Title: Thirty Years of the Open Geospatial Consortium - History, Present, and Future

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Abstract

For 30 years, the Open Geospatial Consortium (OGC) has advanced geospatial interoperability through continuous innovation. The OGC provides strategies and Standards that promote adoption, increase efficiencies, create new opportunities, and transform our relationship with the dynamic planet we inhabit. It has fostered global collaborations among companies, governments, academic institutions, and non-profit organizations, reducing the friction inherent in introducing innovations to the industry.

The article explores the OGC's history and future aspirations, demonstrating how it became a global community of innovators dedicated to ensuring their geospatial tools and data can work together seamlessly, supporting both essential public missions and private enterprises. The OGC brand is renowned not only for its technical innovation pilots but also for its leadership in global standardization within the geospatial technology community. Additionally, the article also highlights the OGC's commitment to enhancing reproducibility through research and development in data representation, discovery, and access as part of its standardization and research activities. The OGC is committed to promoting connectivity between people, technology, and decision-making, leveraging FAIR (Findable, Accessible, Interoperable, Reusable) principles.

Introduction

The use of geospatial data has transformed in ways that were not envisioned some decades ago. This paper attempts to document the journey in the context of the contributions of OGC towards such transformations, based on open standards and the process of building such standards. It also extends the role of current efforts in the OGC to further transform the technology landscape in the near future.

a) OGC as a Brand

Over its 30-year journey, the Open Geospatial Consortium (OGC) has established itself as a symbol of geospatial interoperability and innovation. Decision-makers from both public and private sectors regard the OGC as a trusted entity dedicated to fostering interoperability, keeping pace with the rapid expansion and constant innovation of the geospatial industry (Diaz et al., 2012, Hughes et al., 2018, Tripathi et al.,2020, Vandenbroucke et al., 2020). In response to the interoperability challenges posed by the early days of the Geographic Resources Analysis Support System (GRASS) some 40 years ago, a social movement emerged. This movement advocated for interoperability between various geospatial communities and technologies—whether commercial, governmental, academic, or open source in origin—to better harness geospatial data and make sense of our ever-changing world (Reed et al., 2015).

This movement led to the founding of the OGC in 1994, which has since forged global partnerships between private companies, governments, academic research units, and non-profit organizations with the mission of reducing the friction inherent in introducing innovations to the industry.

The OGC has played a pivotal role in the Geospatial Revolution (Reed, 2014, Percivall et al., 2015, Guler and Tahsin, 2022), advocating for the use of geospatial data and technologies to address grand challenges. Looking ahead to the next decade, the OGC is well-positioned to assist every industry, academic discipline, public agency, and non-profit organization in harnessing the power of geospatial innovation. Promoting interoperability strategies that facilitate adoption, enable efficiencies, create opportunities, and transform humanity's relationship with the ever-changing planet, the OGC's brand represents not just technical innovation and global leadership across the geospatial technology community.

Figure 1 provides an overview of the discussion flow regarding the past, present, and future of OGC.

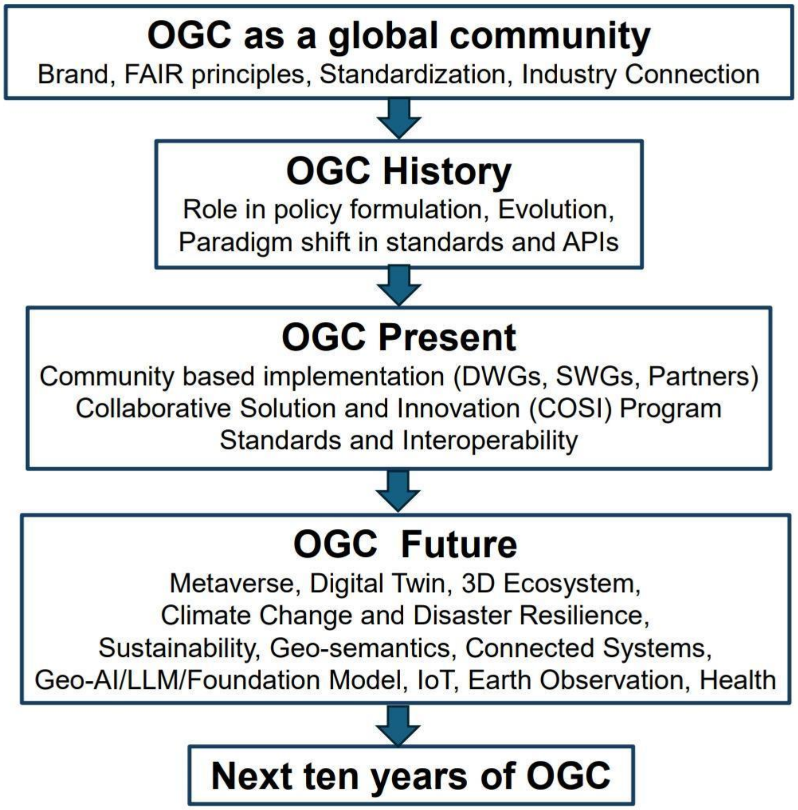

Figure 1. Overview of this paper

About OGC as a Community

The OGC plays a key role in global geospatial standardization, applying FAIR (Findable, Accessible, Interoperable, Reusable) principles to enhance decision-making by connecting people with data, applications, systems, and organizations. The OGC is a much sought after participant in global organizations, research projects, and conferences, including the International Organization for Standardization (ISO), the UN Global Geospatial Information Management (UN-GGIM) Committee of Experts, and the International Hydrographic Organization (IHO). The OGC's Collaborative Solutions and Innovations (COSI) Program leads applied research and development efforts aimed at testing and improving the reproducibility of OGC standards in data representation, discovery, and access. Details about the OGC COSI Program can be found in the 'present' section.

History

a) The emergence of OGC as a global community

By the mid-1980s, geographic information system (GIS) software was widely used in natural resources and defense, especially by government agencies. Other sectors, including state and local governments, civil engineering, transportation, and business marketing, were also exploring the technology. Interoperability issues were widespread in the geospatial domain, stemming from inability to share data across systems and platforms as opposed to exchange standards in engineering design that had already started evolving. Recognizing the need for a market-based consensus on interoperability, the Open GIS Consortium—now the Open Geospatial Consortium (OGC)—was founded in 1994. Established as a neutral, member-driven international organization, the OGC brought together public and private sector entities with a vision of enabling diverse geoprocessing systems to communicate over networks through open interfaces or standards. Starting with 20 member organizations in 1994, the OGC has grown to over 500 members today, thanks to the vision of founder David Schell, the leadership of OGC's first Technical Director, Kurt Buehler, and the commitment of its founding Board of Directors, including Kenn Gardels (University of California, Berkeley), Frederick Limp (University of Arkansas), Emil Horvath (USDA), Quentin Ellis (Camber Corp.), Ed Escowitz (USGS), and Scott Madrey (Rutgers University) (McKee, Lance. 2013).

