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SPATIAL INFORMATION FOR DEVELOPED AND DEVELOPING SMART CITIES

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Abstract

Urban population accounts for more than half of the world's population (World Health Organization, 2014)). By 2030, this is expected to rise to 60%, with 95% of growth occurring in the developing world (United Nations Sustainable Development Goals (SDG), 2015, Goal 11: Make cities inclusive, safe, resilient and sustainable), with a substantial proportion living in poverty in Megacities. High density cities can realize efficiency gains by making better use of spatial information. Geospatial information is often difficult to find, share, fuse, analyze and publish. Open standards are critical to enabling cities to ensure the data is made available to produce information that is actionable and fit for purpose and will work well with existing and emerging technologies. Maximizing the use of the data, selecting an appropriate level of openness and building an enabling infrastructure, supports improved governance.

The OGC has developed a Smart Cities Spatial Information Framework to provide guidance on how ICT location standards for City Models, Sensors, and Mobile enable efficient information management to support informed decisions for such scenarios as coastal flooding, 3D city modelling and Public Security. This talk will present the framework using examples from Dhaka, Bangladesh, the City of Berlin and other cities.

Key Words: Standards, Geospatial, Smart Cities, Sustainable Development

1.0 INTRODUCTION

Today, urban population accounts for 54 percent of the total global population (World Health Organization, 2014). By 2030, this is expected to rise to 60%, with 95% of growth occurring in the developing world (United Nations Sustainable Development Goals (SDG), 2015, Goal 11: Make cities inclusive, safe, resilient and sustainable). Effective integration of human, physical, and digital systems operating in the built environment holds the promise of improving the quality of life of urban residents, improving the governance of cities and making cities prosperous, inclusive, sustainable and resilient. Location is a primary method for organizing Smart City services and communicating anything about location requires standards.

Figure 1. A Smart City uses location as an organizing principal to benefit residents, visitors, and businesses of all types. (Graphic from Steve Liang, University of Calgary)

The framework is structured using an architectural approach for defining information systems organized as a set of viewpoints. The set of viewpoints used here are based on ISO/IEC 10746, Information Technology — Open Distributed Processing — Reference Model (https://www.iso.org/standard/55724.html). Section 2 of the paper provides an Enterprise Viewpoint, including a definition of a Smart City, the Indicators for assessing the value of deploying the technology, and an overall set of components for the information system of a Smart City. Section 3 provides an Information Viewpoint, outlining the spatial information and data that is needed in a Smart City. Section 4 outlines the computational Services Viewpoint including interfaces and workflows pertinent to a achieve interoperability using a service oriented architecture for a Smart City. Section 5 provides a Deployment Viewpoint, identifying approaches for deploying the Spatial Information Framework in cities.

2. SMART CITY INFORMATION ENTERPRISE VIEW

A Smart City provides effective integration of physical, digital and human systems in the built environment to deliver a sustainable, prosperous and inclusive future for its citizens (BSI PAS 180 - Smart Cities Vocabulary).

While the focus in this white paper is on technology, implementing smart cities must consider social policy and the benefits of technology to humans to enable and support "smarter citizens". This emphasis recalls Jane Jacobs's revolution in urban planning some decades ago, which focused on the value of community life and social networks. Jane Jacobs (The Death and Life of Great American Cities, 1961) said, "Cities have the capability of providing something for everybody, only because, and only when, they are created by everybody." Physical city architect Jan Gehl recalls (http://assemblepapers.com.au/2013/06/13/cities-for-people-jan-gehl/, June 13th, 2013) that "fifty years ago Jacobs said – go out there and see what works and what doesn't work, and learn from reality. Look out of your windows, spend time in the streets and squares and see how people actually use spaces, learn from that, and use it." Applied to smart city information development Jacob's ideas point to "Open Information " and "Iterative Development. Architects of Smart City information systems need to think of "openness" as a key technology design principle that helps developers and users of technology see what works and what doesn't work. Low-cost, open-participation iterative experiments, testbeds and pilot projects based on free and open interface and encoding standards encourage innovation and provide insight and guidance that can optimize for improvisation and resilience as well as prevent expensive IT failures. To be successful, a Smart City must enable better choices by its citizens, organizations and governments.

