almost impossible or at best, not without some loss of information or changes to the structure or meaning of the data.[17] This is likely to become one of the most crucial challenges faced by municipalities working towards smart cities and Digital Twins and other contexts where collaboration, trust and transparency are necessary for removing the boundaries and fragmentation we see between domains today.

2.5.3 One example relates to enabling the sharing and exchange of information between the AEC domain with geospatial professionals supporting several of different functions such as city planning and land management. The AEC domain creates much data and information using the technology and processes of BIM, whereas geospatial typically combines GIS and other technologies.[18] There is significant research literature on the topic of data interoperability between AEC and GIS; specifically, between the open 3D data standards of Building Smart's International Industry Foundation Class (IFC) for the AEC industry, and Open Geospatial Consortium's CityGML for geospatial. These two data formats, for the reasons described above, are still largely incompatible. However, efforts are being made to bring the two data formats closer together, such as the Integrated Digital Built Environment joint working group between OGC and buildingSMART to join technical experts from BIM and geo-domains to address this challenge.

2.5.4 Several projects and initiatives are supporting this effort, including a recent research project in Singapore, where the primary focus was the development of tools to enable the data exchange between stakeholders from the construction and geospatial domains. Such examples highlight how engaging domains together in the implementation and development of common standards, can lead to new forms of value and outcomes being achieved quickly



3. The rise of Artificial Intelligence, Big Data and data analytics

Data Science is a growing profession within geospatial information management that combines statistical and analytical techniques with computer programming and algorithm design to generate new and valuable insights from data.

Highlights:

- Continued developments in image recognition and feature extraction, coupled with reduced storage costs, will provide opportunities for faster data capture and maintenance of geospatial information, and will come closer in quality and usability to that which can be achieved by traditional survey methods;
- Increased automation and improvements in machine learning free up time-consuming and resource-intensive tasks leading to higher production efficiency;
- Big Data processing will be the norm as machine learning and deep learning mature and become established functions in geospatial production; and,
- Beyond the next ten years, quantum computing will enable more intensive processing of the increasing volume of location-related data.

3.1 Realising value through Big Data and data analytics

3.1.1 In the era of Big Data and with the increasing generation of real-time spatial data - including social media, the Internet of Things, and other interactive media - an overwhelming flow of data in structured and unstructured formats has emerged. Today, data is created at a rate that is faster than our ability to exploit the data for analysis, decision-making or problem-solving.

3.1.2 Big Data is characterised by the so-called four V's: volume, velocity, veracity and variety and may bring significant value (commonly referred to as the fifth V) through its processing. Consequently, Big Data requires specialised techniques for processing and analysis to extract knowledge. Data science as a discipline refers to the methods used to provide new insight from the analysis of Big Data.

3.1.3 Typically, data science is being used to produce new insights as well as improving operational efficiencies and enhancing decision-making. While the field of data science is proliferating, early results include capabilities beyond heat maps and track analysis. Nonetheless, the spatial dimension is increasingly being added in the data integration method that combines many types of data from various sources - ETL (Extraction, Transformation, Loading).

3.1.4 Overall, there are three main types of analytics: (1) *descriptive analytics* that uses data to describe, summarise and visualise information, as well as mining and aggregating current and historic data to gain insight; (2) *predictive analytics* that uses machine learning with data to make predictions and uses statistical and probabilistic techniques to predict future trends and outcomes; and (3) *prescriptive analytics* that recommends courses of actions to achieve an outcome by making decisions.

3.1.5 Predictive analytics is probably the most widely used modeling technique allowing decision makers to assess options, predict uncertainties, and assess the impact of one factor over another. Predictions offer insights into the likely outcome-based on the analysis of trends, data or patterns. As a result, decision makers will not only have access to what is likely to happen but also information on the impact of various decisions.

3.2 The potential of Artificial Intelligence in geospatial production

3.2.1 One of the biggest opportunities for geospatial information management over the next ten years is Artificial Intelligence - particularly, image analysis and information extraction. Geospatial Artificial Intelligence (GeoAI) is a sub-discipline of Artificial Intelligence that uses machine learning to extract knowledge from spatial data. With an exponentially increasing volume of remote and Internet of Things sensed data, automation is pivotal in enabling the effective processing of more and more data and achieving the goal of real-time data. Over the long-term, machine learning will be essential to deal with the growing requirements of an interconnected world. Automation is one of the initial steps in implementing Artificial Intelligence solutions.

3.2.2 Early adoption examples of data-intensive machine learning methods have shown the potential for more evidence-based decision-making across many industries and applications including health care, utilities, manufacturing, insurance, finance, and public services. Undoubtedly, Artificial Intelligence and machine learning will increase rapidly over the next ten years and its presence will be felt across the geospatial industry and application sectors. It will speed up processes, improve productivity and enhance decision-making procedures but at the same time will require careful adoption and quality assurance measures to ensure tractable decisions. Quality assurance and standards for Artificial Intelligence and machine learning are likely to see increased activities in this area as government bodies and businesses move away from feasibility studies and adopt machine learning into the geospatial production cycle.

3.2.3 Global companies like Google, Facebook and Microsoft are making significant investments in Artificial Intelligence. The areas receiving most interest is reasoning, knowledge, representation, perception, natural language processing, robotics and machine learning. In recent years, machine learning has gone through significant development cycles developing new algorithms that enables reinforcement learning – a branch of deep learning that focuses of how an agent in an environment can develop strategies on its own to complete a goal or set of goals. Applications of deep learning have predominantly focused on object recognition and imagery.

3.2.4 In terms of feature extraction and image recognition, machine learning operates in three main stages: (1) platforms ingest a variety of remote sensing data; (2) machine learning capabilities are developed by training classifiers on sample data to develop signatures for the target identification, classification and change detection; and, (3) these classifiers identify their targets and label them using high-resolution data.

3.2.5 As big volumes of satellite imagery are made available in the cloud, providing global spatial coverage with increasing granularity level (spatial and temporal resolution), both automatic change detection and feature extraction procedures can be performed through neural network algorithms applied to historic time series of images. The Open Data Cube described later in this report supports this kind of temporal analysis. As cloud processing services become increasingly cost-effective and accessible, it is expected that NMGAs will experience efficiency savings and productivity improvements over the next five to ten years.

3.2.6 Machine learning is an assistive technology that allows humans to harness automation improving speed and scale of formerly manual tasks. Developments in machine learning programmes are due to the increasing availability of data linked with high-performance computing power that enables the training of the algorithms in more realistic time frames, and with more data making them higher quality predictors. However, challenges remain around the availability and ratio of labelled training datasets and algorithms versus testing datasets in AI analysis of geospatial data.

3.2.7 There have been marked improvements in computer vision functions such as image classification and object recognition. Early applications include disaster risk response scenarios. Providing timely, dynamic and accurate mapping solutions are crucial in preparation, response and recovery phase of disasters; yet, the nature of disasters due to their scale and volatility have proven a challenge. Initiatives like the Humanitarian OpenStreetMap Team increasingly apply computer vision techniques to speed up and improve the accuracy of mapping data generation and dissemination delivering up-to-date maps for vast geographic territories.[19]

3.2.8 While industry organisations already provide these capabilities in the market, many NMGAs have been training models to classify objects in aerial imagery such as buildings, roof tops, roof types, solar panels, street furniture and further data at street level, to achieve fully automatic change detection of all changes in the built and natural environment over the long-term. The wholesale collection and maintenance of geospatial data themes via Artificial Intelligence by industry for government is likely to grow over the next decade. As society progresses toward real-time observations from sensor grids, technologies like edge analytics and fog computing will enable pattern recognition and interpretation from Big Data.

3.2.9 When trained thoroughly, algorithms offer scalability, speed and increasing accuracy freeing up the workforce to focus on high-value tasks as machines can search more datasets using more variables to discover patterns in a shorter timeframe than humans. The next five years will see government agencies and commercial businesses reassess their technical workforce capabilities and harness automation by educating their workforce on data science.

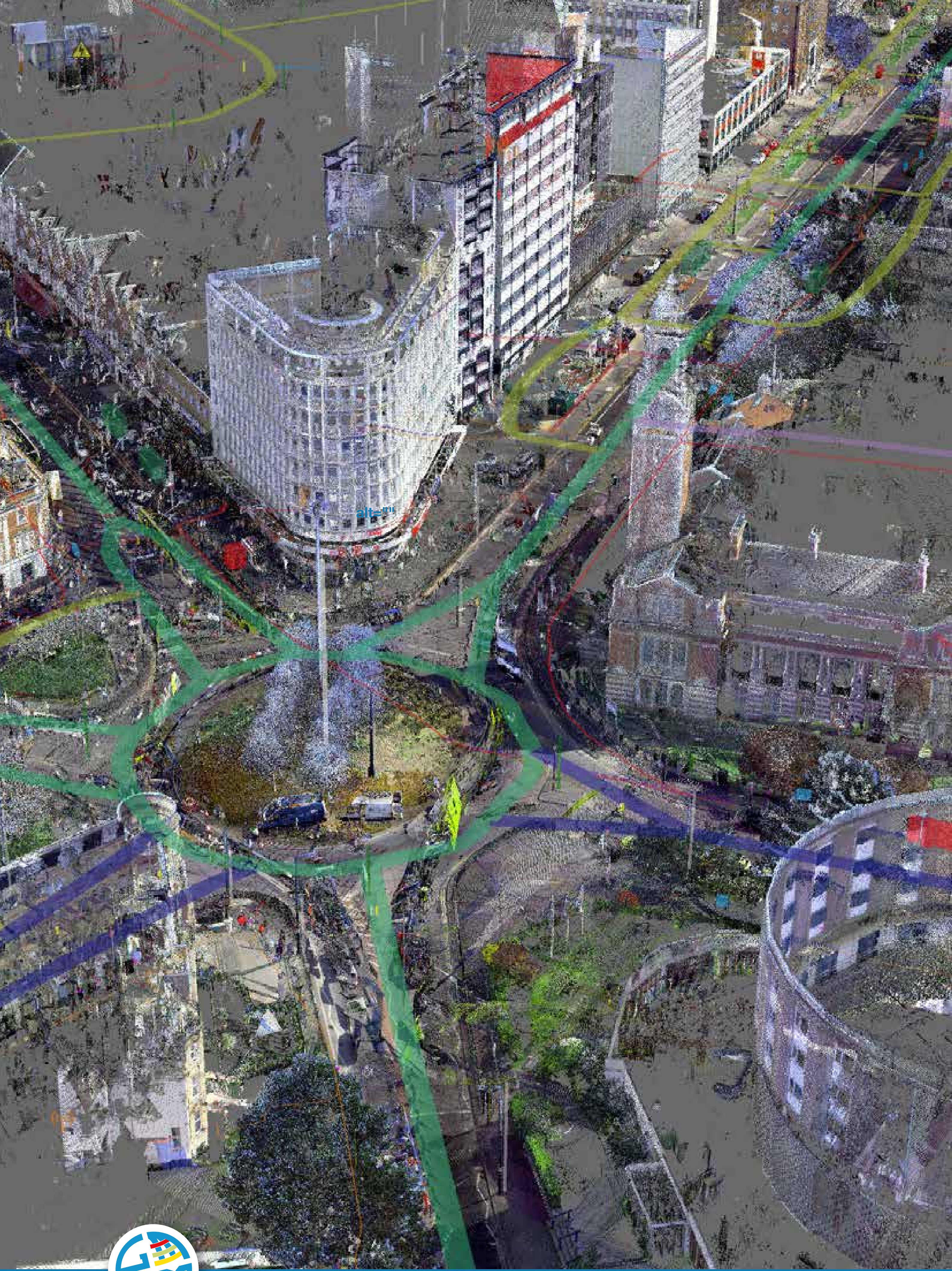
3.2.10 Ultimately, the technology drivers enabling advances in GeoAI can be summarised by three factors: increases in low-cost cloud computing; the availability of cheap sensor technology and the ongoing expansion of geospatial information; and, the development of new algorithms capable of leveraging multiple data sources.[20]

3.2.11 Developments in computing technologies, particularly quantum computing, are promising and provide significant opportunities for processing the increasing abundance of data. Still in the development phase, it is expected that the application of quantum computers could reduce the time it takes to search large unsorted datasets.

3.2.12 While useful GeoAI applications are increasingly being implemented, AI is still in a developmental stage. The level of interoperability and trust behind machine learning algorithms prediction remains a grey area. The overall confidence across the geospatial community in the results of machine learning remains moderate due to a lack of understanding in the algorithms applied and the extent to which the findings can be generalised. More so, concerns around data integrity persist due to the reliance on the cloud and data storage. Fully automated change detection and pattern recognition within geospatial production is predicted to be achieved in the next five to ten years.

3.2.13 Although current applications of machine learning for geospatial data focuses on object extraction and change detection, a wider range of geospatial applications will benefit from the potential of the technology in the future. Application areas include Digital Twins, autonomous mobility, sustainable smart city management, augmented building and energy management.

3.2.14 Currently in development, international standards will ensure wide-spread interoperability and security among those disciplines that work with Artificial Intelligence leading to the ethical and responsible use of Artificial Intelligence technologies in geospatial applications.[21]



UN-GGIM

United Nations Committee of Experts on
Global Geospatial Information Management

4. Trends in technology and the future direction of data creation, maintenance and management

Data and metadata capture, maintenance, management and data integration have been accelerated and improved through the emergence of new technological tools and the use of a greater variety of data sources.