The OGC was founded by geospatial professionals with a shared mission to promote interoperability in their field. They recognized that achieving this goal required practical engineering efforts to develop reference implementations that could be refined and adopted by a wider community. Through collaboration, experimentation, and consensus-building, they laid the groundwork for progress in the geospatial domain. The OGC's origins trace back to the GRASS (Geographic Resources Analysis Support System) community, heavily influenced by the U.S. Army's Construction Engineering Research Laboratory (USA-CERL) in Illinois. Initially focused on the U.S., with support from Canadian collaborators, the OGC quickly grew into a global network of innovators committed to ensuring their geospatial tools and data could interoperate to serve public missions and private businesses (McKee, Lance. 2013).

As the number and variety of geospatial technologies and data offerings grew, the OGC community's commitment to interoperability deepened. Despite competition for market dominance, academic leadership, and fulfilling public sector missions, innovators recognized the need for collaboration on challenging interoperability issues to keep pace with the field's rapid expansion and its increasing potential to address global challenges.

The international makeup of the first OGC Board of Directors was crucial in driving the organization's global reach. Through persistent outreach and advocacy, the initial group quickly connected with counterparts in Europe and Asia, expanding its size and sponsorship. As the OGC evolved into a formal organization, it gained the resources needed to pursue its vision of a global spatial data infrastructure that enables collective solutions to the world's most pressing issues (McKee, Lance. 2013).

b) Role of OGC in standards and broader geospatial community perspective

The OGC has developed a legacy of innovative programs to promote FAIR-based geospatial capabilities globally (Reichardt, 2016; Reichardt and Robida, 2019). Some key accomplishments include:

- **Simple Features (1998):** The first open, vendor-neutral standard that established a common vocabulary for geospatial features, marking OGC's first published standard.
- **Formal Liaison with ISO (1997):** Both ISO Technical Committee 211 and OGC were formed in 1994 with complimentary missions. The two organizations formally established a liaison relationship in 1997 to secure ISO branding and national adoption of geospatial standards developed in OGC as well as to formalize the baseline geospatial concepts as developed in ISO and adopted as OGC's Abstract Specification. Today, over 40 agreements with standards organizations ensure OGC standards are interoperable across IT environments and meet community needs.
- **OGC Web Services Standards (OWS, 1999):** These standards enabled web-based geospatial interoperability across platforms, networks, and the World Wide Web.
- **OGC Interoperability Program (COSI, 1999):** A first-of-its-kind initiative, providing a rapid engineering and prototyping environment to accelerate the development and validation of candidate OGC standards with real-world user requirements.
- **OGC Forums:** Country, region, or language-based forums allow members to collaborate directly within their communities to identify needs and implement OGC FAIR solutions.
- **Sensor Web Enablement (SWE) and SensorThings Framework:** Developed to address challenges in accessing and integrating data from sensors and IoT devices in a geospatial context, originating from efforts to address data integration challenges following the 9/11 attacks.
- **City Models/Digital Twins:** Standards like CityGML, CityJSON, IMDF, 3D Tiles, and I3S support the shift from 2D to 3D visualization of built and natural environments, enhancing data integration and decision-making.
- **Community Standards:** Inspired by technologies like Google's KML, OGC established Community Standards to adopt and endorse widely implemented open technologies developed outside of the OGC.

- **OGC API Standards:** Building on the success of OGC Web Services, these APIs offer modular capabilities to support modern web practices.

c) **Role in policy formulation:**

The OGC has played a crucial role in shaping geospatial policies by fostering collaboration and innovation in location-based information technology. Its influence is particularly notable in countries like Australia, Canada, India, the USA, The Netherlands, the UK, Singapore, and Taiwan, where OGC standards have guided national geospatial strategies.

- **Australia**: OGC standards are integral to the development of the country's Spatial Data Infrastructure (SDI), supporting various government services.
- **Canada**: OGC's framework has shaped GeoConnections, a national program integrating geospatial data across different levels of government.
- **India**: OGC principles are embedded in India's National Spatial Data Infrastructure (NSDI), and more recently in the National Geospatial Policy 2022.
- **United States:** The Federal Geographic Data Committee (FGDC) endorses OGC standards to improve geospatial data sharing among federal agencies and stakeholders.
- **The Netherlands:** OGC standards drive more efficient and collaborative use of geospatial information within the government.
- **UK:** The UK's location strategy emphasizes standardization, influenced by OGC, to support economic growth and environmental management.
- **Singapore:** OGC standards contribute to Singapore's Smart Nation initiative, enabling sophisticated urban planning and management through geospatial technology.
- **Taiwan:** The OGC has significantly contributed to Taiwan's disaster management strategies by establishing national standards for IoT sensors through the adoption of OGC standards such as SensorThings API, ensuring effective and interoperable data sharing for enhanced disaster preparedness and response.

In addition, the United Nations Integrated Geospatial Information Framework (IGIF), actively encourages all member nations to adopt OGC standards in geospatial information management. Extending beyond technical standards, the global scale of OGC's efforts foster open collaboration essential for addressing challenges like climate change, urbanization, and sustainable development.

d) **Evolution since formation:**

In its early days as the Open GIS Foundation, the first official OGC meeting, initially called "Technical Committee Meetings" took place on March 17, 1994. The eight-hour agenda included three panels and an open discussion on an Open Geodata Interoperability Specification. OGC held three more meetings that year and has since maintained a pace of four to six meetings annually, totaling 130 by the time of this publication. Attendance grew from a dozen participants in one to three-day sessions to over 200 attendees at five-day events with four concurrent tracks of working group sessions.

For 30 years, these gatherings have been crucial in advancing geospatial standards through collaboration, technical agreements, and policy advocacy, bringing together experts from government, industry, and academia to drive innovations in areas like GeoAI, Digital Twins, and climate resilience. Additionally, OGC COSI Program events, such as Testbed Kickoffs, have fostered the development and demonstration of cutting-edge geospatial solutions, showcasing the power of real-time interoperability.

e) Paradigm shift in standards and APIs:

Throughout its history, OGC has adapted its standards and technologies to align with changing IT trends. This includes adopting more popular formats, such as shifting from XML to JSON, and transitioning from SOAP (Simple Object Access Protocol) to REST (Representational State Transfer) web architectures. While XML and SOAP remain relevant and effective for many use cases, adopting JSON and REST better addresses emerging requirements.

Since 2014, OGC has also restructured its standards, focusing on simplicity and modularity. Inspired by Then-Board Member Chris Holmes' vision of "little bits of OGC," the new standards are now organized as Location Building Blocks (https://blocks.ogc.org/). Unlike complex, monolithic standards like Geography Markup Language (GML), these modular components solve specific interoperability challenges and can be mixed or reused across different standards.