Cities need metrics to measure their performance. The ISO international standards organization is developing a series of standards to support sustainable development and resilience in cities. A key standard is ISO/DIS 37120 Sustainable development and resilience of communities — Indicators for city services and quality of life ISO 37120 defines methodologies for a set of indicators to steer and measure the performance of city services and quality of life. The indicators in ISO 37120 are organized in themes:

- Economy
- Education
- Energy
- Environment
- Recreation
- Safety
- Shelter

- Solid waste
- Telecommunications and innovation
- Finance
- Fire and emergency response
- Governance
- Health
- Transportation
- Urban planning
- Wastewater Water and sanitation

Developing and communicating data needed for most of these indicators involves geospatial technologies and in many cases geolocated sensors. Spatial information technologies identified in this framework will be supportive of these indicators, not just to calculate and communicate measures for these indicators but to enable planning, development and public leadership in achieving the indicators

Smart Cities require deployment of interoperable information system components in order to effectively support analysis to support indicators such as recreational space, noise pollution mapping and other indicators. The high-level enterprise view of Smart City Components is shown in Figure 2. The components are organized in layers typical of an information system deployment.

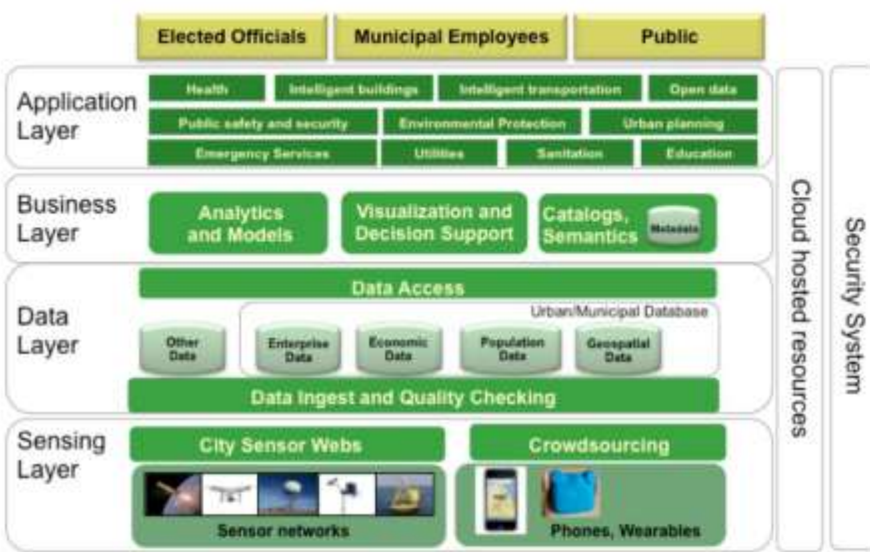

Figure 2. Enterprise Components

The layers in this enterprise component diagram are based on the approach defined by the International Telecommunication Union (ITU) Focus Group on Smart Sustainable Cities (http://www.itu.int/en/ITU-T/focusgroups/ssc/Pages/default.aspx). The layers are also consistent with the approach used in China's Smart City Pilots (China's Smart City Pilots: A Progress Report, IEEE Xplore, Volume 47, Issue 10

3. SPATIAL INFORMATION and SMART CITIES

Spatial information is pervasive and primary. When organized using the concepts of space and time, information about cities can be the basis for many powerful services, analytics and decision-making. This section provides a notional architecture for urban spatial "intelligence" based on open standards, such as CityGML.

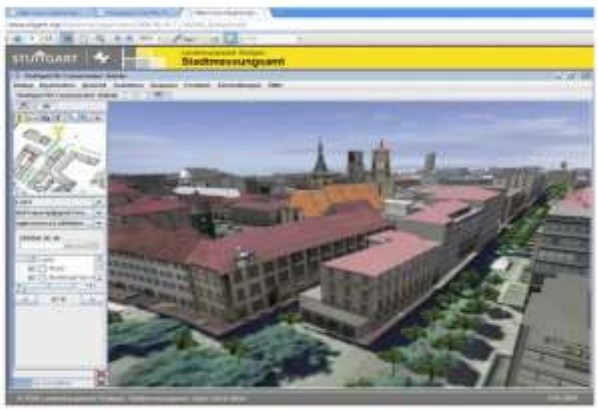

Figure 3. Visualization of a CityGML Model (Source: Thomas Kolbe)

The urban environment must also address multiple scales of spatial information.