Highlights:

- Satellites, Remotely Operated Aerial Systems (ROAS), Autonomous Underwater Vehicles (AUVs), Autonomous Surface Vehicles (ASVs) at sea, and sensor technology are being invested in by leading tech giants, existing providers of sensed imagery and governments;
- Earth observation technology such as satellites, data cubes, high altitude or vehicle-based sensors are providing a greater variety and volume of data about the earth to higher resolution and temporal frequency for lower costs;
- Provision of web service infrastructures enters the mainstream, making it easier to create new technology-based products quickly and more cheaply than before and to outsource costs;
- Applications of sensors, robotics, cameras, encryption, cloud computing and other software, and hardware intelligence are converging, enabling new ways for organisations and their equipment to perceive and capture reality; and,
- Artificial Intelligence-driven solutions and machine learning will drive cost efficiency, accuracy and speed in GNSS and Positioning, spatial analytics and Earth observation.

4.1 The new wave of data creation

4.1.1 Over the next decade, the technologies and data creation methods that will have the greatest impact on geospatial information management are mobile data collection methods; crowdsourcing for real-time data collection; and, social media platforms. These new forms of data collection will enable real-time applications that are increasingly demanded by various users of geospatial data. Across the private and public sector, vehicles with driver assist systems are already a source of detailed 3D mapping data.

4.1.2 The sensor systems and collection platforms are not just collecting the location and the properties of that location, but also the time that the information was collected, providing an important and foundation variable for so many applications and services. The value of the Internet of Things lies in the vast quantities of data collected by connected sensors that are designed into products and increasingly into the physical infrastructure around the world. By leveraging and integrating this data, which is inherently spatial, organisations can scale appropriately, make data-driven decisions, and improve operational efficiencies and overall performance. It is expected that the growing sensor network will generate a continuous flow of geo-referenced data - pre-processed on the spot - and will provide a source for dynamic infrastructure data.

4.1.3 Data creation is both active and passive. Modern smartphones have roughly between eight and eleven sensors that capture information on the location of the device through GPS, the speed at which the device is moving, and whether the device is being held to the ear. As social media and other online platforms become increasingly used, their disruptive potential in imagery capture is starting to rival traditional collection methods. Users of social media are creating ever increasing amounts of spatially located information, without it being a conscious decision. The volumes of unstructured data are multiplying daily through geo-tagged photos and raw telemetry information from smartphones. Images of buildings, streets, and other city facilities may be used to build 3D models of cities.

4.1.4 In relation to data integration, a growing number of businesses are merging geospatial data, such as satellite imagery, with other data sources including social media to contextualised location-enabled insights. The information generated through social media and other everyday devices will further reveal patterns and predict behaviour. Although not a new trend, the use of social media to provide realtime information on top of other functionalities increases new opportunities for location-based services.

4.2 Managing a world of data

4.2.1 The size and complexity of existing information resources as well as the constantly growing number of new data sources cause problems with the ability to search and discover the right data and services. Users often face the problem of finding and using the right and best data for their applications. It is necessary to improve the methods and tools for identifying and searching databases and related services by streamlining and standardising the process of creating metadata or access to available metadata through appropriate catalogue services in a spatial data infrastructure (SDI) framework, developing data directories and the development of popular search engine search tools.

4.2.2 Discovery of geospatial data on the web remains a challenge that hampers its effective use. Currently, geospatial data is invisible to the mainstream web, which means that search engines are unable to discover spatial resources without explicit directions to access the catalogue. There are developments in the delivery of persistently identified catalogue information to the web through the Catalogue Services for Web (CSW) in multiple formats, such as ISO19115, schema.org, Geo-DCAT, or Dublin Core.

4.2.3 Another problem relates to metadata which, in most cases, are insufficient by either being missing or in a format not suitable for automated consumption. Moreover, traditionally spatial metadata is often detached from the spatial resource in that they are stored in separate documents and derived manually resulting in an ambiguous free-form text in a closed-community jargon without navigable links to the actual resource these metadata describe.

4.2.4 To ensure consistent accurate data good metrics about data quality, trust, and reliability are imperative. ISO 19157 on data quality is currently being revised. There are suggestions from the project to put a data quality register in place. Displaying data quality indicators will enable the user to consider the level of confidence they should have in the underlying information.

4.2.5 Interoperability, accessibility, and discoverability of data – via data portals, application programming interfaces (APIs), and linked identifiers – will enable effective data use. Providing geospatial information that is discoverable via search, documented with metadata to assess the appropriate use of the data, and easy to access and use can be described as the most significant developments in geospatial data management. The ease of access has evolved from being able to download entire data files at a moderate speed, to being able to access a subset of data via a web service as a “stream”, on to a demand-driven geoprocessing service that “streams” only the result to the consumer. Over the coming years, advancements regarding “ease of use” and “user-preferred” will aim to achieve the objective of data services that are “mission-ready”. As such, the use of cloud infrastructure for hosting APIs, web services, and applications will continue to improve ease of use by providing highly reliable and very responsive services.

4.2.6 With the ever-increasing generation and use of geospatial data in a diverse range of domains, awareness of the standards developed by the geospatial community needs to be raised constantly. There will be a continued demand for open standard data file formats to ensure the open market can provide a variety of software tools and applications that can use the data. Also, these open standard data file formats need to be flexible and simple enough to be used and expanded for other domains. Rather than custom-API’s, there will be developments towards the creation of more standards-based protocols and APIs to support ease of use by enabling several different applications to share a common source code library, thus reducing the need for limited-use custom source code.

4.2.7 Data integration provides support in developing new streams of information and new opportunities for organisations. The rapid integration of simulation models and geospatial data increases the effectiveness in the decision-making processes and the credibility in the application or service being offered. It can be used as implicit validation in many cases. For instance, New Zealand is putting increasing emphasis on data integration to make optimal use of geographic and property data. Initiatives underway in this area include services linking disparate datasets related to a property and a joint land and sea project enabling the consistent linking of sea and land datasets and coastal mapping.

4.2.8 Another topic of interest is the capturing and maintaining of historic data for insight analysis. The development of Big Data has raised questions about the cost of storage and the long-term maintenance that will need to be addressed.[22] Some initiatives preserve historical information by using tools to digitise, locate and navigate through this digitised data. Others keep "alive" the access to old versions of products and produce new digital products based on old data or documents.

4.2.9 The digitisation and proper archiving of all geospatial related maps is a crucial concern for many LDCs and SIDS as data has been lost due to inappropriate handling and storing. Trends in data collection and Big Data can only be addressed once effective ways to digitise and archive current data holdings have been achieved.

4.2.10 Data preservation is a growing issue, particularly where it is software or sensor dependent. Standards for fully self-describing information about geospatial data allows a future reconstruction of the dataset without external documentation (ISO 19165-1).

4.3 Integrating statistical and geospatial information

4.3.1 The integration of statistical and geospatial information and the resulting geospatially enabled statistics are a critical component towards meeting the data demands that informed decision-making required at either the local, national, regional or global level.[23] Put simply, linking data about people, businesses and environment to a place or geographic location, and its integration with geospatial information through the medium of location, can result in an improved understanding of social, economic, and environmental issues – the key three pillars of sustainable development, and by extension, the SDGs.

4.3.2 Key advancements have been achieved since the last publication of the Future Trends Report; amongst which is the adoption of the Global Statistical Geospatial Framework (GSGF) by UN-GGIM in August 2019. As a Framework for the world, the GSGF enables a range of data to be integrated from both statistical and geospatial communities and, through the application of its five Principles and supporting key elements, permits the production of harmonised and standardised geospatially enabled statistical data.

4.3.3 With the adoption of the GSGF, future work turns towards developing guidance and recommendations to facilitate geocoding to link statistical data to a location; interoperability improved efficiency and simplification in the creation, discovery, integration, and analysis of geospatially enabled statistics and geospatial data; privacy and confidentiality to ensure that data custodians can store and release data in accordance with prevailing privacy and confidentiality norms; and, the use of common geographies to enable the integration and dissemination of data.

4.3.4 The ongoing digital transformation agenda will start to transform and influence the production of geospatially enabled statistics. Leveraging new and innovative opportunities from Earth observations with non-traditional data sources such as Call Data Records and crowdsourcing will provide new insights and possibilities to use data for decision making. The future of statistical and geospatial integration will lead to enhanced knowledge and understanding of geospatially enabled statistics and by that of social, economic, and environmental issues, support the data demands of national and global developmental priorities, and ultimately strengthen the statistical and geospatial capacity of countries.

4.3.5 Nonetheless, challenges in the process of integrating statistical and geospatial information remain. Several nations have identified that the lack of alignment between their NMGAs and national statistical agencies are hindering the sharing of information. As a result, they have started to look at implementing a collaborative working arrangement and sharing of geospatial data infrastructures. It is anticipated that over the next ten years, national geostatistical frameworks will be established as part of the more comprehensive national geospatial data infrastructures.

4.4 Linked data

4.4.1 As shown in the first edition of the Future Trends report, the interest in the use of semantics and ontologies to move the World Wide Web from human-centric to be more readily consumed by machines continues as the most promising way to handle the massive volumes and variety of data. Linked Data is seen as the key enabler for data integration.

4.4.2 The integration of Linked Data and Spatial Data Infrastructures (SDIs) is considered a promising alternative to overcome issues concerning the discovery, access, exploration and use of spatial data through the Web that impair the full development of SDIs. If successful, it is considered a relevant trend that may lead to the unfolding of the third generation of SDIs over the next five to ten years. OGC and the World Wide Web Consortium (W3C) are working together to advise on best practices for the publication of spatial data on the Web, based on the Semantic Web´s concept of Linked Data, and its counterpart in the public Open Data realm (Linked Open Data).

4.4.3 With changing consumer behaviour leaning towards personalised and immediate access to information needs, the ability to derive knowledge from information whenever and wherever will become the new norm. While Semantic Web technologies and Linked Open Data have been available for some time, the geospatial industry has been hesitant to assume its use, and the publication of Semantic Web formats is not yet common practice. However, it is expected that, in the next five to ten years, the primary function of an SDI will extend beyond providing access to data and will evolve to delivering knowledge-on-demand by combining the Semantic Web, Artificial Intelligence, machine learning and Linked Data in knowledge apps for real-time, reliable question-and-answer responses. As governments are increasingly making their data available in machine-readable Linked Data formats, this trend is set to take off.

4.4.4 As the trend to develop richer ontologies continues, the benefits extend beyond human-driven queries and enable machine-driven queries. Semantic and ontology Linked Data will become essential to support the next generation of autonomous systems as a critical source of information to connect with their direct sensors for improved situational decision-making, monitoring, alerting, and even forecasting.[24] For instance, edge computing is set to provide faster access to information with the Internet of Things enabled devices, such as autonomous vehicles, ROAS and sensors. When combined with the Semantic Web, edge computing will interconnect the physical and information technology world by simultaneously generating and harvesting spatial data, and producing this data in a format that can be queried by both humans and computers to deliver new information; thus, providing knowledge-on-demand.

4.4.5 More recently, landform ontologies have been created for scenarios where feature extraction might be needed to answer a query. An ontology approach has the potential benefit of not needing to pre-compute or to pre-extract a feature, so the process can be reactive to the situation by taking advantage of real-time data sources where pre-processing is not an option. Aiding search, rescue, or recovery situations, landform feature extraction can be performed using ontologies to search for peaks, valleys, plateaus using a variety of imagery, elevation, lidar data or other remotely sensed data to quickly map the terrain of an area from the latest sources.

4.5 Cloud computing

4.5.1 As mentioned previously, the increasing volume of data generates challenges on how this data is stored, maintained, and used. Cloud computing and the internet have transformed the way in which organisations manage data. It has been designed to treat IT as a scalable service that can increase or decrease capacity to match user demands, leverage shared technologies and hardware, and ultimately realise economies of scale. A service-orientated architecture is adopted in cloud computing and enables a reduction in up-front business investment in hardware, through the development of a range of facilitating services, including Data as a Service (DaaS), Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a Service (SaaS). The success of DaaS is based on the delivery of geospatial data for search and download through simple APIs.

4.5.2 The cloud computing model is rapidly becoming the established model for those working with medium and large-scale data sets. All enterprises are increasingly dependent on the data and data infrastructure provided by third party providers that offer software, platforms and infrastructures directly connected to a cloudbased environment. As cloud computing services mature, more tools, platforms and applications will become available. Among others, these include Google Earth Engine, Amazon Web Services (AWS), and Esri's ArcGIS Online.

4.5.3 Today, an increasing amount of data is stored in cloud services. There are several advantages, including the opportunity to access, adjust and share information more efficiently. This means that multiple users/services can rely on the same physical stored representation of data, reducing the risk of old/corrupted local versions of data being used in data analysis processes, and increasing economies in data storage.

4.5.4 Users need to be aware that each cloud service has different benefits and that the usage should inform which service to choose from. Some benefit from the way data is ingested (this can include preloaded data), others provide scripting language (for data processing). However, one of the main drawbacks of using cloud computing services is the lack of interoperability, meaning the user must decide between flexibility and ease of use.

4.5.5 Despite the increasing use of cloud computing, certain issues around the uneven global distribution of available technology as well as the challenge for some regions to meet the needs of basic electricity and high-speed internet connectivity for accessing, sharing, and processing large quantities of data need to be addressed. Thus, software developers are challenged to factor in the requirement to function offline along with the capacity to download the required data sets, so that models can be run locally. The SDO community is focused on intra and inter cloud interoperability with multiple OGC testbeds addressing this challenge.[25]

4.6 Developing fit-for-purpose open standards

4.6.1 There are a number of organisations, both at the national and international level, who are responsible for the development of standards for acquiring, implementing, maintaining and using geospatial information. At an international level, the Open Geospatial Consortium (OGC), the International Organization for Standardization (ISO) and the International Hydrographic Organisation (IHO), in partnership with broader technology standards organisations to ensure interoperability, lead on those matters.