Present

a) Community-based implementation

The OGC maintains two types of subcommittees: Domain Working Groups (DWGs) and Standards Working Groups (SWGs). DWGs focus on the application or potential for OGC standards in specific domains, such as agriculture, urban digital twins, meteorology, oceanography, or in technologies like 3D information management and discrete global grid systems. Currently, there are over 45 active DWGs.

SWGs are responsible for the development and maintenance of specific standards and their extensions, with over 50 active SWGs. OGC standards are often multipart, with SWGs adding functionality to a core standard. Each year, OGC publishes 10 to 20 new standards or standard extensions.

Over the past three decades, membership has grown globally, now representing 47 countries, with a balanced composition of 40% from industry, 30% from government, and 30% from research and academia. As of 2024, OGC has over 450 members worldwide. The organization has also established partnerships with key organizations such as ISO, the International Hydrographic Organization (IHO), buildingSMART International, and the World Wide Web Consortium (W3C), in addition to media groups, industry associations, and scientific bodies (Reichardt, 2016).

b) Innovation Programs, Pilot, and Testbeds

The OGC Collaborative Solutions and Innovation (COSI) Program, which operates code sprints, pilots, and test beds (Figure 2), employs a unique model that combines competition and collaboration to address a range of problems within larger challenges, such as disaster response. While participant selection is competitive, the actual work is highly collaborative, with teams working together to create a cohesive set of tested, interoperable solutions. This model has the potential to be replicated and scaled in various contexts (Percivall et al., 2015; Simonis, 2019b). For example, in the field of AI, it is particularly well-suited to realize the emerging paradigm of a world model—a unified, multi-dimensional view of a system—that leverages interoperable submodels (i.e., different foundation models) to simulate and predict complex, real-world phenomena.

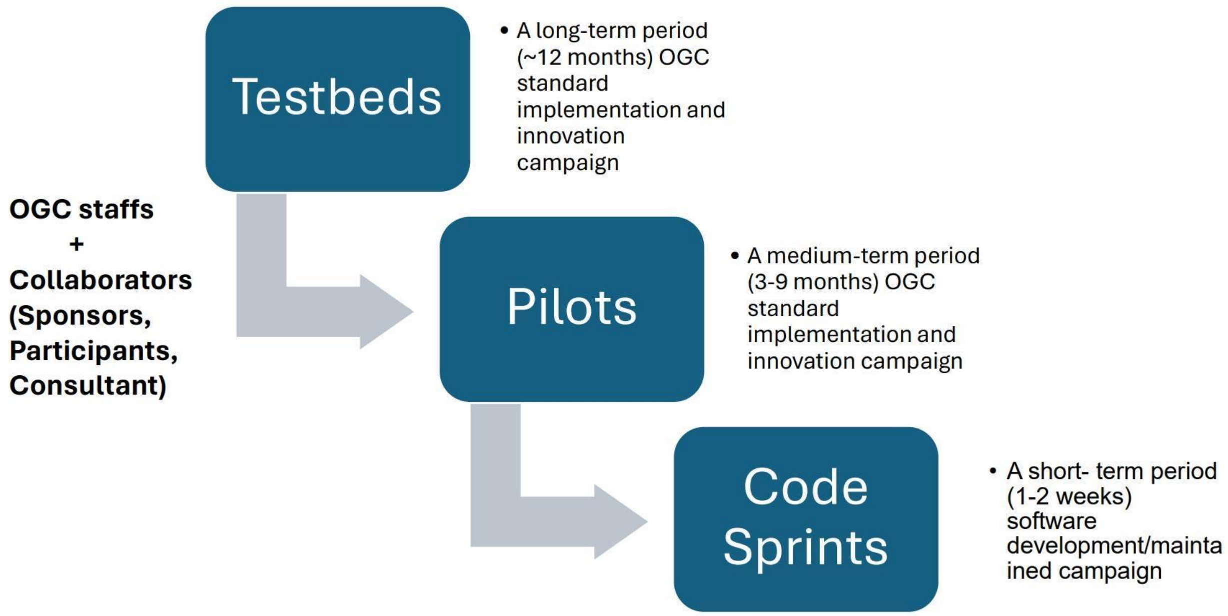

Figure 2. OGC COSI program development process

Disaster response pilots, for instance, have developed real-time monitoring and early warning systems tailored to natural disasters like typhoons, earthquakes, and floods, revolutionizing disaster preparedness and response. OGC standards enable seamless integration of diverse geospatial data, essential for building efficient systems that enhance public safety. These systems provide authorities with the tools to make quick, informed decisions, improving response times and reducing risks and damages in many countries worldwide.

Beyond operational efficiency, these standards contribute significantly to building community resilience, allowing for faster and more effective recovery from natural disasters. This highlights the crucial role of OGC standards, not only in advancing technology but also in improving human safety and community well-being.

c) Standards and Interoperability

OGC provides a portfolio of standards to address specific aspects of enterprise architecture and support geospatial domains (Reed et al.,2015; Reichardt and Robida, 2019). Figure. 3 highlights the range of these standards and their roles in enabling interoperability. More details and abbreviations used in Figure 3 can be found at OGC Standards Architecture Diagram (https://www.ogc.org/standards/standards-architecture-diagram/). These standards are highly interoperable, allowing, for example, sensors using the OGC SensorThings API to integrate with a CityGML model and be accessed through one or more OGC API instances. Data updates can also be shared via a Publish-Subscribe interface.

Reflecting the trend toward greater modularity, many new OGC standards address specific issues and can be reused in other standards or implementations. For instance, the GeoPose Standard defines a uniform way to describe an object's six-degree-of-freedom position and orientation, applicable to Moving Features, Sensors, or other objects in OGC standards, as shown in Figure. 4.