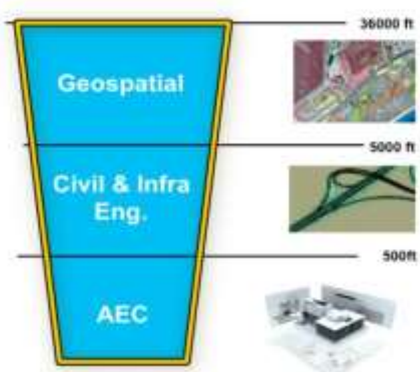

Figure 4. Scales of spatial information

Spatial scales from geographic to civil engineering to building information models are the basis for accurate and comprehensive spatial modeling for Smart Cities.

Figure 5 depicts some of the data model standards or encoding standards that make up the open information technology standards framework. Members of the OGC are actively involved in developing best practices for integrating these approaches. Such best practices will become part of the Smart Cities Spatial Information Framework.

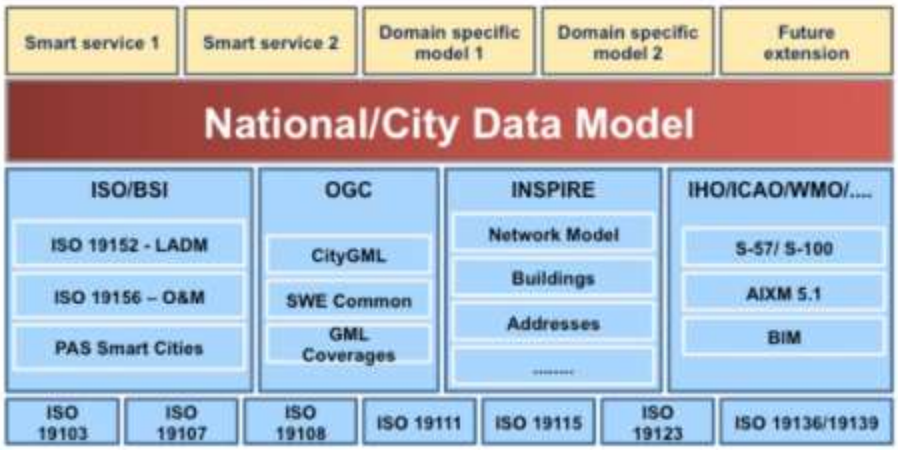

Figure 5 Elements of a set of coordinated spatial information data standards and technology standards for use by Smart City information system architects (Source Carsten Röensdorf)

Smart cities require a framework of trusted/authoritative data; for example, core reference data in 2D and 3D (i.e. topography), identifiers and addressing, smart infrastructure (Building Information Models, smart grid), and sensor feeds. Also critical is a Smart City's openness to data types, such as volunteered, unstructured and linked data. Such a framework needs a robust data integration platform, which is provided, in part, by OGC City Geography Markup Language (CityGML). With CityGML, spatial data becomes an “operating system” for a virtual version of a city. Practical use cases include, for example, optimization of transport and efficient energy use. Berlin's city model enables a variety of improved city services including economic development/investment, real estate, city marketing and event management. For decades, cities have used GIS and geospatial data to improve various services and operations. A good example is London’s use of geospatial data for the 2012 Olympic and Paralympic Games (The London 2012 Olympic and Paralympic Games – a legacy of geospatial support? Ordnance Survey Blog, December 11th, 2014) to establish the route network and determine traffic impacts. Authorities in London also used geographic data to manage security operations and help direct building of needed infrastructure.

Smart cities require standards that enable data and apps to easily interoperate, but this requirement is often overlooked. A good way to begin is to develop a citywide 2D and 3D urban data model to integrate different sources of available geospatial data. The data model becomes the city's open standard, a language that all actors, datasets and technologies use to interact.