4.6.2 Since the publication of the last Future Trends report, the three Standards Development Organisations (SDOs) have contributed to the draft IGIF Strategic Pathway on Standards. The chapter provides information on best practice standards and compliance mechanisms that enable legal, data, semantic and technical interoperability to allow different information systems to communicate and exchange data, enable knowledge discovery and inferencing between systems, and provide users with lawful access to and reuse of information.

4.6.3 An increasing effort has been made to respond to new expectations in the development of standards for the future application of technology. The OGC has established a Technology Strategy that tracks technology trends providing quarterly updates on the impact and horizon of the emerging trends affecting the geospatial industry as well as inform the development of new work programmes. By categorising a subset of these trends as highest and second priority, OGC can anticipate and address issues that can be resolved through standardisation.

4.6.4 Over the medium-term, the approach to standards is expected to shift from a focus on providing data to enabling real-time data streaming. As the Internet of Things and sensor networks mature, standards for V2V and V2I communication will become crucial. Although standards for real-time data streaming exist, the standardisation of streaming of geospatial data has still to be achieved. Thinking beyond the timeframe of the report, it is expected that R&D related topics such as quantum computing will be addressed by the standards community. However, it remains unclear what these standards will look like.

4.6.5 There is also increasingly a need for machine readable standards and some have already been published by ISO/TC211. In addition, after establishing the ISO geodetic register, the need of other Authoritative Registries has become evident – among others, for data quality and addresses.

4.7 Trends in 'professional' data creation and maintenance

4.7.1 The remote sensing industry is becoming increasingly dynamic in terms of global coverage, rapid revisit rates, diverse spectral content, and analytic capabilities. This has stimulated improvements in quality, quantity and timeliness of imagery and other forms of remote sensing available, as well as advances in accessing data and communicating observations and findings.

4.7.2 Overall, many organisations have been focusing on automating the workflow from collection to application. Over the past five to ten years, with the emergence of cloud computing, better processors, graphics processing units, small satellites, crowdsourcing and a wider variety of sources of high-resolution terrain data from ROAS[26], have reduced the time and cost necessary to generate terrain models. Those functions automated include polygon generation, linking of data sets, and adding attributions.

4.7.3 Important trends in data collection and sources utilised by the geospatial community and its consumers encompass new methods of Earth observation including ROAS, small satellites, sensor networks, and point clouds. An Earth observation system with high temporal resolution, high spatial resolution and high spectral resolution will be built up, which will enable it to identify features better. Accordingly, with the launch of high temporal, spatial, spectral resolution remote sensing satellites, the proliferation of low-cost launch systems and affordable satellites, the increase of powerful multi-band sensors, and the increasing use of ROAS, the quantity and quality of global remote sensing data will be greatly increased while costs reduce.

4.7.4 Developments in laser scanning and point cloud processing through ground-based, airborne and spaceborne platforms can provide improved data quality. In combination with automation, increased measuring frequency and point cloud density can deliver improved detail in mapping. The efficiency brought by automation has led to programmes of national laser scanning in Sweden, Finland, the Netherlands, and the United States.

4.7.5 **Space** – Technological advances in Earth observation have created a step-change in the quality, accuracy and precision available which makes it possible to map from space at resolutions less than five meters worldwide.

4.7.6 Emerging low-cost satellite constellations have altered data collection techniques by providing imagery that can be produced in volume which has democratised access to satellite data. Small satellite and nano satellite technology have made significant advances in recent years and have found strong uptake by developing countries. As a low-cost application, it enables nations with limited budgets to develop geospatial capabilities that can support a variety of sectors. In addition to small satellite technology, the accessibility of space-based data is another enabler for LDCs and SIDS to access and use the data. Not least, because the existence of national Space Agencies is limited to those nations that can afford them.

4.7.7 The space industry has seen further disruption with the emergence of the CubeSat concept. Particularly popular with academic researchers and space agencies, CubeSats have made space more accessible to a wider group of stakeholders. Overall, these developments will lower barriers to entry for potential new market entrants.

4.7.8 The last five years have seen significant developments in space-based ground deformation monitoring. In particular, advances in new sensors for Synthetic Aperture Radar Interferometry (InSAR) are accelerating. Combined with open data policy developments, this will significantly increase the potential of InSAR to be used for initiatives in climate change adaptation, geo-hazard risk assessment, infrastructure management, and natural resource extraction. Programmes for continuous deformation monitoring on a regional- or nationwide scale are already ongoing in Norway, Denmark, Germany, Belgium and the Netherlands. The European Union's programme for Earth observation (Copernicus) makes deformation rate data fully available, free and open; thus, sparking the development of products and services in both the public and private sector. With the upcoming launches of additional SAR satellites by space agencies and small SAR satellite businesses around the world, global land monitoring datasets are expected to become available within the next decade.

4.7.9 The increasing availability of high-resolution satellite imagery has transformed remote sensing by improving accessibility and frequency of updates; thus, enabling better evidence-based decision-making and service delivery. In several countries, the seasonality of water features plays a crucial role. Enhanced with the combined use of SAR data, high-resolution imagery that provides insight into water flows and water levels are increasingly utilised. The currently under-exploited high-resolution high-revisit imagery sources are expected to become more widely used and have the potential to become a valid alternative to aerial imagery. Yet, at the moment, there are only few globally consistent sources of high-resolution high-revisit data. For nations to see the benefits of these developments, the cost of purchasing will have to decrease and/or access will need to be broadened.

4.7.10 Another trend that has been observed is the establishment of a community of individuals and organisations aiming to build capability for working with global satellite data. The Open Data Cube (ODC) is an open source technology that allows for structured geospatial data - time-series of satellite images - to be ingested, stored, and analysed. Essentially, the ODC seeks to increase the value and impact of open satellite data by providing a free and open data architecture. Since its inception, the approach has been used by the Australian Geoscience Data Cube serving as the basis for Digital Earth Australia and the Africa Regional Data Cube serving as the foundation for Digital Earth Africa – including five countries in central Africa: Kenya, Senegal, Sierra Leone, Ghana and Tanzania. Both implementation programmes deliver analysis-ready satellite data that have been processed to a minimum set of requirements and organised into a way that allows immediate analysis with a minimum of additional user effort and interoperability. The ODC builds the capacity of users in those countries involved to apply satellite data to address local and national needs as well as SDGs.[27]

4.7.11 **Aerial mapping** – Traditionally, aerial imagery has been captured by manned aircraft equipped with large format aerial survey cameras which continue to play an important part in national aerial survey programmes in the foreseeable future. Since the publication of the Second Edition, ROAS technology has seen two main trends. Firstly, due to the decreasing costs and increasing demands for timely, accurate, high-resolution data, ROAS have become an integral part of the geospatial industry. Secondly, the miniaturisation of sensors continues, ROAS will become a primary source of geospatial data capture in high-income economies, LDCs, and SIDS.

4.7.12 ROAS can be described as the most critical technology to revolutionise the aerial mapping industry. As ROAS become commercially affordable and combined with oblique camera systems, highly detailed maps at lower cost than conventional mapping can be created. Projects like urban asset mapping and 3D city models or mine and quarry site surveys are the main application area. Yet, legal aspects of ROAS projects in terms of the height limitation of drones to safeguard the people privacy will need to be considered. Over the next five years, ROAS will establish themselves as a viable alternative to conventional mapping for small area surveys.

4.7.13 Although a prototype that can provide imagery for extended periods of time is yet to be showcased, new sources of imagery could increasingly be available from High Altitude Pseudo Satellites (HAPS). HAPS are solar-powered ROAS with massive wingspans that fly higher than traditional ROAS and/or aircraft and have the ability to stay airborne for time spans ranging from weeks to months collecting sensor data. Combined with automated feature extraction, HAPS have the potential to reduce the cost of geospatial information.

4.7.14 **Terrain mapping** – Mobile laser scanning (MLS), particularly vehicle-mounted laser scanning systems, are in the process of becoming a newly established way in measuring road and urban environments. Further, with the development of algorithms that enable simultaneous localisation and mapping, MLS has progressed to deliver 3D data from environments not covered by Global Navigation Satellite System (GNSS), such as tunnels and indoor environment.

4.7.15 **Sub-surface surveying** – Until recently, the sub-surface infrastructure was hardly considered by those developing utility networks and urban underground transportation systems. The little data that does exist is often fragmented and outdated. More so, studies have shown that uncertainty in the location of underground assets can have serious knock on effects on the economy as missing or inaccurate data can cause construction delays.

4.7.16 Economic development is a key driver for the application of geospatial technology in this field. The lack of information regarding the location of buried assets increases the cost of its management and maintenance and, therefore, has a direct impact on a nation's economy.[28] Quantum sensing is said to revolutionise how surveys are performed, by using sensitive sensors that can detect even the slightest fluctuation in gravity speeding up survey times and increasing accuracy. Nonetheless, it should be noted that, whilst quantum sensors exist, they only do so within a laboratory environment and the resolution required to meet the expectations of underground assets surveys are yet to be developed.

4.7.17 **Under water surveying** - Although not often associated with emerging technologies, the marine geospatial industry has been an early adopter of autonomous systems on and under the water to increase efficiency, accuracy and data resolution. Autonomous underwater vehicles (AUVs) and autonomous surface vehicles (ASVs) have disrupted the way in which marine geospatial data is captured.

4.7.18 As autonomous survey techniques mature and become more widely adopted, the application of AUVs and ASVs will optimise coverage and fill gaps in the survey. Over the next ten years, AUVs and ASVs are likely to become the norm in hydrographic surveys providing high-resolution information about the seabed that had previously not been surveyed. This new technology represents an effective way to support the aims of the UN Seabed 2030 programme.

4.7.19 **Emerging opportunities for LDCs and SIDS** – There are different levels of maturity in technology uptake in different geographic regions. Historically, Europe and North America have been proactive adopters of new technology and processes. While, emerging economies have benefited from the learning and have been able to leapfrog enabling those nations to mature their geospatial capabilities more quickly.

4.7.20 As a previous chapter has shown, Artificial Intelligence is expected to make significant contributions to the way in which geospatial production will evolve over the next five to ten years. Advances in geospatial processes such as image classification, object detection, feature extraction and resolution enhancement will become increasingly more powerful. When coupled with the increasing affordability of ROAS technologies and low orbiting satellite cube technology, it is conceivable that costs of data acquisition will decrease and the availability of high-quality data will increase, benefitting LDCs and SIDS.

4.7.21 Developing nations are more vulnerable to the impact of climate change and naturally occurring hazards but often find themselves unable to afford high-quality data. Today, data sources freely available to developing nations are often provided at a resolution too low to monitor, study and model the characteristics and impacts of events such as flooding, landslides and other phenomena. The ability to collect data at higher resolutions and/or enhance the resolution of data through Artificial Intelligence processes will benefit developing nations due to relieving the cost pressures of acquiring high-resolution satellite imagery.

4.7.22 Beyond the timeframe of this report, more affordable ROAS and satellite technologies equipped with advanced Artificial Intelligence image classification capabilities will reduce the degree to which experts with advanced image processing skills are required. This will benefit nations in disaster risk simulation and modeling, the quantification and quality of post-disaster impact analyses through automated change detection and other areas of application.

4.7.23 Despite the advances in the application of Artificial Intelligence, operational forecasting requires fast processing and computational capabilities which are often limited. New techniques and partnerships will need to be established to allow LDCs and SIDS to benefit from the advances in data creation and maintenance.

4.8 Positioning ourselves in the next five to ten years

4.8.1 Satellite positioning technology is expected to improve due to a new generation of navigation satellites and receivers. This is possible because of the continued investments in hardware and international cooperation between national governments and international agencies. In combination with 5G mobile communication signals, global positioning is likely to deliver higher accuracy over the next decade.

4.8.2 Developments in satellite positioning are advancing rapidly, and once the European satellite programme Galileo, the GPS Block III, the modernised Russian GLONASS and the Chinese Beidou are fully operational, product development based on positioning services will become more accessible. For instance, Galileo’s High Accuracy Service (HAS) is expected to be freely accessible from 2020 and will provide an accuracy of 20 centimetres or better.

4.8.3 Positioning services are crucial to many governments; among other activities, Brazil has set out to develop functions in GNSS multi-constellation data processing and analysis, tide gauge data analysis, and multi-constellation orbit computation over the next five to ten years. As an example, the Australian and New Zealand government announced joint funding to support the development of a regional satellite-based augmentation system (SBAS) to improve GPS accuracy significantly. The system will enable innovation related to position-based applications in a diverse range of areas including aviation, forestry, agriculture and cadastral boundary definition.

4.8.4 Over the long-term, 5G could be used to augment positioning services as low latency may use the time difference of arrival between sending and receiving antennas. Using the geometry of the antennas will make it possible to calculate the angle from which the signal arrives and as the number of measurements increase an accuracy of 5 centimetres or better can be expected. GNSS and 5G in combination may also prove effective for transitioning between indoor and outdoor positioning, as with all emerging technologies there are challenges that need to be identified and addressed.

4.8.5 The use of systems and services that have utilised GNSS data and/or Artificial Intelligence raises questions of data integrity and provenance. While it may offer access to capable services and systems, the data that is produced has the potential to present additional hazards that will require mitigation and/or establishment of integrity/provenance assurance.

4.8.6 Development in ITS is undergoing strong growth and will clearly place demands on continuously connected users of positioning services. The quality of positioning services will need to be ensured so that information and services are accessible and correct at the point of use. Accurate positioning will also be expected by service users at low cost within a few years. Although, GNSS is not expected to be the primary positioning service for CAVs - since GNSS is not available everywhere - sensor networks in collaboration with GNSS are expected to be part of a solution. Yet, different approaches exist, indicating a need for standardisation and possible regulation as some businesses in the automotive industry rely upon GNSS, which has been demonstrated to be affected by GPS interference and spoofing trials.