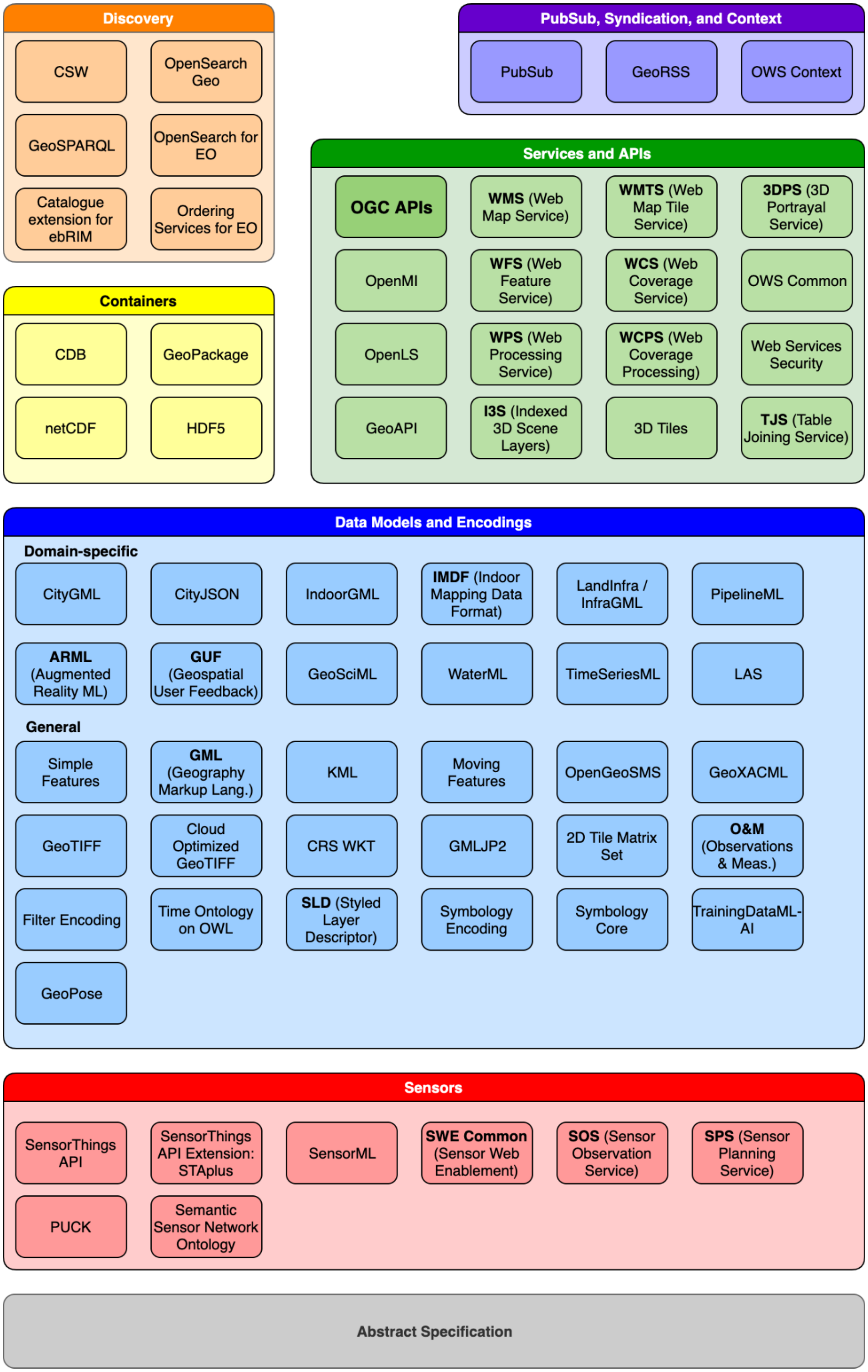

Figure 3. OGC current Standard architecture diagram

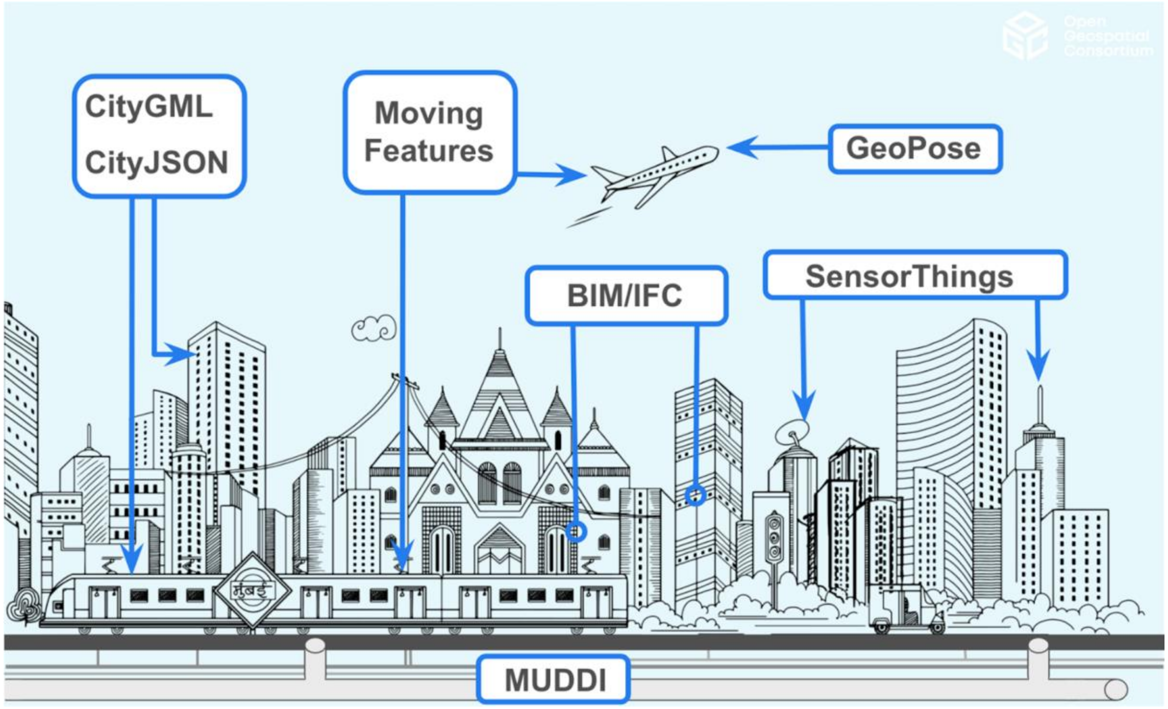

Figure 4. Standards integrated in an urban environment (BIM: Building Information Model; IFC: Industry Foundation Classes; MUDDI: Model for Underground Data Definition and Integration)

Future:

a) Metaverse and Digital Twin

The concept of interoperable platforms allowing users to collaborate and interact within immersive, virtual representations of our world is known as the metaverse. An open metaverse would provide a realistic and cohesive geo-representation of the physical world, enabling diverse 3D experiences. Delivering such seamless experiences is aided by interoperability among client applications, platforms, and data. Open standards and expertise in working with geospatial data will be essential to the metaverse's development, making the OGC a key player in realizing this vision. To support this, the OGC formed the Geo for Metaverse DWG (https://www.ogc.org/about-ogc/committees/dwg/geo-for-metaverse-domain-working-group/), focused on organizing knowledge and defining geospatial data and technology requirements for the metaverse. This group adheres to the OGC's approach of creating modular, lightweight, and extensible open standards that can evolve with technology while providing a stable foundation for innovation.

The OGC has played a crucial role in developing standards for digital representations of the physical world, contributing significantly to the concept of digital twins. These digital twins are dynamic models that mirror real-time changes in urban environments, aiding in decision-making and planning. The OGC's recent formation of a DWG on Urban Digital Twins (https://www.ogc.org/about-ogc/committees/dwg/urban-digital-twins-domain-working-group/) sets the stage for establishing foundational standards guided by the FAIR principles. These standards ensure that digital twins can seamlessly integrate diverse data sources, making them increasingly accurate and valuable for simulations, analytics, and predictive modeling, even within a metaverse context (OGC Location Powers 2021; https://www.locationpowers.net/events/2101urbanvirtual/index.php).