Figure 6. CityGML as an integration platform (Source: Carsten Röensdorf,)

CityGML has been implemented in many cities including Berlin and Abu Dhabi, and it has been implemented countrywide in the Netherlands, Bahrain and Germany. CityGML enables semantic modeling, that is, each element in the model includes data about that element's meaning, structure and relationships. The Berlin 3D City Model is one of the world's largest municipal city models. It contains 560,000 fully textured building models in Level of Detail 2 (LoD2) and more than 200 detailed models in LoD3 and 4. The city model is the basis of the Berlin Economic Atlas and the Solar Atlas referenced earlier. INSPIRE Data Specification on Buildings (http://inspire.ec.europa.eu/index.cfm/pageid/2) specifies a harmonized data specification for the spatial data theme Buildings as defined in Annex III of the INSPIRE Directive (Directive 2007/2/EC). The 3D representations of buildings are generally described using the well-defined levels of detail of the CityGML OGC standard. This INSPIRE specification is the basis of the visualization of the noise mapping example provided earlier.

The national 3D standard in The Netherlands has been established using CityGML as described in OGC Best Practice: CityGML ADE - Dutch 3D standard (OGC document 12-066). Additional developments are underway using CityGML;

- The Finland national initiative to build up a nationwide 3D model
- 3D National Data Model for Kingdom of Bahrain Malaysian 3D SDI
- 3D Singapore
- CityGML and ARML applied to the I-35W Bridge Collapse
- I-Scope Project
- The City of Lyon, France is distributing city model in CityGML

The OGC IndoorGML Encoding Standard specifies an open abstract data model and XML schema for indoor spatial information, specifically for modeling indoor spaces for navigation purposes (e.g. indoor location-based services, indoor route analysis, indoor geo-tagging services, and emergency control). IndoorGML is designed to work with CityGML. IndoorGML provides a framework to represent contained spaces (such as rooms and corridors) as cells. Connections between spaces and constraints on movement between spaces (such as doors) are represented as relationships between cells. This OGC Standard defines the following information about indoor space:

- Navigation context and constraints
- Space subdivisions and types of connectivity between spaces
- Geometric and semantic properties of spaces and connectivity
- Navigation networks (logical and metric) and their relationships

LandXML is a non-proprietary XML (eXtensible Mark-up Language) data file format containing civil engineering and survey measurement data commonly used in the Land Development and Transportation Industries. The LandXML user community consists of over 650 organizations with 750 members in over 40 countries and the standard is supported by over 70 registered software products.

The OGC Land and Infrastructure Domain Working Group (DWG) has developed a new candidate standard – the OGC InfraGML Encoding Standard. This candidate standard provides a use case driven subset of LandXML functionality, but that is implemented with the OGC Geography Markup Language (GML) and supported by a Unified Modeling Language (UML) conceptual model.

One of the initial goals of the LandInfra DWG was to gain a better understanding of exactly what LandXML is and does. LandXML 1.2 contains almost 5000 lines of minimally documented XML code covering some 16 subject areas. There is no formally published documentation, user guide, requirements definition, or underlying conceptual model.

The Land and Infrastructure Standards Working Group (LandInfra SWG) was therefore chartered. Its first task was to develop a UML as-is conceptual model of LandXML-1.2 to:

- Aid in the understanding of what LandXML 1.2 is and does
- Provide the basis for a conceptual model of what a future Land standard should do, based on an assessment of user requirements
- Establish a single set of consistent concepts that could be implemented in any set of potential implementation-specific standards, such as a LandXML 2.0, a LandGML, a LandSQL, etc.

This reverse engineering of a LandXML conceptual model revealed a number of problems with LandXML as well as broad disparity with the OGC standards baseline. Fixing LandXML and extending it to support new technologies would result in a non-backwards compatible version. Consequently, the LandInfra SWG decided to embark upon the development of the new InfraGML standard. Initial subject areas will include alignments, road, survey, terrain, and land parcels. Use cases have been documented for these subject areas. The group published the results of the work for public comment on January 17th, 2017, as part of the standards adoption process (OGC seeks public comment on candidate InfraGML encoding standards, http://www.opengeospatial.org/pressroom/pressreleases/2520).

OGC is working with other standards development organizations (SDOs) to converge Building Information Model (BIM), 3D and Geospatial standards. ISO/TC 59 Buildings and civil engineering works, buildingSMART, and the OGC are coordinating for the development of standards as a foundation for the convergence of building and civil engineering design and geospatial technology.