4.8.7 The continued rise in use and reliance upon GNSS-based services and systems is causing concern for government bodies as society expects an always available service that is subject to numerous threats and vulnerabilities. The threats and vulnerabilities to GNSS services and systems are widely understood and include space weather, constellation issues, non-intentional and intentional interference, and user error. The impact of regional or global GNSS outage has the potential to cause catastrophic impact. At a local level, denial of service or attempted denial of service (often associated with mobile phone denial) continues to rise using systems designed to deny and/or spoof GNSS. The need to develop and incorporate safeguards into GNSS reliant infrastructure and services requires significant work.

5. Legal, policy, and ethical developments

In the legal and policy domain, a one-size-fits-all approach cannot be applied due to differences in national legal systems and varying levels of maturity of national geospatial information management. However, several common trends have been identified.

Highlights:

- National governments are increasingly developing national geospatial strategies or master plans to access the social and economic benefits that geospatial information can deliver;
- Technologies continue to generate more data, raising further questions over who controls, who owns and who benefits from the value of the data;
- The ever-increasing generation and use of geospatial data, geolocation and data integration raise questions relating to the responsible use of data and has advanced the dialogue on developing ethical principles and solutions; and,
- The pace of technological and digital advances continues to outpace the legislative development process leading to an increase in concerns around privacy and cyber security.

5.1 Growing awareness within government

5.1.1 Since the publication of the last edition of the report, there have been several positive developments regarding the awareness of the potential social and economic value that geospatial information can unlock.

5.1.2 Nations and Regions[29] around the world have put significant effort into the development of National Geospatial Strategies or National Geospatial Master Plans to foster economic growth, employment opportunities and to combat societal challenges related to climate change, urbanisation, disaster resilience and resource management. In tandem with the development of these plans, some countries have put in place a national geospatial body with oversight of the national geospatial policy and strategic plan development that coordinates the activities of all NMGAs. It is expected that a growing number of national geospatial bodies will be set up throughout the next 10 years.

5.1.3 Overall, increasingly national geospatial plans are part of the wider digital and data agenda and often mark a transformation process of a nation. This rise in digitisation provides new opportunities for knowledge creation, and policies increasingly focus on data sharing, collaboration, privacy, security and interaction between different public bodies.

5.1.4 One of the common denominators of most of these plans is the quantification of the potential value which the use of geospatial data can unlock for an economy. Although different in size, many nations have calculated the potential economic value to be in the US$ billions.

5.1.5 Similar to this report, most national geospatial plans have a wide remit and provide a platform for public bodies, private sector businesses, and academia to shape and implement the future of the initiatives undertaken. Despite differing national priorities, most geospatial plans have set out initiatives relating to improving data and semantic interoperability, data accessibility, and data quality metrics. Given the significant increase in national geospatial strategies, there is a likelihood that more national governments will take the lead and set out their own national geospatial priorities. Regional initiatives like Europe's INSPIRE Directive aim to create a European Union spatial data infrastructure for the purposes of EU environmental policies and policies or activities which may have an impact on the environment. This European Spatial Data Infrastructure enables the sharing of environmental spatial information among public sector organisations, facilitate public access to spatial information across Europe and assist in policy-making across boundaries. The publication of the IGIF Strategic Pathways will further fuel a globally coordinated approach to the development of national geospatial strategies and the prioritisation of geospatial initiatives.

5.2 Funding in a changing world

5.2.1 Historically, it has been the role of government to invest in consistent and trustworthy geospatial data. However, as the demand for current and more detailed information increases, growing constraints on fixed or declining budgets are becoming more apparent. There have been expectations that in the future, governments will increasingly create partnerships to fund data acquisition and will encourage the national geospatial industry to adopt common specifications to promote widespread data reuse.

5.2.2 There are several examples of how different nations aim to overcome shortcomings in funding allocations. Some governments consider granting tax advantages to data owners for release of their relevant data stocks for public use under open terms. Other suggestions include pooled funds and Public Private Partnerships (PPP). Both examples are described in more detail below.

5.2.3 The US Geological Survey topographic mapping programme has a long history with partnering, and most recently embarked on a goal to acquire the first-ever national baseline of consistent high-resolution elevation data – both bare earth and 3D point clouds – collected in a timeframe of less than a decade. On the back of a cost-benefit analysis that estimated the cost of the data alone to be US$1 billion, it was determined that the same data could potentially generate US$13 billion in new benefits through applications that span the breadth of the US economy. Having a comprehensive, documented business case has been foundational for building programme support with partner agencies and legislators. Since its inception, investments in data acquisition by federal government agencies and state/local government and other entities have been growing every year, and it is likely that further partnerships will be developed over the years to come. The private sector mapping firms who collect the data on contract and other stakeholder organisations also play a role in educating legislators about the programme. For example, the 3DEP Coalition includes more than 40 organisations that support the programme and communicate on its behalf. This mix of stakeholder support and pooling funding by partners to invest in consistent (specification-based), freely available, highly accurate, detailed, maintained, and trusted fundamental geospatial information has the potential to spear to other nations as national budgets are increasingly cut.

5.2.4 Particularly, SIDS are operating on limited budget allocations and staffing. One option considered is the increasing use of PPP; while PPP are applied across a variety of sectors in developed countries, the concept is only just emerging in SIDS. Meanwhile, concerns remain as the private sector is seen to boldly seek to expand into the SIDS market raising misapprehensions and lack of trust by the SIDS in relation to being primarily viewed as a customer only. The challenge for SIDS is to develop legal and regulatory structures that can guide PPP engagement.

5.3 Open Data

5.3.1 It is widely recognised that open data is an essential part of a transparent, innovative and effective government, that enables the better and more varied provision of services and products for citizens and other sectors. Enhancing the economic standing of a nation, it has been proven that the value created with open data outperforms its initial value many times over through larger ROI for governments as tax revenues for the services and products created rise.

5.3.2 The lack of a consistent universal open data definition has led to the creation of many differing open data licences within the geospatial community, making it challenging to combine different datasets from a variety of public sector organisations. As part of a European Union public open data initiative, the Open European Location Services (OpenELS) project sought to set up a framework of principles that will guide the users in accessing and reusing data.[30] The project also provides a framework for establishing a licensing model that will clearly describe the user's rights and obligations resulting from the reuse of the data. In return, the project offers harmonised pan-European public and open datasets available under an open licence and made available to the users that can be accessed, searched, viewed and reused free of charge and restrictions. The project follows the latest trends in good geospatial data management by providing the data in machine-readable form, so that it can be processed by computers using the semantics of the data via its metadata.

5.3.3 Open data policies affect how NMGAs sustain their operational costs while continuing to deliver on their open data commitments. Concerns around the long-term open data funding arrangements remain. It is assumed that without compensation to cover the extra costs, the continuous publication of high-value open data will be challenging.[31]

5.3.4 Although, the argument that data created with public funds should be 'open by default' continues, it has been acknowledged that there are several reasons for some data to remain more proprietary.[32] Those include exceptions around national security, law enforcement and personal privacy, as well as the protection of indigenous people's knowledge and rights around the location of cultural artefacts and endangered species.[33] Concerns within the EU over slow progress in releasing open data has seen the 'Re-use of Public Sector Information' legislation reviewed and renewed as the 'Open Data Directive'.

5.3.5 New open data principles around open and exchangeable knowledge have become widely acknowledged, recognising that data can be closed if necessary. Following the FAIR approach, it has become recognised that data should be Findable, Accessible, Interoperable, and Reusable.[34] Given the growing number of alternative geospatial sources of information, improved access to and quality of geospatial data and metadata may ensure that these datasets will not be replaced by external data of lower quality and accuracy by government bodies.

5.3.6 In terms of satellite data, the industry experiences an increasing volume of available open source data. The two most prominent open data examples include the US Geological Survey's Landsat and the European Union's Copernicus programme. While Landsat provides the longest temporal records of moderate resolution data, Copernicus offers global high-resolution imagery leading to an increased activity in scientific research based on satellite data. The data has been used in various hazard models, ocean forecasting systems, and environmental and climate monitoring.[35]

5.4 Licensing, pricing and data 'ownership'

5.4.1 Ownership of data is becoming an increasingly important issue; perhaps even more important than the curation of the data. With the increasing number of sensors collecting information, ownership and licensing become more complicated when data is aggregated from different sources to produce new products, solutions, or insight. Geospatial experts as well as law makers will need to address this emerging issue to ensure licensing harmonisation in the future.

5.4.2 The wide variety of data and service licensing represent a real barrier to interoperability and data sharing. Integrating different datasets when the terms of the licences differ remains a significant challenge. Over the next decade, the industry anticipates the development of a set of simple, standard and clear licences.

5.4.3 While there is a desire to have more data available under open terms, there are incidences where data cannot be made open. Licensing provides a gateway to encourage organisations to share more of the data they hold. One potential example is the development of harmonised data exploration licences that enable the free access to data for research, development and innovation purposes. Other options include improved accessibility to and use of data via APIs.

5.4.4 It is expected that there will be an increasing move towards business licensing providing a more customer-like experience, such as a move towards "transactional purchase" rather than "rental". This development is seen as a natural progression as geospatial data becomes more ubiquitous in its use moving away from being used GIS professional form analysis to gain greater insight into a particular issue. There will be an increasing expectation that geospatial data is almost an invisible part of that process.

5.4.5 As a result of the increase in machine-to-machine communication, machine-to-machine licensing/machine-readable licensing will increasingly need to be considered. Many licensing specialists foresee changes towards a more sophisticated type of digital rights management. This may mean that the transactional price is set by the value-to-customer of the activity that is being undertaken by the user. In so far, the use of value-based pricing will require a degree of pricing sophistication that is currently not widely used by businesses and can be analysis heavy.

5.4.6 In terms of pricing, developments in areas such as data science and analytics have brought about several new pricing models. These may include (1) consultancy-type hourly billing; (2) value-based pricing; and, (3) revenue sharing. Consultancy type pricing is the simplest pricing model by charging an hourly or a day rate with a margin added. This is a relatively easy pricing model and offers low risk to both the supplier and the customer. On the other hand, a value-based pricing model provides a precise value to a customer for a specific, specialist piece of work that can be determined with confidence. However, this approach requires the need for additional pre-sales work, which must often be undertaken free of charge in order to obtain the evidence upon which to make a sale. Last, a revenue share contract, whereby instead of charging up-front, the supplier can share in a percentage of the profits on an ongoing basis. As the geospatial industry moves towards the provision of solutions and continues to adopt new technologies, an increasing variety of pricing models is likely to emerge over the coming years.

5.4.7 Another emerging topic of interest to a variety of geospatial individuals relates to the legal rights and intellectual property of indigenous and local knowledge. The traditional knowledge of indigenous people relating to location and environmental-related topics are not protected in law and as a result this group is in danger of losing control of their valuable environmental knowledge. Developing countries as well as advanced economies with significant indigenous populations such as Canada, New Zealand, and Australia, may increasingly develop methods to safeguard this knowledge asset for the future.

5.4.8 In many countries, the protection and ownership of data belonging to groups or nations, such as indigenous people, is recognised by the United Nations Declaration on Indigenous Peoples (UN-DRIP). The right to self-determination also comes with a right of sovereignty over data that belongs to the Nation. Therefore, it is a crucial topic to be considered when setting up the legal and political context for the management of geospatial data.[36]

5.5 Data privacy, data ethics and cyber security

5.5.1 In 1930, Edmond Locard - the French pioneer in forensic science – determined that 12 points of a fingerprint are enough to uniquely identify an individual. A 2013 study of human mobility data established that human mobility traces are vastly unique, highlighting that four spatio-temporal points are sufficient to uniquely identify roughly 95 per cent of individuals that move within an average radius of less than 100 km.[37] Accordingly, the findings of this study show the significant implications for an individual's privacy and for those institutions designing frameworks to protect the privacy of the individual.

5.5.2 The study mentioned above has revealed that mobility data is one of the most sensitive data currently collected. Even an anonymised dataset that does not contain the name, home address, phone number or another identifier can be used to reconstruct movements across space and time identifying the individual by triangulating other information. Thus, modern information technologies and the advances in digital infrastructure shows the uniqueness of individuals.

5.5.3 Inevitably, with unlimited connectivity, the adoption of the Internet of Things, and the rise of the algorithm-driven economy, comes the increased risk of data breaches. In an increasingly transparent world, security and privacy are key concerns relating to data ownership, data access, and data usage. This implies that improvements in how the digital data infrastructure is secured and how ethically this mixture of historic and live-streaming data can be accessed are increasingly necessary.

5.5.4 Within the legislative environment, the General Data Protection Regulation (GDPR) of the European Union can be described as the most comprehensive and most restrictive law on data protection and privacy. Its implementation in May 2018, addressed the main privacy concerns of the digital age ensuring anonymity. The regulation acknowledges location as an identifier, but traditional geospatial data is not considered personal data as it identifies a physical feature rather than an individual. In many cases, technology creates new challenges for location privacy. For instance, an app developed in one country may infringe on the privacy legislation of the country where the app is used. In such cases, questions are raised regarding how the developers of the app from another country can be prosecuted.

5.5.5 Advances in how data is used and the deployment of emerging technology puts increasing pressure on understanding, anticipating and responding to emerging ethical issues. The use of geospatial information poses serious ethical questions related to privacy, accuracy, and accessibility. Ethics related to geospatial information management focuses on the relationship between the creation, organisation, dissemination, integration and use of geospatial data and services, and the ethical standards and moral codes governing human conduct in society.