Looking ahead, the OGC's commitment to open standards will not only enhance urban planning and management but will also extend to other sectors, such as transportation, utilities, and emergency response, where real-time geospatial data is critical. The ongoing advancement of these standards will ensure that digital twins and other geospatial technologies remain at the forefront of innovation, supporting numerous applications, as shown in Figure 5.

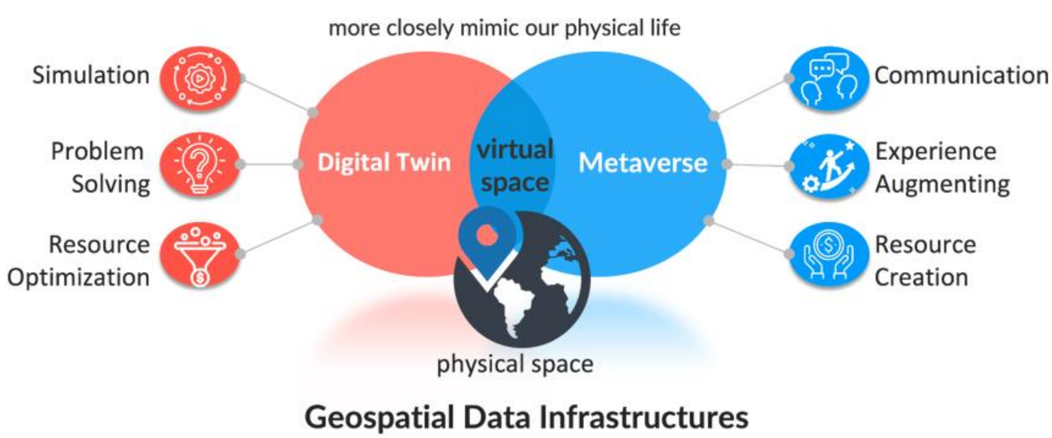

Figure 5. The relationship between Digital Twins and the Metaverse.

b) 3D Ecosystem

The OGC's open and free geospatial standards define interoperable approaches to data encoding, access, processing, visualization, and metadata and catalog services. From a 3D perspective, the OGC has been leading the development of emerging and recently published standards, such as the OGC API - 3D GeoVolumes and 3D Tiles, designed for rendering and streaming 3D geospatial content like BIM/CAD, 3D buildings, photogrammetry, instanced features, and point clouds. The proliferation of three-dimensional (3D) data and ecosystems has revolutionized various industries and applications, as 3D data provides more precise and realistic representations of the real world.

Several advancements have been instrumental in the standardization of 3D data and ecosystems:

1. Data Formats and Standards: The OGC is increasingly building its standards for the 3D ecosystem on a foundation of industry-normative formats, such as glTF (.gltf) for representing 3D models.
2. 3D Scanning and Capture: The development of advanced 3D scanning technologies, including laser scanning, photogrammetry, and structured light scanning, has facilitated the efficient and accurate capture of real-world objects and environments. The LAS file format is a fundamental standard for storing LiDAR datasets although requirements of such storage continue to evolve (Sen and Turel, 2020).
3. 3D Content Delivery: The OGC has recognized and endorsed the 3D Tiles and I3S Community Standards for sharing and interacting with 3D scenes. For example, the Google Maps Platform uses Photorealistic 3D Tiles in the OGC 3D Tiles format, enabling next-generation visualization use cases. Additionally, the 3D Portrayal Service standard advances geospatial 3D content delivery by focusing on interoperable 3D portrayal, specifically defining how geospatial 3D content is described, selected, and delivered.

These advancements have driven the rise of 3D data and ecosystems, enabling a wide range of applications in industries such as manufacturing, healthcare, entertainment, and architecture. Looking ahead, the potential for 3D data continues to grow with advancements in artificial intelligence, augmented reality, and virtual reality further expanding its reach and impact. Many of these standardization objectives are discussed in forums such as the Point Cloud DWG, 3D Information Management DWG, and Interoperable Simulation and Gaming DWG, showcasing the collaborative progress of the OGC as a community.

c) Geo-AI/LLM/Foundation Models

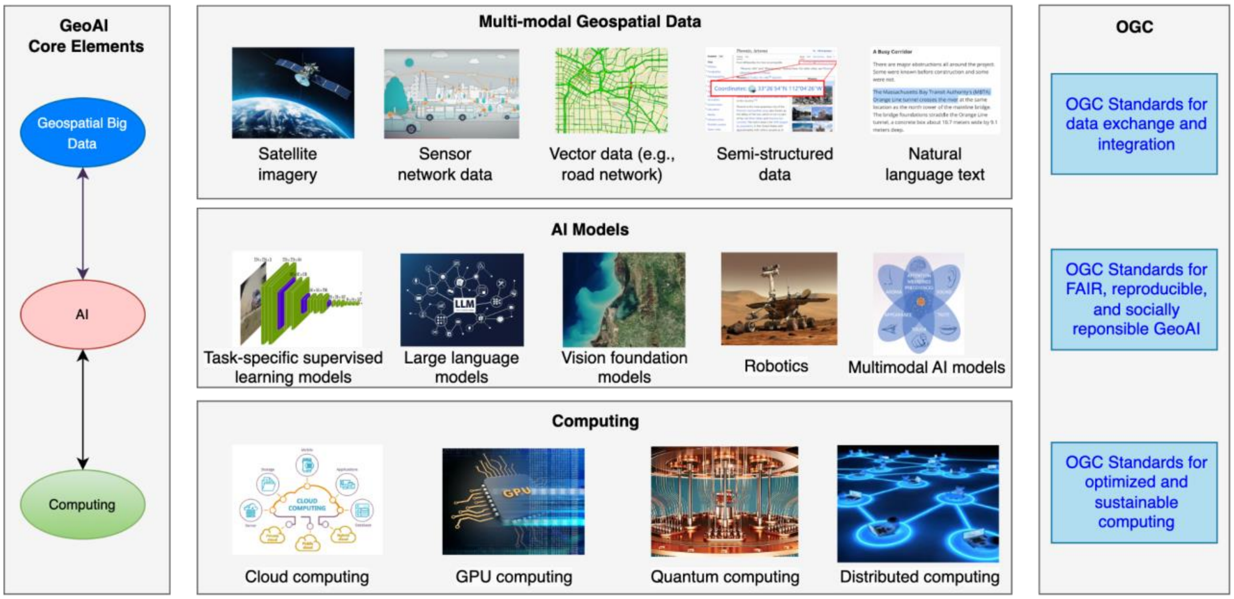

Figure 6. OGC plays a key role in building the GeoAI research and development ecosystem

The geo-knowledge base that our interconnected world relies on today is being generated by data from sources ranging from sensors in mobile devices to satellites, and this data is growing exponentially. Consequently, interest and work in developing applications for geospatial artificial intelligence (GeoAI) have been rapidly increasing (Janowicz et al., 2020; Li, 2020). Defined as "the amalgamation of artificial intelligence (AI) with spatial computing to develop a better understanding of the physical world around us at the levels of individuals, communities, cities, nations, and the planet using geospatial data", GeoAI's diverse applications and use cases represent a highly interdisciplinary field requiring the integration of ideas from disciplines far beyond computing and AI (Figure. 6).