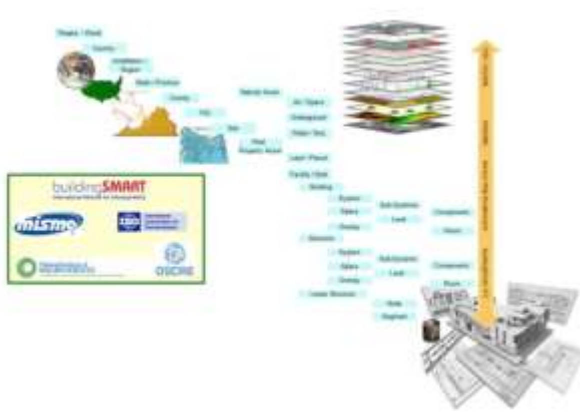

Figure 7. Seamless spatial data modeling across multiple SDOs

4.0 INTEROPERABILITY COMPUTATIONAL SERVICES for SMART CITIES

Geospatial Services Architecture access and processing of geospatial information for smart cities is achieved in a service oriented architecture using open standards as shown in Figure 8. The OGC services are grouped in the figure and discussed in the following sub-sections.

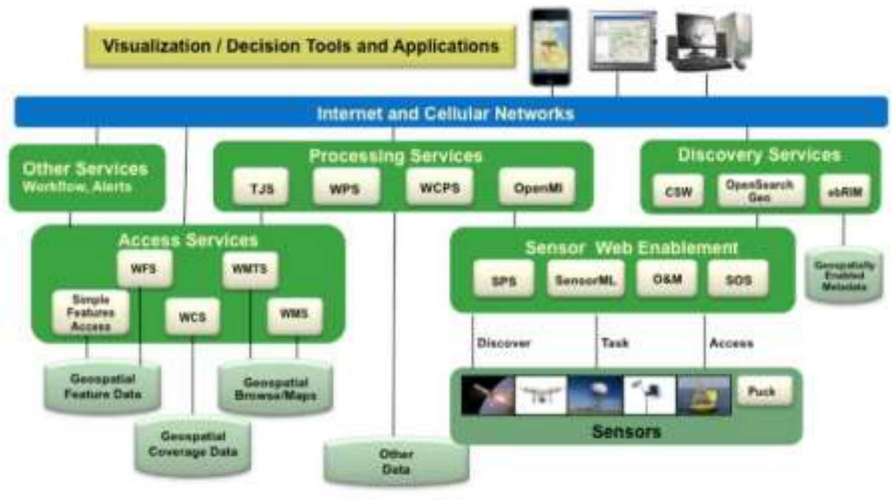

Figure 8. OGC Services Architecture for interoperable access and processing of geospatial information for decision support.

The OGC's Sensor Web Enablement (SWE) standards enable developers to make all types of sensors, transducers and sensor data repositories discoverable, accessible and useable via the Web. The OGC SWE standards are:

- Observations & Measurements (O&M) –The general models and XML encodings for observations and measurements.
- Sensor Model Language (SensorML) – Standard models and XML Schema for describing the processes within sensor and observation processing systems. Sensor Observation Service (SOS) – Open interface for a web service to obtain observations and sensor and platform descriptions from one or more sensors.
- Sensor Planning Service (SPS) – An open interface for a web service by which a client can 1) determine the feasibility of collecting data from one or more sensors or models and 2) submit collection requests.
- PUCK Protocol Standard – Defines a protocol to retrieve a SensorML description, sensor "driver" code, and other information from the device itself, thus enabling automatic sensor installation, configuration and operation.
- SWE Common Data Model – Defines low-level data models for exchanging sensor related data between nodes of the OGC® Sensor Web Enablement (SWE) framework.
- SWE Service Model – Defines data types for common use across OGC Sensor Web Enablement (SWE) services. Five of these packages define operation request and response types. The OGC Sensor Web Enablement (SWE)

The recently adopted SensorThings API (August, 2016) standard is an important standard for the Internet of Things (IoT). It builds on the OGC's comprehensive SWE standards suite, but it is designed to be lightweight and easily implemented. It incorporates a REST-like API and JSON encoding, supports standards-based location encodings (indoor/outdoor, mobile/stationary), is linked data ready (JSON-LD), and is Pub-Sub ready (MQTT).