5.5.6 In light of the COVID-19 pandemic, governments are increasingly collecting information about individuals with limited information about how governments will control personal data. This dialogue will increasingly be prioritised.

5.5.7 Governments, business and individuals can equally be affected by cyber-attacks leading to infringements of privacy, disruption of services, and national security risks. The advent of autonomous vehicles represents a significant source for cyber threats as the vehicles will be connected to networks such as the internet. Without cybersecurity, the ability to exploit the increasing availability of data and the rapid technological advancements will be at increased risk.

5.6 Disparities between technological advances and the legal and policy frameworks

5.6.1 The relationship between regulation and innovation can be complex and contradictory: existing regulatory frameworks can constrain innovation; regulatory interventions can be used to facilitate innovation; and, innovation can be the result of regulatory arrangements.

5.6.2 Although it is widely recognised that digital has become the new normal, the collection and use of geospatial information through mobile devices and ITS has raised concerns around privacy and data sensitivity by regulators and law makers. With increases in machine-to-machine processing, new insightful data is generated, and sensitive knowledge exposed - creating new legal and regulatory issues. Particularly in areas of technological innovation, such as advancements in Artificial Intelligence, regulatory caution is often exercised.

5.6.3 In recent years, regulatory frameworks had to be reactive by default as new products or services emerged across industries. In addition to establishing ethical codes, governments often revert to 'sandboxing' innovation to establish expertise about the potential risk and opportunities presented by certain innovations. As described in an earlier chapter, developments in change detection and feature extraction highlight the potential of Artificial Intelligence in autonomous decision-making, as such governments are testing the biases of Artificial Intelligence based on which regulatory requirements will be made.

5.6.4 Over the next decade, an increase in 'sandbox' activities regarding the impact of the increased collection of geospatial information through a variety of data sources is likely. Due to the diversity of national legislation, different approaches to dealing with privacy and data sensitivity will emerge globally.

5.6.5 The ability to adapt and respond to technological and digital change especially in terms of governance, regulation, and policy will be slower; yet, pressure remains to address any shortcomings.

6. Skills requirements and training mechanisms

The rate of change in the skills required across all disciplines in geospatial information management is accelerating. This requires changes in the education and training systems as well as the re-skilling of the workforce to retain knowledge.

Highlights:

- The skillsets required by the geospatial industry are refocusing towards disciplines such as data science and analytics, computer science, and data visualisation;
- The acceleration of technological developments and the of increased automation makes regular workforce reskilling and upskilling necessary;
- A sector skills strategy is likely to become a critical tool to meet the future skills requirements of the geospatial community;
- Knowledge transfer and capture in an aging workforce will expand as a new generation of professionals enters the workforce; and,
- The value of workforce diversity around learning difficulty or disability, age, gender, and ethnicity is increasingly recognised within the industry.

6.1 Skills and capabilities for effective organisations

6.1.1 The skill needs of businesses and nations are constantly evolving as economic and technological innovation, growth, productivity and competitiveness are dependent on the skillsets of its workforce. It is estimated that around 50 percent of the working population in many parts of the world will need reskilling in the next five years due to the impact of digital transformation. Given the fast pace of the digital revolution, this is a serious challenge for companies and national governments alike as the lack of effective intervention could create a bottleneck in economic growth.

6.1.2 The disciplines associated with geospatial information management have diversified significantly over the last decade. While geographers, cartographers, GIS analysts, remote sensing scientist, surveyors, photogrammetrists, and Earth observation scientists still make up a large part of the workforce, the range of geospatial career paths has diversified and incorporates expert groups previously not covered. Among others, the increased use of computers in imaging and geospatial technology has seen a growth in disciplines such as data science and analytics, computer science, and data visualisation.

6.1.3 The changing nature of work due to the increase in automation offers great opportunities despite the challenges associated with it. The rapid pace of changes and the ongoing automation of collection processes, basic data interpretation and elements of Artificial Intelligence are in many ways replacing the human factor in repetitive tasks. This requires greater emphasis on the development of lifelong training, reskilling and upskilling of employees for more higher-value tasks in the use, creation, and maintenance of spatial information and related services. The next five years will see significant changes in the geospatial production process and, while the ability to restructure, reprocess, retain and potentially downsize functions will cause friction over the short-term, productivity, accuracy and efficiency are projected to increase over the medium to long-term.

6.1.4 For instance, developments in ROAS technology have lowered the barriers of entry through the increasing availability of commercial off-the-shelf ROAS and affordable cloud processing options. One of the key benefits identified by developed and developing countries is the ability to map certain geographic areas in minutes and to process the data captured within hours saving both money and time. Using ROAS technology for national mapping, development, resilience building, emergency preparedness, planning and research have enabled countries and institutions around the world to provide updated maps at reasonable costs. Its ability to carry cameras for topographical survey data, multispectral sensors for assessing vegetation health or thermal sensors for asset inspection and search and rescue, has made ROAS a universal tool for terrestrial surveying projects. As with most new technologies there is a skills shortage in surveyors qualified to conduct a survey using the flight parameters and associated survey methods, as well as the type of equipment and processing software to ensure reliable and usable survey data is produced. It is anticipated that over the upcoming five years, training in the use of ROAS for mapping purposes will increase and be established as a component in the national mapping efforts.

6.1.5 Visualisation skills to enhance the user and decision-maker experience will increasingly be required. If data is presented in "bite-size" visualisations it can make the information more accessible and easier to understand. For example, being able to visually represent the effect of different levels of a storm surge, or increasing wind velocity, may increase the number of citizens adhering to evacuation notices in the event of an extreme weather event. Early warning systems and emergency response agencies will see a rise in the demand for such information in emergency situations as well as for the development of policy and regulation.

6.1.6 It is expected that in the coming years, investment in the domain of data science will increase. As mentioned elsewhere in this report, the understanding of location and geography within the data science community remains relatively immature; however, data science will become a vital component for the exploitation of disruptive technologies that can be linked to data science, namely Artificial Intelligence, machine learning and deep learning, cloud computing, sensor networks, or blockchain.

6.1.7 While some parts of the world lack qualified people to effectively manage and utilise geospatial information, others continue to struggle with retention rates of professionals. In particular, national governments are at risk of losing top Artificial Intelligence and data science talent as the private sector can pay better and often offers more attractive career paths. Over the long-term, this represents a major challenge to the public sector who is already competing with an increasing number of private sector businesses that are entering the geospatial value chain.

6.1.8 Despite the hype around the increased recruitment of data scientists and visualisation experts, industry bodies have voiced the concern that this has led to a hold on hiring people with expertise in using insights to make decisions.

6.2 Education and advocacy

6.2.1 Currently, geospatial training and education appear to be mainly focused at the tertiary level (graduate/post-graduates) or in the upskilling of current workforces. With the increasing exposure of geospatial data through smartphone devices and wider integration within the gaming industry, geospatial experts are advocating for the inclusion of geospatial concepts at primary and secondary levels. These concepts and technologies include topics such as standard data sharing, data integration, data quality, data usability as well as aspects of data privacy and personal privacy.

6.2.2 Spatial thinking in younger people has greatly been enhanced by the opportunities brought about by digital technologies. Smartphone devices make location-based services like Uber and Tag Your Ride as well as applications such as Google Maps, Apple Maps and OpenStreetMap easily accessible, and it can be expected that the next generation will be fluent in the use of dynamic maps as part of multimodal interfaces.[38]

6.2.3 Since the publication of the Second Edition of the report, machine learning, deep learning and Artificial Intelligence have established themselves as disruptive forces within the geospatial domain. Although pure Artificial

Intelligence is still in the research stage, several sources have highlighted that coding has a level of bias, because of which Artificial Intelligence systems need to be built by a diverse team. Given that Artificial Intelligence, statistics and geospatial are coming together rapidly and being promoted as the next 'big thing' to enable evidence-based decision-making and policy delivery, it is crucial that diversity within all types of teams is high on the technology agenda.

6.2.4 As highlighted earlier in this report, all the identified geospatial trends whether they cover technological, data or legislative developments, need to be increasingly considered by those reviewing education curricula and training programmes. Taking account of the fast pace of change, it is crucial for the geospatial industry to consider the variety of drivers, trends and their impact in order to build capacity and develop professionals who are equipped to respond to the new challenges as they arise.

6.2.5 There have been concerted efforts by several sectors to develop industry-specific skills strategies, these are aimed at future-proofing the industry and developing the skills needed. In many cases the industries are developing national and cross-regional education and training curricula. A Sector Skills Strategy has been proposed by groups in the geospatial industry. It aims to bridge the skills gap between the supply and demand of education and training and addresses the short- and medium-term skills needs of the geo-information sector ensuring a workforce with the right skills enters the labour market. For instance, EO4GEO is designing a series of curricula directly linked to the occupational skills required by the industry focusing on the tasks and duties needed by the workforce.[39] The programme takes into account the fast changing developments in the sector by engaging with the academic, public, and private sectors. It is anticipated that more sector strategies will emerge through national and cross-regional initiatives over the coming five to ten years.

6.2.6 Driven by the COVID-19 pandemic, the significant rise in virtual learning opportunities, eLearning portals, and online webinars are expected to lead to a long-term change in how skills development, education, and collaboration are delivered by geospatial societies, industry bodies, the private sector, and educational institutions. Prior to the outbreak of the pandemic, long and short courses offered by tertiary educational institutions were gradually increasing. Particularly, the younger generations are seeking ways to complete certification and skill development programmes through online platforms. Among others, these include certificate level courses in Digital Twins, Digital Earth Visualisation, and Artificial Intelligence/Machine Learning ethics.

6.3 Open science and collaboration

6.3.1 Open principles in education are a big enabler in making geographic literacy, geo-education and entrepreneurship opportunities accessible to all. Outreach programmes, such as Geo for All, have been initiated by scientists and academics as a means of providing a strong foundation for Open Geospatial Science. Today, the initiative has dedicated research labs worldwide and dedicated journals to advance the discipline of Open Geospatial Science.[40]

6.3.2 In relation to open access to research publications, the reproducible research and openness in data analysis and scholarly communication will be more and more accepted as requirements for transparency and evidence-based decision-making. The real knowledge does not lie in the published article, but in the combination of the textual workflow description with the underlying code and data. This is also the case for geospatial sciences, where challenges in communicating spatial information and making results reproducible and conclusions replicable are different from other communities.[41]

6.3.3 The need for higher reproducibility and transparency will have a significant impact on the format of scientific manuscripts and scholarly journals, including the review process and accreditation of merit. Independent journals run by universities or academic societies on open source platforms and open infrastructure will revolutionise the transparency in science communication.

The continued success of the open access movement will soon point to the next steps after opening the results, namely open science and reproducibility. The realisation that 'Open is not enough' will impact the way researchers learn, work, collaborate, and communicate, because transparency and evidence-based reproducible workflows cannot be an afterthought in research. This realisation will spark innovative new collaboration and publication infrastructures, and lessons learned by other communities will be adopted and enhanced to suit geospatial data and geospatial infrastructures.

6.3.4 There is an increasing trend in trans-disciplinary research that includes collaboration across disciplines and with non-academic sectors. Trans-disciplinary research moves beyond the bridging of divides within academia to engaging directly with the production and use of knowledge outside of academia. Societal impact is a central aim and solutions that emerge from the research may be put into place through an action-oriented process built on direct collaboration with the groups involved.

6.3.5 The next ten years are likely to see greater collaborative working between government and academia. Often government departments and public bodies do not have the internal capacity to perform regional analysis, develop predictive models and other types of processing that add value to the data and create knowledge having the potential to inform both academic research and decision-making. The challenge is in generating sustainable alliances between government and academia.

6.4 Enabling diversity at work

6.4.1 Greater diversity in the workplace and across the industry has become more prominent, including a mix of ages and experience, cultural background, gender, and neuro-diverse skillsets. The procedure for the election of the co-Chairs and a Rapporteur for the United Nations Committee of Experts on Global Geospatial Information Management from among its Member State delegations highlights the effectiveness of a truly diverse global representation.

6.4.2 There has been a tendency to focus predominantly on graduate skills and apprenticeships while underplaying the need of reskilling, skills transfer, and knowledge capture from more experienced colleagues. Institutions are beginning to create programmes and strategies to capture tacit knowledge from employees and to manage workforce transitions in an environment of in-person and increasingly remote engagement. Activities that have proven successful include mentorship programmes, professional networks, and informal communities of practice with common interests.

6.4.3 Particular attention has been paid to increasing the visibility of women in the industry due to the continued underrepresentation of women in science, technology, engineering and mathematics (STEM). Building capacity has led to the creation of female networking groups both within organisations and across the industry. Advocacy groups like 'Women in Geospatial' and 'Women in GIS' are likely to see continued growth in their networks.[42]

7. The role of the private and non-governmental sectors

Over the past decade, business models have emerged that show how geospatial data and technologies are increasingly used across a variety of industries. Technological advances and the advent of digital platforms have drastically reduced the barrier to entry making it easier for new players to enter the geospatial markets.

Highlights:

- The geospatial industry continues to become more mainstream as a wide variety of traditional industry players, mainstream technology companies, internet giants and tech start-ups develop new types of platform business models;
- The increasing affordability and ubiquity of mobile devices trigger new growth opportunities in 'As-A-Service' products;
- Product and service offers for the urban environment will be the primary focus for many in the private sector; and,
- The quality and quantity of crowd-sourced location-based content grows. The willingness of 'crowds' to provide data or content for free, which is then monetised by the collectors of the data, continues mostly unchallenged.

7.1 Making mapping available to the masses

7.1.1 Historically, national governments have been predominant producers of geospatial data. However, advancements in geospatial technology and data capture techniques have changed the landscape of data producers. In tandem with the rapidly growing demand for data from traditional and non-traditional geospatial data users, the diversity of geospatial data producers has increased as well.