Geospatial data includes various modalities such as geometry, raster, natural language text, semi-structured data, and multispectral data capturing the ever-changing near-surface of the Earth. This makes GeoAI distinct from general AI because it leverages unique characteristics such as spatial autocorrelation and spatial heterogeneity to solve problems in our physical world (Goodchild & Li, 2021; Li et al., 2021). The GeoAI DWG (https://www.ogc.org/ogc-topics/geospatial-and-artificial-intelligence-geoai/) conducted a detailed survey to understand the needs of the community and then organized a GeoAI Roundtable (https://www.ogc.org/ogc-events/geoai-roundtable/) to use the survey results in scoping AI activities to be pursued within OGC. A significant focus area for the GeoAI DWG is determining how OGC can support and nurture the development of multimodal geospatial foundation models, including large language models with an inherent understanding of space and time, to assist in various geospatial domain tasks.

Open standards lower development costs, ensure interoperability, and enhance safety, creating a seamless GeoAI ecosystem. The following standard ideas are being considered to support this ecosystem:

1. **Updating standards for geospatial data and metadata representations** optimized for use with large language models to enable reliable geographic queries.
2. **Standardizing communication among different GeoAI applications** through APIs and attributes to support interoperability within an API/microservices-based paradigm.
3. **Establishing a standard to communicate how methods or models leverage spatial autocorrelation** for improved performance, as well as quantifying uncertainty in predictions through sensitivity analysis.
4. **Creating a public repository of potential AI risks and harms** is crucial for future adoption and trust in the technology. Therefore, the geospatial community needs a standard for reporting any incidents of harm caused by GeoAI applications, specifying the nature of the harm, where and when it occurred, and how it should be reported.

The rise of foundation models, particularly large language models (LLMs), marks a major milestone in AI development (Bommasani et al., 2021). These pre-trained models excel at encoding representations across diverse tasks, thanks to transformer architectures that focus on relevant features in sequential data. LLMs have expanded AI applications, especially in natural language processing. NASA Science has applied foundation models to enhance geospatial workflows, from data acquisition to analysis (Jakubik et al., 2023), while techniques like zero-shot learning reduce the need for large datasets. Future advancements may focus on multimodal applications and address ethical issues like bias and sustainability (Janowicz, 2023).

OGC Standards will provide the spatial context for AI

The digital world is transforming through LLMs like ChatGPT, which compress vast web text into contextual embeddings that predict missing values. Models like OpenAI's text-embedding-ada-003 condense large data (~8191 tokens: https://learn.microsoft.com/en-us/azure/ai-services/openai/concepts/models#embeddings-models) into a 1536-dimensional space (OpenAI, 2022). However, geospatial data remains siloed and disorganized, resisting similar compression.

Addressing this challenge requires aligning geospatial data from various applications through the use of shared ontologies and standardized protocols. This approach would establish an interconnected semantic framework, like what has been achieved with text data on the web. Standardization is necessary to develop geospatial models that understand space and time with the same precision that LLMs bring to text data.Integrating vision agents with geospatial data enhances real-time decision-making and situational awareness in disaster response and autonomous systems.

OGC standards have laid the foundation for advancing AI in geospatial data by enhancing accessibility and interoperability. Standards like OGC API - Processes facilitate AI integration into geospatial workflows, while formats like GeoTIFF for raster data and GeoParquet for large datasets, combined with GeoSPARQL and OGC APIs, support seamless data sharing across platforms. This standardization ensures consistent, accessible, and Analysis Ready Data (ARD), essential for AI applications in predictive analytics, pattern recognition, and spatial decision-making. These foundations pave the way for innovations in areas like autonomous driving, disaster response, and smart city planning, as well as emerging applications involving vision agents that interpret and process geospatial imagery in real time.

The OGC will lead initiatives to enhance GeoAI, focusing on data, modeling, validation, and ethics. Collaborating with OGC/W3C, they will address privacy, fairness, and transparency. While frameworks like GDPR guide ethical use, all stakeholders must act responsibly. The GeoAI DWG will host discussions with researchers on advancements and impacts, while OGC Testbeds will drive collaboration, incubating solutions like real-time object tracking and advancing reproducibility in GeoAI research.

Adopting OGC standards and FAIR data approaches will create a modular, adaptable toolset that evolves with technology. Initiatives like Training Data Markup Language for AI (TrainingDML-AI) build on existing standards to connect geospatial data, similar to LLM training data. This will lead to geospatial foundation models with unprecedented precision in understanding space and time, while addressing ethical concerns such as bias to ensure responsible AI use in geospatial applications.

d) Internet of Things (IoT) and Connected Systems

The Internet of Things (IoT) has revolutionized how we interact with the world, and the OGC has been a pivotal force in this transformation. From the early SensorML standard to the modern SensorThings API (https://www.ogc.org/standard/sensorthings/), the OGC has promoted interoperability across diverse sensor networks. SensorML facilitated seamless integration of sensors, while the SensorThings API now provides a unified approach to connecting IoT devices and applications. This has enabled the development of smart cities and intelligent infrastructure, where sensors gather and share data to optimize efficiency and improve public services. For instance, traffic lights can adjust in real time based on traffic flow, waste management systems can optimize routes, and energy distribution can be managed more efficiently through geolocated measurements.

Sensors play a vital role in monitoring and maintaining infrastructure within a geospatial context. In smart cities, sensors continuously monitor the health of structures, detect anomalies, and trigger maintenance alerts when necessary. This constant data flow is essential for optimizing urban systems and improving services. The use of location-based standards ensures that IoT devices and applications can seamlessly share geospatial data, which is critical to the success of many IoT applications. As the IoT landscape evolves, OGC's role will remain central in addressing challenges such as scaling solutions, ensuring security, and maintaining privacy, which are essential for sustainable and resilient communities.

The integration of IoT technology, led by OGC standards, marks a significant advance in real-time environmental monitoring and disaster management. Networks of interconnected sensors can capture critical data in real-time in disaster-prone areas, detecting threats like floods and landslides early. OGC standards ensure that this data can be shared and integrated into disaster management frameworks, enabling swift response and reducing potential damage. By ensuring that the data is accurate, timely, and accessible, OGC standards empower emergency response teams to act quickly, enhancing the resilience of vulnerable communities against natural disasters.