4.1 ACCESS SERVICES

The Access Services include the WFS and WCS Standards. The OGC Web Feature Service (WFS) standard, also published as ISO 19142, allows a client to retrieve and update geospatial data encoded in Geography Markup Language (GML) and other encoding formats. WFS define interfaces for data access and manipulation operations on geographic features. Via these interfaces, a user client can combine, use and manage geodata from different sources. Open standards for encoding feature data include GML, JSON, and KML.

The OGC Web Coverage Service (WCS) standard supports electronic retrieval of geospatial data as "coverages" – that is, digital geospatial information representing space/time-varying phenomena. WCS provides access to coverage data in forms that are useful for client-side rendering, as input into scientific models, and for other clients. Open standards for encoding coverage data include NetCDF, HDF, GRIB, BUFR and GeoTIFF.

4.2 PROCESSING SERVICES

The OGC Web Processing Service (WPS) Interface Standard provides rules for standardizing how inputs and outputs (requests and responses) for geospatial processing services, such as polygon overlay. The standard also defines how a client can request the execution of a process, and how the output from the process is handled. It defines an interface that facilitates the publishing of geospatial processes and clients' discovery of and binding to those processes. The data required by the WPS can be delivered across a network or they can be available at the server.

The OGC Table Joining Service (TJS) offers a way to expose this corporate data to other computers, so that it can be found and accessed, and a way to merge that data with the spatial data that describes the framework, in order to enable mapping or geospatial analysis.

4.3 CATALOGUE SERVICES

Catalogue services (also sometimes called registry services) provide interfaces to discover, browse, and query metadata about data, services, and other potential resources. The OGC Catalogue Service for the Web (CSW) is a binding defined in the OpenGIS Catalogue Services Implementation Standard (CAT). An OGC OpenSearch Geo standard has been adopted as an OGC standard and OpenSearch is supported by several major browsers

4.4 WORKFLOW

Several SDOs define workflow standards that have been used by OGC. Often spatial processing will require several steps. The combination of workflows services and the OGC WPS provide a robust architecture for geospatial information processing. The OGC Geoprocessing Workflow Architecture Engineering Report (https://portal.opengeospatial.org/files/?artifact_id=34968 , October, 2009) provides a summary of Geoprocessing Workflow practices and methods that have been implemented in a services architecture using OGC services.

4.5 CONTEXT DOCUMENT AND GEOPACKAGE

An OGC Web Services Context Document (OWS Context) can be used to organize a set of spatial information about a given topic and location. The Context document is shareD with user clients that open the OWS Context, retrieve the information, e.g., map layers and display the information. This OGC GeoPackage Standard defines SQLite Extensions for direct use of vector geospatial features and / or tile matrix sets of earth images and raster maps at various scales. GeoPackages are interoperable across all enterprise and personal computing environments, and are particularly useful on mobile devices like cell phones and tablets in communications environments with limited or no connectivity and bandwidth. Context and GeoPackage work well together to send geospatial info to mobile devices.

4.6 VISUALIZATION AND AUGMENTED REALITY

The OGC has adopted standards that support visualization of geographic information. These standards allow applications to separate portrayal functions from processing functions in a single device or in distributed environments. For example:

- The OGC Web Map Service (WMS) Interface Standard provides a simple HTTP interface for requesting geo-registered map images from one or more distributed geospatial databases. The images are returned in specified format such as TIF or JPEG.
- The OGC Web Map Tile Service (WMTS) standard provides for serving spatially referenced tile images with predefined content, extent, and resolution. WMTS trades the flexibility of custom map rendering – as provided by WMS – for the scalability possible by serving a fixed set of tiles.
- The OGC Symbology Encoding Standard is an XML language for styling information and related symbology rules.
- OGC SLD allows Different cartographic styles to be applied to the same data, enabling delivery of different map styles for different user populations, such as assessors and first responders. OGC KML is an XML language focused on geographic visualization, including annotation of maps and images. Geographic visualization includes not only the presentation of graphical data on the globe, but also the control of the user's navigation in the sense of where to go and where to look.