7.1.2 As the private sector develops new data collection technologies that outperform the in-house capabilities of the NMGAs in terms of producing the volume and the types of data consumers demand, PPP is becoming instrumental in facilitating cross-sector collaborations to access data and technologies, and establish new relationships. This trend highlights a shift away from the historic pattern of agencies storing and maintaining data in silos to the development of system-of-systems.

7.1.3 The reduction in the barriers to entry, the growth of web and mobile mapping has massively increased the role of the private sector and the crowdsourcing community over the last decade. There has been significant investment in mapping capability as a result of car manufacturers developing autonomous vehicles and self-healing maps.

7.1.4 Devices and the increase in spatially related services have ushered in an era where public users are not only consumers of geospatial information, but also act as producers of enriched geospatial data. It has been global businesses like Google who have made digital mapping accessible to the masses.

7.1.5 Although public bodies cannot be described as technology averse, it has mainly been the private sector that provides and develops technologies to enable the production and collection of vast quantities of data. The management of geospatial information and the provision of analysis tools for decision-making are often provided through the private sector, although often enabled by government investment or an environment that empowers innovation. The value of government-backed innovation in space programmes, satellites, grants, basic and applied research, and many other funding mechanisms have, and do, enable the geospatial industry. In addition, many governments have invested in research labs and centres to conduct their own R&D which have resulted in technology advancements outside of the private sector.

7.2 The future role of the Private Sector

7.2.1 There are numerous examples of how the private sector has developed which provides the opportunity to predict how it may evolve in the years to come; this section will specifically focus on the platform business model, Artificial Intelligence-based geospatial analytics, and smart city product and service offers.

7.2.2 In the 2000s, the user experience of Google Maps changed how people expect to interact and use geospatial applications. Today, the emergence of smartphones and other digital devices has set new standards for mobile applications that challenge traditional GIS products. Yet, desktop applications still dominate the portfolio of traditional vendors. The short to medium-term, will see a dramatic increase in the availability of mobile applications.

7.2.3 Over the last five years, the power of platform business models has gained significantly by simply connecting producers and consumers. This shift from physical to digital is providing opportunities to digital platform companies such as Amazon, Apple and Microsoft as well as start-ups including Uber, Airbnb and Uber Eats to dominate. Although Uber does not own any cars it has built the largest transportation business in the world; while Facebook does not create content it is the largest global content business; similarly, Airbnb does not own property but it offers more rooms than any other hotel business. Other than that, the emergence of platforms has blurred the lines between the traditional notion of producers and consumers.

7.2.4 In the same vein, the industry has seen an exponential rise in the number of private sector companies from outside the geospatial industry utilising geospatial technologies and its data to provide services to users. By utilising the platform business model, companies like Uber, combine geospatial analytics, location data, route networks, and other information to offer a simple data-driven service solution. The same business model has been applied successfully numerous times for similar service offers. While the private sector is continuously exploiting the potential of geospatial technologies and information, it appears that public sector bodies are lagging behind the private sector in utilising these new business models.

7.2.5 Early research-led developments in Artificial Intelligence-based geospatial analytics and machine learning have opened new business opportunities and market niches for established businesses as well as start-ups. Although the private sector will continue to offer off-the shelf products and solutions, technological advances have enabled companies to move towards responding to specific customer challenge. Technology will increasingly enable businesses to run purpose-specific queries that do not require the creation of bespoke solutions.

7.2.6 Other trends include the demand for the development of 3D models of the urban and built environment has surged dramatically. This sharp rise in the need for 3D geospatial data has driven an increased focus on the AEC industry by the private sector. Infrastructure and construction projects – and smart city operation as mentioned in a previous chapter - all around the world have led to the increasing availability of products, services and solutions specifically designed for the urban environment.

7.2.7 As cities increasingly base their planning, operation and maintenance functions on 3D representations and Digital Twins of the built environment, geospatial data will be both the backbone of the digital replica and the force behind bringing together diverse data. The geospatial private sector is likely to continue its focuses on delivering advanced geospatial tools that offer 3D models that solve the specific needs and challenges of the urban environment.

7.3 Regenerating the business ecosystems

7.3.1 With the commercialisation of many technologies and data being readily available, the last decade has seen the transformation of start-ups into global multi US$ billion businesses. For example, businesses such as Uber, Ola, Didi, Booking.com, and WebChat are is a combination of technologies that were once considered disruptive—smart phones, GNSS positioning and navigation, online payments, cloud computing, sharing of personal assets, accurate street and address data, and more—that are now commonly accepted. It can be anticipated that in the future use of spatial data in empowering Artificial Intelligence, machine learning, and predictive analytics will be commonplace.

7.3.2 Numerous examples highlight the ability of geospatial start-ups and university spin-off companies to use the potential of emerging technologies and new business models in building business concepts that venture capital firms invest US$ millions in.

7.3.3 For instance, Mapbox emerged as a mapping platform that runs some of the biggest applications in the world including Uber, Snapchat, Tinder, and many more who rely on map accuracy and live location data. With 300 million users of apps with embedded Mapbox software development kit (SDK), it collects over 220 million miles of anonymous data every single day which is fed back into their map. It may be argued that the inherent agility of start-up businesses remains with businesses as they grow, enabling them to adjust more easily to technological change and adapt more quickly to emerging business models.

7.3.4 Skillsets not as readily found in established private and public bodies are employees described as 'creative problem-solvers'. Flat hierarchies, informed risk-taking, and unbureaucratic management styles enable these companies to act more agile to user and industry demands. This allows them to scale up rapidly and drive international business expansion.

7.3.5 It can be expected that over the coming decade, geospatial start-ups and university spin-offs will reshape the geospatial industry and put pressure on NMGAs, and established private sector businesses, to retain their competitive edge.

7.4 The future role of social media data, VGI, and crowdsourced geospatial data

7.4.1 The increase in crowdsourced and user-produced data has significantly enhanced the availability of geospatial data globally. More so, it has blurred the lines between the authoritative data and non-authoritative data. As innovation advances and technology capabilities increase, devices have become more widely available and prices have dropped which has enabled users to collect data 'on demand' for their specific needs.

7.4.2 Further, crowdsourced content feeds are one of the top geospatial trends identified earlier in this report. Despite technological advances, traditional cartographic products of NMGAs go through an established production process that currently does not allow for real-time updates. Yet, OpenStreetMap enables access to data as the content is created allowing users to use, enrich, or evaluate the content whenever and wherever.

7.4.3 In a recent publication the International Federation of Surveyors (FIG) concluded that the wider citizen science participation can successfully contribute to mapping-related projects. The publication specified that land administration in developing countries could benefit from crowdsourcing and volunteered geographic information (VGI) as missing and outdated authoritative land and tenure information is often due to the lack of human, budgetary or other resources. However, questions around correctness (authenticity) and quality continue to hold back the wider uptake of crowdsourced information by public bodies of developed countries. Still, as the technology matures and new possibilities arise, new processes and algorithms continue to be developed with the aim that data sources will comply with the same standards and quality that is expected of authoritative data.[43]

7.4.4 Using VGI also creates new challenges for privacy. Both, Google and Twitter monetise the information they gathered - a trend that has spread to the geospatial industry. Private geospatial companies use passively sensed data to help law enforcement with the location of speed cameras.[44]

7.4.5 Stakeholders in the VGI community have suggested changes of the cartographic perspective towards a process of reflection and production of knowledge with the direct participation of people, starting from an exercise of the virtual reconstruction of reality. On account of new forms of multimedia and multisensory presentations, different ways to display results of geospatial analysis that people can readily understand are required. This approach is described as cybercartography – a term for all kinds of information both qualitative and quantitative linked by location. These new forms of communication mainly use small screens and mobile devices and aim to establish new processes and results leading to interactive cartography.[45]

7.5 Coordination and collaboration

7.5.1 Collaboration within the industry is an integral part of today's working practices. Interoperability agreements between different private sector companies have existed for some time to ensure that data and capabilities can be leveraged from other platforms. The launch of the World Geospatial Industry Council is a prime example of the increasing drive of tech vendors to leverage each other's expertise while continuing to broaden the visibility and contribution of the geospatial industry across markets, the global economy and society.

7.5.2 Recent developments have shown an increase in the number of partnership and collaboration agreements across the industry and with businesses from outside geospatial. As the awareness of the value of geospatial increases across applications, so will the dominance of this business model. Collaborations between the private industry are well established and it can be expected that the trend will continue to involve a wide variety of stakeholders including academia, public bodies, and specialist institutions.

7.5.3 It has become apparent that these new types of partnerships often consist of more than two businesses or institutions that bring unique know-how to a project. The development of offers for 5G has shown product and solution developments that draw on the specific capabilities of the individual stakeholders.

7.5.4 Mapping for CAVs is one of the great driving forces for more collaborative working arrangements between geospatial businesses and expert groups from other domains. The automotive industry, geospatial experts and academia are the most notable example of this drive to create strategic partnerships and R&D collaborations to gain a competitive edge in this competitive environment.

7.5.5 On a different note, there has been a noticeable rise in the number of commercial firms and non-profit sector organisations that facilitate free access to imagery, data, analytical tools and expertise to respond to humanitarian efforts and similar scenarios. Given the developments in recent years it can be predicted that commercial companies and charitable organisations will continue to support geographic areas that are in need of geospatial expertise to combat humanitarian crises.

8. The demands of the future users

As producers and users of geospatial information, early-career professionals and entrepreneurs disrupt the established way of doing business. Faced by similar challenges, both the public and the private sector aim to tap into and understand the needs and expectations of this new generation of data users.

Highlights:

- Geospatial-enabled innovation programmes and hubs are set up by national bodies and private companies alike in order to stimulate the disruptive potential of tech-start-ups;
- The reshaping of consumer behaviour and expectations towards an outcome-focused, personalised experience that is instantly gratified will dominate the user experience of future products and services; and,
- ‘Digital natives’ expect their technology experience to equal their social media experience – mobile, frictionless, and convenient.

8.1 Rise of innovation-based incubation

8.1.1 Geospatial innovation-based incubation centres are not a new concept but have seen a surge in interest in recent years. Championed by national agencies, geospatial innovation is fuelled by the creation of innovation hubs aiming to support new and emerging start-ups in the geospatial sector through seed funding, mentorship and access to national geospatial datasets solving real-world challenges. NMGAs have set up national location innovation incubators to generate geospatial activity and grow their national geospatial industry.

8.1.2 In 2015, the award-winning Geovation Hub opened in London. Since its inception, the Hub has supported over 100 businesses creating solutions for over 10 market sectors while creating jobs and supporting economic development in the process. Similarly, Singapore’s GeoWorks actively brings together the private sector, users, academia and government agencies to drive geospatial innovation developing new business and a dynamic geospatial community.

8.1.3 More recently, private sector organisations have started to embrace the notion of innovation programmes providing tech-start-ups with access to industry-expertise in business management, marketing, funding, product development, as well as mentorship. The Ignite programme, launched by Intel in Tel Aviv in 2019, has funded start-ups in Artificial Intelligence, autonomous systems and other data-centric technologies and business models.

8.1.4 In the digital age, innovation hubs have become part of enterprise innovation strategies helping to self-disrupt the geospatial industry. To keep pace with the ever-increasing user expectations and technological advances, we will see an increase in the number of geospatial innovation incubators set up and programmes run both by NMGAs and private sector organisations throughout the next decade.

8.2 Digital Natives: The future user of geospatial information

8.2.1 The expectations and needs of a new generation – often referred to as ‘digital natives’ – of geospatial information users require different types of maps that can be accessed in new ways;[46] not least because this emerging generation has grown up with the internet, multimodal interfaces and are used to dynamic maps.

8.2.2 As producers and consumers of geospatial information, there is an expectation that the user experience of technology is similar to social media interfaces – mobile, frictionless, and convenient. Driven by increases in global smartphone possession, their technological capabilities and the improvements in the digital infrastructure, users expect to receive products and services directly to their mobile devices. The adoption of apps will continue to drive the way in which data is consumed as younger users adapt more quickly to digital innovation and are accustomed with using services through mobile apps.