After nearly 25 years of work on SensorML and the Sensor Web Enablement (SWE) architecture, the OGC is now entering a new era of interconnected systems with its upcoming OGC API—Connected Systems Standard. This new standard will support the integration of all types of sensors and platforms across diverse domains such as space, air, land, sea, and cyber, along with various sensing technologies. It aims to synchronize all systems on and around Earth in both space and time, making geospatial data inherently spatiotemporal. This future framework will enable advanced capabilities for monitoring, reasoning, and action, transforming how systems interact with and respond to the world around them.

e) Earth Observation

Earth observation (EO) involves collecting and analyzing data about Earth's physical, chemical, and biological systems using remote sensing technologies, such as satellite and aerial sensors. This field is crucial for applications like environmental monitoring, climate research, urban planning, and disaster management. As EO technologies continue to evolve, the volume of data generated has grown exponentially, creating challenges in managing, processing, and analyzing this data efficiently.

The OGC develops internationally recognized standards to ensure the interoperability, accessibility, and sharing of EO data across diverse platforms and organizations. These standards enable seamless integration of data from various sources, allowing stakeholders to derive meaningful insights. OGC's work is essential for EO applications, where harmonizing data from multiple sensors and platforms is critical for comprehensive analysis and decision-making.

OGC's initiatives also include cloud-native geospatial standards such as Zarr and GeoParquet, which enhance the scalability and efficiency of EO data storage and access. Additionally, the organization supports other widely used data encodings, including HDF, NetCDF-CF, and GeoTIFF, further broadening the range of tools available for handling large, complex datasets. The adoption of these standards improves the usability and accessibility of EO data for a wide range of applications.

The OGC plays a leading role in advancing EO technologies through specialized working groups, such as the EO Image Exploitation DWG (https://www.ogc.org/about-ogc/committees/dwg/earth-observation-exploitation-platform-domain-working-group/) and the Meteorological and Oceanographic (Met/Ocean) DWG (https://www.ogc.org/about-ogc/committees/dwg/meteorology-oceanography-domain-working-group/). These groups focus on developing and refining EO data standards and technologies. Tools like the OGC API for Environmental Data Retrieval (API-EDR; https://www.ogc.org/standard/ogcapi-edr/) facilitate standardized access to real-time environmental data, enabling better decision-making in critical fields like climate resilience, environmental policy, and disaster management.

f) Health

The use of geospatial data in health services is undergoing a significant transformation, particularly in the location-based analysis of risk factors and infectious disease modeling. The OGC Health DWG (https://www.ogc.org/about-ogc/committees/dwg/health-domain-working-group/) brings greater awareness to geospatial analysis by incorporating health use cases in its pilots and annual Global Health Summits. The OGC Concept Development Study for a health spatial data infrastructure (OGC, 2022) provides an opportunity to develop tools and systems that rapidly transform EO, IoT, Internet-of-Medical-Things (IoMT), and citizen science data into Analysis Ready Datasets (ARD) and Decision Ready Information, assisting physicians, epidemiologists, and public health policymakers in driving positive health outcomes.

Through its various pilot activities, the OGC has supported the development of a wide range of health risk analytics, from identifying in advance the health risks posed by natural disasters (hurricanes, wildfires, droughts) and climate change to managing medical supply chains responsive to delivery needs during concurrent pandemics and natural disasters. Additionally, the OGC has addressed current risks associated with plastic pollution in our oceans and waterways, as well as heat exposure in urban environments.

Areas for further advancement include developing standards for aggregating public health data at various subnational administrative boundaries, continuing efforts to extract health-related features from EO data, as well as developing health use cases for Urban Digital Twins.

g) Sustainability

Sustainability has become a global imperative, and the OGC has empowered organizations to leverage geospatial data in pursuit of the United Nations Sustainable Development Goals (SDGs). Established by the UN in 2015, these 17 interlinked goals serve as a "blueprint to achieve a better and more sustainable future for all" by 2030. They address critical issues like poverty, inequality, climate change, environmental degradation, peace, and justice.

By setting and promoting standards for geospatial data, OGC plays a key role in advancing the SDGs. Reliable and interoperable geospatial data are essential for tracking progress and achieving goals such as sustainable cities and communities (Goal 11) and climate action (Goal 13). OGC’s efforts ensure that data from diverse sources can be effectively integrated, analyzed, and shared, supporting informed decision-making and policy planning.

Looking ahead, OGC's commitment to innovation and collaboration will be crucial in addressing the environmental challenges of our time. The consortium's work will continue to enable the sharing of critical geospatial data across borders and sectors, improving environmental monitoring, resource management, sustainable mobility, climate mitigation, adaptation, and disaster preparedness—all vital for building a sustainable future for generations to come.

The OGC has been a key player in promoting global sustainability through its open geospatial standards and initiatives, including:

- **OGC Location Powers 2022, London:** This event focused on the power of location-based data in addressing global challenges. Discussions highlighted the role of geospatial data in ESG reporting, the need for international cooperation, and standardized data formats to improve data sharing and interoperability (event page: https://www.ogc.org/blog-article/principled-and-powerful-geospatial-data-for-esg-reporting-at-location-powers-2022/).
- **Climate Change Special Session 2022:** This session explored the impact of climate change and the role of geospatial data in mitigation and adaptation

efforts. Case studies on EO data for monitoring environmental changes emphasized the need for international collaboration and standardized data formats for effective climate action (webpage: https://www.ogc.org/blog-article/7-key-takeaways-from-the-ogc-climate-change-special-session/).

- **OGC Innovation Days 2023:** This event brought together climate, disaster, and emergency resilience communities to discuss advancements in geospatial technologies, including AI integration, smart cities, and remote sensing. Researchers, industry leaders, and policymakers shared insights and collaborated on innovative solutions (event page:https://www.ogc.org/ogc-events/2023-ogc-innovation-days-and-climate-and-disaster-workshop/)
- **Climate Resilience Pilot 2024:** This pilot project demonstrated the practical use of geospatial data to enhance climate resilience. It deployed advanced sensors and data analytics to monitor climate risks like flooding, wildfires, and heatwaves, showcasing the benefits of OGC standards in supporting decision-making for disaster management and urban planning (pilot page:https://www.ogc.org/initiatives/crp/) .

These initiatives highlight OGC's ongoing role in shaping global sustainability efforts through open geospatial standards and collaboration.

h) Disasters/Climate Change

The OGC Disaster Resilience pilots, now in their sixth consecutive year, demonstrate how geospatial technologies provide first responders, emergency operations managers, and the public health community with greater visibility into disaster scenarios. These pilots have covered a wide range of scenarios, including flooding, drought, pandemics, hurricanes, wildfires, landslides, and medical supply needs, across multiple countries, including the US, Canada, Peru, and Taiwan.