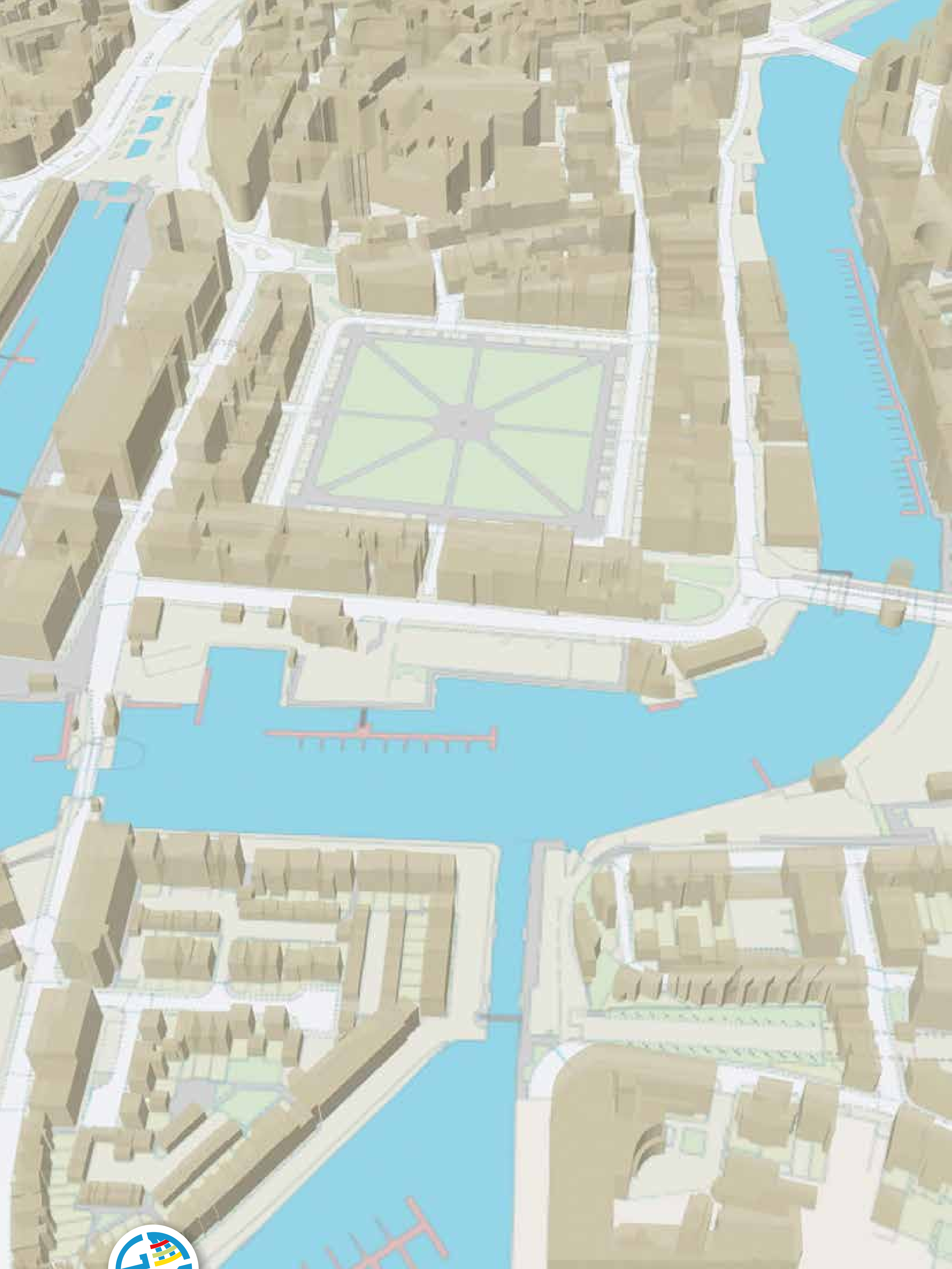
8.2.3 Further, a shift in customer needs relating to - what the World Economic Forum calls - the 'outcome economy' can be identified highlighting a move away from the provision of products, services and subscriptions to a marketplace in which the needs of the customer are addressed. This includes the ability to deliver solutions that directly deliver results answering the customer needs and/or questions. Overall, this will require a clear understanding of the customer needs through proactive engagement and personalised interactions; a data-driven approach to analysis; and, a focus on outcome-driven results that align to the customer needs.[47]

8.2.4 Progressively, more users live in an environment where the lines between real and virtual are increasingly blurred. The gaming industry has been one of the main enablers of the introduction of augmented reality and virtual reality and has mainstreamed the technology to user communities. Disruptive examples such as the mobile game Pokémon Go have emphasised the potential of augmented reality. Since, geospatial data has very much become part of AR development as nearly all AR apps use spatial data. As AR technology matures further, users will be able to manipulate space on a screen. Early adopters are already planning to introduce AR in training, shopping and business meetings which is likely to translate into how digital natives will expect to interact with maps in the years to come.

8.2.5 Also, games like Minecraft have pioneered new ways to teach young generations the skills required to interpret spatial representations, code, share and select data for given tasks. The notion of trust that has been associated with authoritative data from government organisations does no longer apply to the everyday user of location data. Whether or not data is considered "good enough" will increasingly depend on the outcome the user has in mind. Customers of paid for data and services are likely to expect a more detailed, authoritative and bespoke, tailored offer.

8.2.6 Driven by the rise and use of online platforms and/or location-based services (such as Uber, TripAdvisor and Airbnb) maps have become everyday tools integrated into applications. Customers will expect to receive their data through cloud access, to mobile devices and will expect these along with platforms and services that enable further insight and value generation.

8.2.7 The next decade will see increasing expectation of instant knowledge. People want answers they can trust, contextualised for them and their situations, and available in their time-frames and increasingly from natural language queries rather than through specialist software. This interface between human and machine is increasingly happening through natural language, and step by step could eventually be through 'brain-machine interfaces'. Timely, trusted answers to complex questions, knowledge, is achievable from the powerful combination of new semantic web, analytical and integrative techniques including Artificial Intelligence/Machine Learning deriving knowledge from the vast repositories of information available and constantly being collected through global sensors. This report has highlighted the technologies that are being considered to bring geospatial into this environment.



9. The future role of governments in geospatial data provision and management

Governments are undergoing rapid change, and the ability of public authorities to respond quickly and accurately to emerging demands from within and outside of government will increasingly become necessary.

Highlights:

- The continuing pressures on public finances and accountability have put emphasis on demonstrating value for money across all governments and for sharing services and working collaboratively;
- Spatial Data Infrastructures are moving towards Spatial, or Geospatial, Knowledge Infrastructures – the development of the IGIF is one of these developments;
- The UN Seabed 2030 project will significantly advance the availability of marine geospatial information as it progresses to map the entire ocean floor;
- Authoritative data remains a unique selling point for NMGAs and should form the basis of a strategy to ensure their future relevance; and,
- NMGAs will continue to consider adopting alternative non-traditional data sources.

9.1 Beyond NSDI

9.1.1 For decades, SDI has been a trustworthy foundation platform for facilitating the sharing of geospatial data among numerous public authorities, private companies, and citizens.

9.1.2 Despite the advances in SDI at the global level and the implementation of national spatial data infrastructures (NSDIs), nations around the world have struggled to witness tangible results. The lack of fundamental, standardised, up-to-date, and accurate data is one of the challenges holding back further advances. Many nations have experienced duplication as various stakeholders create data for their own purposes using different specifications and standards, data formats, and data redundancy, as well as using a different base map or source for data capture. Those involved in the implementation of NSDIs have experienced challenges aiming to avoid inefficient bureaucratic processes for the production, integration and sharing of fundamental data.

9.1.3 Access to and sharing of data between government departments remains one of the main challenges on a technical, policy and legal level. Both, national security and privacy concerns continue to be the main barriers. While the technical means to address interoperability are developing rapidly, the political and human issues related to breaking down silos remain. Also referred to as 'human interoperability', this desire between and among government departments to protect their mandate and position, as well as their budget allocations prohibit the effective allocation of resources and sharing mechanisms of geospatial information.[48]

9.1.4 On a theoretical level, research suggests that the improvements in SDIs will require the transition from the notion of human readable SDI data supply approaches towards delivering machine readable knowledge on-demand capabilities, or 'spatial knowledge infrastructure'. A Spatial Knowledge Infrastructure (SKI) is 'a network of data, analytics, expertise and policies that assist individuals or organisations to integrate real-time spatial knowledge into everyday decision-making and problem-solving'.[49]

9.1.5 Recognising that SDI is moving towards a 'knowledge infrastructure', the IGIF builds on the achievements in planning and implementing SDI and NSDIs but focuses on more than the collection of data and the implementation of technology. As highlighted several times throughout this report, many of the future trends are exposing the inherent limitations of a traditional SDI. Firstly, the emerging data ecosystem due to the growing availability of more diverse data and the continuous digital and technological disruption that is more dependent on location and integration. Secondly, the increasing requirement for data to be more flexible, readable, timely and integrated with other data. Finally, the focus of SDI has predominately been on geospatial data rather than developing geospatial capacity to support the diverse responsibilities of government. Similar to the top geospatial trends and drivers introduced earlier in the report, the IGIF addresses additional variables including governance, policy, financial, education, and communication that have previously not been covered by the SDI.[50]

9.1.6 Another emerging 'knowledge infrastructure' concept is the Geospatial Knowledge Infrastructure (GKI), which seeks to bring a geospatial dimension to the wider digital ecosystem. With geospatial information at the heart of the knowledge environment, GKI leverages the new opportunities enabled by the Fourth Industrial Revolution, cognition as the path to knowledge, and location as a key element of analytics and data, including geospatial information.[51]

9.1.7 It has been suggested that the following areas will receive the most attention over the short-term: (1) Improved exposure of spatial resources to the web and creating a national framework to access open public data, including geospatial data; and, (2) Redefining spatial resources' metadata and their production and their provenance.

9.2 Mapping the Ocean: Marine geospatial information

9.2.1 The Decade of Ocean Science for Sustainable Development and related international initiatives, including the Seabed 2030 project, has emphasised that marine geospatial information is an integral part of global geospatial information management. At its Sixth Session in August 2016, the Committee of Experts recognised the need to consider its relevance and established the Working Group on Marine Geospatial Information.

9.2.2 While most of the trends within this report are from a land-based perspective, most of these trends also apply to the marine environment, albeit implemented with different technologies. In terms of connectivity the marine environment relies on satellites; instead of CAVs, autonomous vessels revolutionise navigation and data collection; and, legal concerns are supportive of safety.

9.2.3 As highlighted by the last report, the marine element of established NSDI is often less well developed and the overall need for better integration of marine data is becoming more apparent. As a component framework within a NSDI, national hydrographic offices are mostly separate entities with somewhat loose connections to the NMGAs. Integrating marine-based charting and land-based mapping as one continuous surface continues to be a constraint; for this to be achieved, new tools, new data collection methods, data specification standardisation, and improved data management will be required. The Working Group on Marine Geospatial information is in the process of producing a best practise guide for working across the land and sea interface in order to bring terrestrial and marine data standards together.

9.2.4 Due to increasing coastal populations and a rise in the frequency and severity of extreme weather events, the demand for integrated marine data and Big Data analytics has become more prominent. Regular predictions and forecasts of the ocean environment and weather trends would allow for improved response measures to be taken in extreme weather events.

9.2.5 With less than 20 per cent of the ocean being mapped, the Seabed 2030 project aims to rectify this lack of marine geospatial information and has set the goal to complete the mapping exercise by 2030. The output will be a definitive, high-resolution bathymetric map of the entire ocean floor that provides an authoritative picture of the global ocean's depth and shape. Having access to this type of data will drive a better understanding of ocean circulation, tides and tsunami forecasting, as well as environmental change and underwater geo-hazards. To achieve this goal, a collaborative approach is needed that gathers existing data sets from across governments, the private sector and academia.

9.3 Maintaining an accurate, detailed and trusted geospatial information base

9.3.1 Even though the term 'authoritative dataset' is widely used, there is no universally agreed definition. The two factors that most descriptions agree on state that the data should be officially certified and provided by an authoritative source. A less common factor specifies that the source of authoritative data should be an officially mandated body.

9.3.2 Capturing, aggregating, processing, ensuring quality, and delivering authoritative data is a core and critical role of NMGAs. Beyond these responsibilities, many NMGAs contribute to interoperable standards development, conduct geospatial research, influence policy, provide expertise and guidance to state and provincial governments making NMGAs critical players in solving obstacles that are preventing geospatial advancements. Authoritative administrative systems based on international standards may signal a trend toward standardising the authoritativeness of data/information and may increasingly have a role in integrated geospatial information management.[52]

9.3.3 As technology matures and becomes more widely available, the overall price of geospatial content appears to be falling. Providers of authoritative data find it increasingly challenging to articulate and place a monetary value on these assets. Further, there is a trend for governments to trust data from more agile sources of geospatial information including crowdsourced information platforms and global private corporations. The last five years have witnessed crowdsourced information becoming richer in detail and increasingly accurate, and in some circumstances the quality of the data may be similar if not better than those data provided by NMGAs or commercial entities. As this trend progresses, providers of authoritative information may find themselves having to present use cases and scenarios that highlight the value of certified data as a backbone for critical national infrastructure. In 2018, the UN-GGIM Working Group on Global Fundamental Geospatial Data Themes produced a minimum list of themes that have been identified as fundamental to strengthening a country's geospatial information infrastructure and may be used as examples in illustrating the case for authoritative data.

9.3.4 One of these examples is related to land and property rights. The ability of governments to organise and integrate land and property information can be greatly improved if attributes relating to rights, restrictions, and responsibilities - including spatial extent, duration, people involved, and purpose - are geospatially enabled, defined in a coherent fashion and stored as authoritative records. Legislation should enable and not prohibit innovative use of technology and alternate tools to capture data and complete transactions. Legislation must consider data privacy and licensing issues, incluzding protecting and safeguarding indigenous and local knowledge.[53]

9.3.5 However, critical authoritative data and geospatial infrastructure are not universal and still lacking in many developing countries which brings about its own operational challenges. In many cases, the authoritative geospatial base layers and census data are often not existent or outdated. For instance, projects around recording place names have revealed error rates in authoritative data exceeding 50 per cent. Especially in humanitarian situations, this lack of geospatial capacity constraints the ability to respond appropriately. In the absence of authoritative data and despite the limitations of user-generated data, crowdsourcing platforms such as OpenStreetMap or Crisis Mappers provide the functions that support data aggregation, data curation and data management.[54]

9.3.6 As more geospatial data sources become openly available and data analytics continue to be widely used, NMGAs are in danger of losing their competitive advantage when deep learning allows anyone to mine new data. Suggestions have been made that NMGAs may start to consider embracing the notion of owning a digital platform by predominately acting as a connector rather than a producer of authoritative and trusted geospatial data.

9.3.7 According to this suggestion, four separate categories of players would interact with each other in a business ecosystem based on a digital platform for authoritative and trusted data: (1) the public authorities accountable for datasets; (2) the data maintainers represented by the private sector and government bodies; (3) the application suppliers through the private sector, non-government and government bodies; and, (4) the end-users that can be citizens, the private sector, as well as non-government and government bodies. The digital platform business approach provides strong opportunities for mutually beneficial cooperation between government and the private sector.