Additionally, the OGC hosts Disaster Stakeholder Community Coordination Group Meetings, providing a platform for stakeholders to share insights into their needs before, during, and after disasters. The Emergency and Disaster Management DWG (https://www.ogc.org/about-ogc/committees/dwg/emergency-and-disaster-management-domain-working-group-2/) also plays a crucial role in discussing how GIS technologies can meet these needs. As climate change increasingly influences the frequency and severity of disasters, the OGC has integrated its climate and disaster efforts into a joint Climate and Disasters Resilience pilot series to encourage interoperability and collaboration across these two, interrelated domains.

The OGC will continue to support critical research areas focused on understanding and adapting to global climate change, including Arctic permafrost thaw, urban heat islands, and extreme weather, with the goal of improving human well-being, particularly for indigenous and underserved communities. Geospatial data interoperability is an area where the OGC can provide significant support. For instance, in the Arctic, datasets are managed by mapping agencies across different countries (Li, 2018). Coordinating mechanisms for data sharing and interoperability will enhance collaboration and enable researchers to address complex questions on a pan-Arctic scale.

As geospatial research increasingly relies on AI, it is essential for the OGC to lead in standardizing the organization and documentation of training data to create highly reusable AI-ready datasets. This effort will not only improve the reproducibility, replicability, and transferability of geospatial methods (Kedron et al., 2021), but it will also support the cross-validation of results across geographically diverse regions and climate zones (Li et al., 2024). A crucial aspect of understanding climate change is the ability to forecast future changes, which requires the alignment and integration of multi-modal datasets from diverse sources. The OGC's pioneering work in managing spatial and temporal data from both Earth and extraterrestrial environments will provide invaluable guidance for future climate projections.

i) Geo-semantics/OGC rainbow

The Standards developed by the OGC are focused on the interoperability issue at the structural level. However, the standards required to address geospatial semantic interoperability are currently limited (Durbha et al, 2010). Standardized Semantic models and services are not yet fully developed. Some OGC initiatives in semantics are described below.

GeoSPARQL-A Geographic Query Language for RDF Data

OGC publishes a standard called GeoSPARQL(https://www.ogc.org/standard/geosparql/) that supports representing and querying geospatial data on the Semantic Web. GeoSPARQL defines a vocabulary for representing geospatial data in Resource Description Framework (RDF) (https://www.w3.org/RDF/), and it describes an extension to the SPARQL query language for processing geospatial data.

SSN and SOSA

OGC and W3C jointly developed a set of ontologies to describe sensors, actuators, samplers, and their observations, actuation, and sampling activities (OGC and W3C Semantic Sensor Network Ontology: https://www.w3.org/TR/2017/REC-vocab-ssn-20171019/). The ontologies have been published as a W3C recommendation and an OGC standard. The set includes a lightweight and modular ore module called SOSA (Sensor, Observation, Sampler, and Actuator) and a more expressive extension module called SSN (Semantic Sensor Network) [Haller et al., 2019].

QB4ST: RDF Data Cube extensions for spatio-temporal components

QB4ST (https://www.w3.org/TR/qb4st/) is an extension to the existing RDF Data Cube ontology to support the specification of key metadata required to interpret spatio-temporal data. QB4ST provides generalized support for numeric and other ordered reference systems, particularly Spatio-temporal Reference Systems.

Time Ontology in OWL (OWL-Time)

OWL-Time is an OWL-2 DL ontology of temporal concepts describing the temporal properties of any resource denoted as URI. The ontology provides a vocabulary for expressing facts about relations among instants and intervals, together with information about durations, and about temporal position including date-time information (https://www.w3.org/TR/2017/REC-vocab-ssn-20171019/). OWL-Time is published jointly by OGC and W3C.

OGC RAINBOW (https://www.ogc.org/resources/rainbow/) is a web-accessible registry that serves as a node within an ecosystem of resources, hosting and linking definitions, vocabularies, and specification registers, via stable URIs that resolve to detailed definitions. This platform supports various data formats (e.g., HTML, JSON-LD, TTL) to ensure both human and machine readability, aiming to facilitate a common understanding across different communities and foster innovation in the use of spatial information. RAINBOW includes features for term resolution, content negotiation, and a modular open-source architecture, enhancing data sharing and standardization across diverse applications.

Next ten years of OGC:

Over the next 10 years, OGC's initiatives in areas such as the metaverse, digital twins, GeoAI, and IoT are poised to become integral parts of the marketplace. By promoting open standards, OGC is driving interoperability and the seamless integration of geospatial data, enabling industries like smart cities, transportation, and disaster management to leverage real-time geospatial insights. These advancements are moving from theory to reality, supporting the integration of diverse data sources and fostering more accurate simulations and decision-making processes across multiple sectors.

A key focus for the future is the democratization of geospatial data access. OGC’s work on APIs, cloud-native technologies, and simplified data formats will enable non-geospatial industries to integrate geospatial capabilities into their operations without requiring specialized expertise. This accessibility will drive the commoditization of geospatial technology, making it a vital tool for industries beyond traditional geospatial fields.

Artificial intelligence (AI) will play an increasingly significant role in processing spatio-temporal data over the next decade. OGC's efforts in GeoAI will enhance the potential for AI to unlock geospatial data's full value, supporting new applications and expanding its impact across industries. By fostering innovation and collaboration, OGC’s leadership in advancing real-world solutions will solidify its role as a key player in shaping the future of geospatial technology

Conclusion

Over the past 30 years, the Open Geospatial Consortium (OGC) has established itself as a cornerstone of geospatial interoperability and innovation. From its inception in 1994 to its current status as a global leader in geospatial standardization, the OGC has consistently promoted connectivity between people, technology, and decision-making. Its commitment to developing open standards has been instrumental in advancing the geospatial industry, enabling seamless data sharing and integration across diverse platforms and applications.

As we look to the future, the OGC is poised to play a pivotal role in shaping the next generation of geospatial technologies. The organization's focus on emerging areas such as the metaverse, digital twins, GeoAI, GenAI, and the Internet of Things demonstrates its adaptability and forward-thinking approach. By continuing to develop and refine standards that address the challenges of these new technologies, the OGC is ensuring that geospatial data remains accessible, interoperable, and valuable across a wide range of industries and applications.

The OGC's ongoing efforts in enhancing reproducibility through research and development, coupled with its commitment to fostering collaboration among diverse stakeholders, position it as a key enabler of geospatial innovation. As the world faces increasingly complex challenges related to climate change, sustainability, and disaster resilience, the OGC's work in standardizing geospatial data and technologies will be crucial in supporting informed decision-making and driving positive outcomes. By maintaining its focus on open standards and embracing new technologies, the OGC is well-equipped to continue its mission of making location information FAIR (Findable, Accessible, Interoperable, and Reusable) for the benefit of society as a whole.

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