9.4 The impact of change: Adapting to alternative sources for data collection

9.4.1 Throughout this report, the rapid growth of volumes of data and the increasing digitisation of society have been highlighted as a main influence on geospatial information management. In tandem, the demand for higher accuracy and real-time information will continue to drive change in the years to come. The report has pointed out that authoritative data will continue to remain a crucial data source for many applications; yet, some areas will see an increasing demand for data from alternative data sources.

9.4.2 The first edition of the Future Trends report identified the apparent challenge for NMGAs to adapt to alternative sources of location-based data. As more data sources become available due to the commoditisation of data capture technologies, alternative sources for collecting data increase in relevance. Not least due to the increasing pressure on government institutions to be more technology and digital savvy.

9.4.3 As referred to throughout the report, low-cost sensors in smart phones and tablets, social media platforms, and mobile mapping platforms in vehicles, airplanes and satellites offer a variety of data unattainable through traditional mapping techniques. Collaboration with alternative data providers will likely become the norm for NMGAs.

9.4.4 Despite the potential for incorporating data from mobile devices, social media and mobile mapping, there are several implications that will need to be explored. The management and storage of large volumes of structured and unstructured data are likely to require additional funding which will put additional pressure on already tight public finances.

9.4.5 As referred to in a previous chapter, adapting to alternative sources of data will raise issues around data quality, data currency, licensing, privacy and cyber security. Effective standards frameworks for data quality and assurance will need to be put in place to ensure the level of trust and ease the incorporation of the data into the NMGA geospatial information base.[55] In addition, integrating multiple data sources will require changes to existing legal and ethical frameworks to ensure acceptable and effective levels of cybersecurity to lessen the risk of data breaches.

9.4.6 If successful, alterations to the traditional data collection methods of NMGAs will deliver increasing richness of the data available. Even so, questions around liability, data ownership, licensing, and data management will need to be addressed first.

Presenting the true value of GI

The introduction of this report referred to the geospatial digital divide – particularly the access to data, tools and expertise. Despite numerous development initiatives, the indirect dependence on a continuous flow of financial, technical and human resources to narrow the gap in geospatial capacity between LDCs and SIDS with high income economies remains. Several recent public-private use cases have aimed to developed sustainable long-term propositions by illustrating the value of investing in and providing access to authoritative data, geospatial knowledge, and technical resources.

The development of the IGIF has been a crucial milestone in enabling governments across the world – but especially LDCs and SIDS – to establish the capabilities for geospatial-driven decision-making. Even more, integrating geospatial into a nation's data strategy will need to consider the data, people, and technology requirements for building a sustainable environment in which a country can function and develop efficiently on the back of geo-enabled processes.

Although the report has focused on many of the latest technological and digital trends in geospatial information management, their relevance will differ by country, industry segment, discipline, et cetera. Not least because the degree of maturity of technologies is influenced by a variety of factors. Some technologies have been around for years and are only just starting to affect geospatial information management, while others are maturing rapidly. However, focusing on technology alone is not the answer; the availability of 2D printed paper maps will continue to help communicate with local communities and those unfamiliar with digitally displayed data and imagery.

The third Future Trends report: Reviewing progress

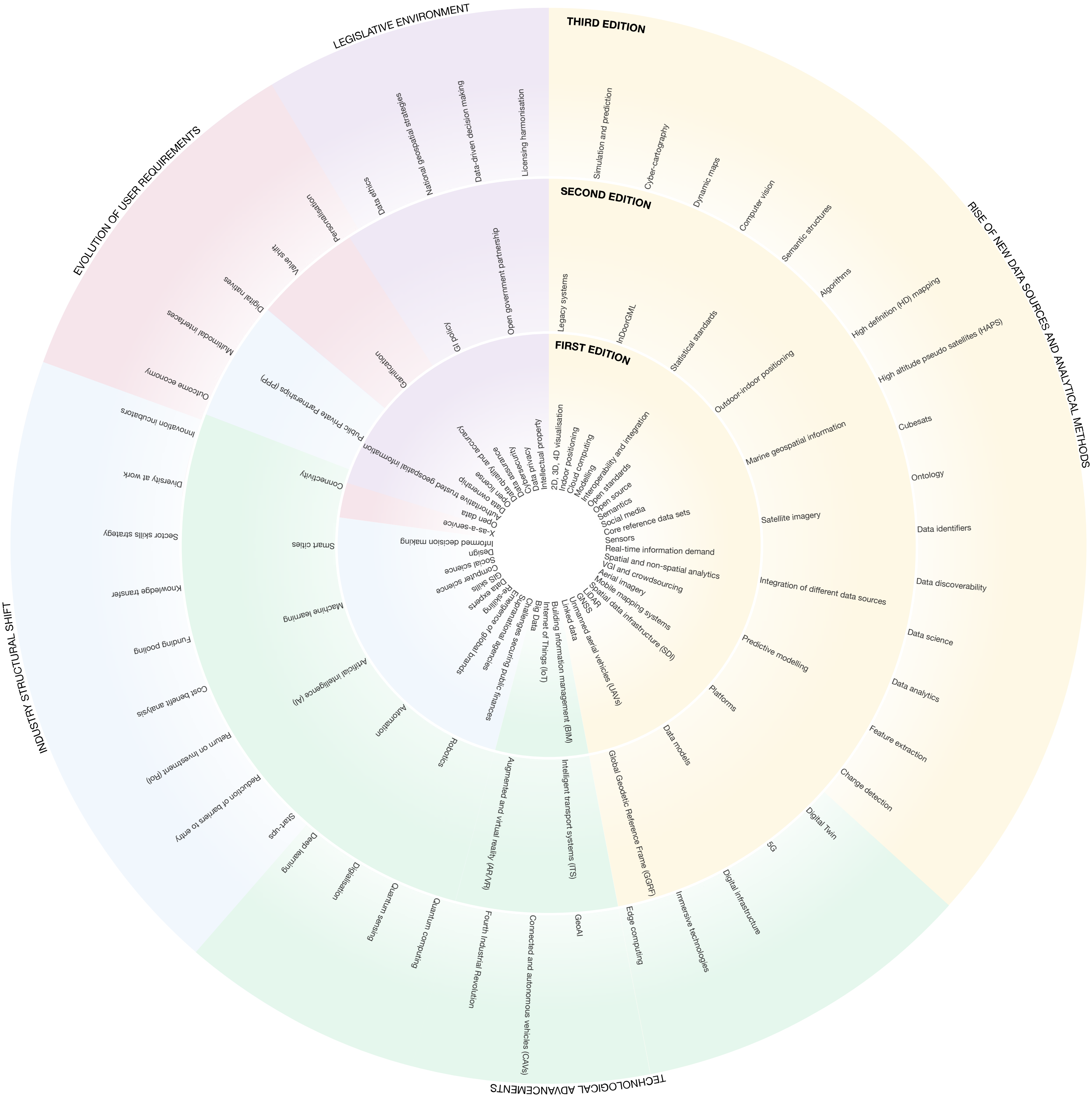
Since the publication of the First edition of the Future Trends report in 2013, the variety of topics covered by each of the three editions have expanded considerably. Graphic 2 below provides a hint about the unprecedented pace of change that the geospatial industry experiences. More than ever, it has become imperative to review how these trends and forces evolve and shape the future of the industry.

Graphic 2 is designed around the five geospatial drivers identified earlier in this report. This breakdown highlights that two of the drivers have been prime areas of interest to the geospatial community throughout the existence of the Future Trends reports; namely, data sources, data collection, maintenance, and management, as well as policy and legal developments. On the other hand, the focus on the impact of technological advancements took off significantly around 2015 when the second report was published. Last, changes in the way in which the industry operates as well as the focal point on emerging requirements of those using geospatial information and technologies are increasing drastically.

By paying particular attention to all themes identified throughout the three Future Trends reports, it becomes clear that this report does not simply focus on what is 'new' but provides a brief overview of how previous trends have developed over time and how the direction of geospatial information management is likely to evolve.

Overall, assessing what drives development in geospatial information management will enable the community to reassess its outlook over the short, medium, and long-term. This report hopes to have established some clarity as the diverse influences on geospatial information management continue to grow.

Graphic 2. Increase of topics covered by each of the Future Trends reports, 2013-2020



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17 An example of such challenges within the ITS domain is currently being addressed by a technical report and a gap analysis that aims to map and describe the differences between the current GDF and ISO/TC211 conceptual models to suggest ways for harmonising and resolving conflicting issues (ISO 19169).
18 Current work in ISO/TC 211 defines the conceptual framework and mechanisms for mapping of information elements from Building Information Modeling (BIM) to Geographic Information Systems (GIS) to access the needed information based on specific user requirements - BIM to GIS conceptual mapping (B2GM) (ISO 19166).
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36 For further information, see The Firelight Group report for a review of the challenges associated with the “Dissemination of open geospatial data under the Open Government Licence-Canada through OCAP principles”.
37 Montjoye, Yves-Alexandre de, et al., ‘Unique in the Crowd: the privacy bounds of human mobility’, Scientific Reports, Vol. 3 (1993), pp. 1-5.
38 EuroSDR, Mapping places for digital natives and other generations, 2018.
39 A European Sector Skills Alliance between academia, public and private sector for skills development and capacity building in the EO/GI field.
40 Other industry examples include the FOSS4G International Conference that enables attendees to exchange knowledge and best practices while having access to free and open source software for geospatial data storage, processing and visualisation.
41 The University Information System RUSSIA (UIS RUSSIA) is a mutual project of Research Computing Center and Economic Faculty at Lomonosov Moscow State University. Starting in 2003, the development team concentrated on statistical databases to build an infrastructure for educational courses to support social and economic studies. Visualisation options include cartography and advanced analytical tools to enhance the educational and research value of the system.
42 Another example is “Geochicas” - a growing community of women linked to the OpenStreetMap project who are working on female empowerment aiming to reduce the gender gap in OpenStreetMap communities and in communities associated with the world of free software and open data.
43 International Federation of Surveyors, New Trends in Geospatial Information: The Land Surveyors Role in the Era of Crowdsourcing and VGI, 2019.
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45 Engler, Nate J., et al., ‘Cybercartography and Volunteered Geographic Information’, *Modern Cartography Series*, Vol. 9 (2019), pp. 69-83.
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50 Greg Scott, Beyond SDI – Towards an Integrated Geospatial Information Paradigm, European Umbrella Organisation for Geographic Information, accessed: 2nd March 2020; UN-GGIM, Solving the Puzzle: Understanding the Implementation Guide, IGIF – Global Consultation Draft, accessed: 2nd March 2020.
51 Geospatial Knowledge Infrastructure discussion paper, 2020.
52 These models include ISO 19152 and IHO S-121.
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List of abbreviations

2D	Two-dimensional
3D	Three-dimensional
3DEP	3D Elevation Program
5G	Fifth generation technology standard for cellular networks
AEC	Architecture, Construction and Engineering
AI	Artificial Intelligence
API	Application programming interface
AR	Augmented reality
ASV	Autonomous surface vehicle
AUV	Autonomous underwater vehicle
AWS	Amazon Web Services
BIM	Building Information Modelling
CAVs	Connected and autonomous vehicles
DaaS	Data-as-a-Service
EFL	Extraction, Transformation, Loading
EU	European Union
FIG	International Federation of Surveyors
GDP	Gross domestic product
GDPR	General Data Protection Regulation
GeoAI	Geospatial Artificial Intelligence
GIS	Geographic Information System
GKI	Geospatial Knowledge Infrastructure
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GRID3	Geo-Referenced Infrastructure and Demographic Data for Development
GSGF	Global Statistical Geospatial Framework
HAPS	High Altitude Pseudo Satellites
HAS	High Accuracy Service
IaaS	Infrastructure as a Service
ICT	Information and Communication Technology
IFC	Industry Foundation Class
IGIF	Integrated Geospatial Information Framework
IHO	International Hydrographic Organisation
InSAR	Interferometric Synthetic Aperture Radar
IoT	Internet of Things
ISO	International Organization for Standardization
ITS	Intelligent transport systems
LDCs	Least Developed Countries
MLS	Mobile laser scanning
NMGA	National mapping and geospatial agency
NSDI	National spatial data infrastructure
ODC	Open Data Cube
OGC	Open Geospatial Consortium
OpenELS	Open European Location Services
PaaS	Platform as a Service

PPP	Public Private Partnerships
R&D	Research and development
ROAS	Remotely Operated Aerial Systems
ROI	Return on Investment
SaaS	Software as a Service
SAR	Synthetic Aperture Radar
SBAS	Satellite-based augmentation system
SDGs	Sustainable Development Goals
SDI	Spatial Data Infrastructure
SDK	Software development kit
SDOs	Standards Development Organisations
SIDS	Small Island Developing States
SKI	Spatial Knowledge Infrastructure
STEM	Science, technology, engineering, and mathematics
UN	United Nations
UNICEF	United Nations Children's Fund
UN-DRIP	United Nations Declaration on Indigenous Peoples
UN-GGIM	United Nations Committee of Experts on Global Geospatial Information Management
UX	User experience
V2I	Vehicle-to-infrastructure
V2V	Vehicle-to-vehicle
V2X	Vehicle-to-everything
VGI	Volunteered geospatial information
VR	Virtual reality
W3C	World Wide Web Consortium
WGIC	World Geospatial Industry Council

Suggested further reading

We acknowledge that the report can only provide an overview of the various topics covered. For a more in depth understanding, we suggest the following reports and online resources as useful follow up reading.

Defence Geospatial Intelligence, *A view from the cloud: Sourcing, storing and analysing imagery in the digital era*, 2018.

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