- The OGC ARML 2.0 standard provides an interchange format for Augmented Reality (AR) applications to describe and interact with objects in an AR scene, with a focus on mobile, vision-based AR.

3D portrayal standards are being finalized by an OGC Standards Working Group. The group is to progress the Candidate Web 3D Service Interface Standard and the Web View Service Discussion Paper to the state of an integrated, adopted OGC standard. The SWG will achieve this objective by processing the comments submitted during the public comment period and ensuring that the candidate standard is consistent with the OGC baseline and business plan. The 3D Portrayal SWG builds on the success of the OGC 3D Portrayal Interoperability Experiment (3DPIE) (http://www.opengeospatial.org/projects/initiatives/3dpie, 2012)

The 3DPIE report contains technical details on processing 3D information in an OGC service environment as well as best practices on how to portray large data sets in urban planning scenarios, considering architectures and capabilities of interactive 3D graphics, Especially Web 3D Service and Web View Service. Two draft standards (published as OGC discussions paper), have been in the focus of 3DPIE. A demonstration at Mobile World Congress of three major AR browsers showed the vision of interoperable AR (http://www.opengeospatial.org/pressroom/pressreleases/1960 , February 10th, 2014)

5. DEPLOYMENT AND DEVELOPMENT of SPATIAL INFORMATION FRAMEWORKS for SMART CITIES

This paper outlines one step in a process of applying open standards to the spatial information vital to Smart Cities. Possible next steps include for the OGC Standards Program include:

- Discussion of Spatial Information Framework for Smart Cities with several OGC Working Groups including the Urban Planning DWG and the 3D Information Management DWG.
- Development of an OGC Best Practice for Smart Cities. This paper serves as input to such a best practice.
- Identification and development of profiles of OGC standards needed for Smart Cities.
- Coordination with other SDOs about standards that work together to provide an operational set of standards for Smart Cities.

The Location Powers Smart City Summit was held on 2 December 2014 in Tokyo with a follow up Locations Powers Linked Big Data event scheduled for March 22nd in Delft, NL. The Summits focus on understanding the location and place needs of a Smart City and location. Participants tested assumptions of what a Smart City is, explored the role of the citizen, looked at the fundamental infrastructure, and looked at how we "see" and understand a Smart City.

The OGC Innovation Program provides an agile, rapid engineering environment to accelerate development and testing of standards based on real world use cases. Candidate information exchange standards are developed at the same time that OGC vendor members are developing prototype software solutions. The OGC has conducted more than 80 of these international multi-firm R&D experiments in the last 15 years, each based on user-supplied scenarios. OGC testbeds have repeatedly demonstrated success at transitioning research into operations based on open standards. The OGC Interoperability Program is carrying out a strategy for Smart Cities. Activities include:

- OGC Testbed 11, Climate Resilience, San Francisco
- OGC Future Cities Pilot, Phase 1, Greenwich, Rennes, Sant Cugat del Vallès, Berlin, Rotterdam
- Indian OGC Interoperability Plug fest
- New York City Pilot, Above ground CityGML model,
- Below ground Infrastructure model , New York City, Greenwich, Singapore
- ESPRESSO, OGC-led European Commission funded project on Smart Cities

The pilots will carry out the deployments described in the next section and additional activities.

5.1 BUILDING a CITY MODEL

Building a model of the urban environment using OGC CityGML is a first step for many of the deployments described below. Having a CityGML representation of a city is the modern day equivalent of having a 2D map. Having a 3D, semantically enabled information model of the city enables many functions. OGC is currently preparing a report – "Rapid model-building for venue owners" – on the steps and costs associated with building a CityGML model from multiple information sources.

5.2 COMMON OPERATING PICTURE

Accurate, timely, and georeferenced information is vital to operational and strategic decision-making. The incompatibility of proprietary databases and software used by the in previous emergencies has been a hindrance. Based on lessons learned, government agencies are requiring the private sector to support open standards based approaches in particular for creating a Common Operating Picture (COP) for emergency response. Working with government and industry, OGC has led development of a COP Architecture for emergencies. This COP architecture has been applied in multiple OGC initiatives for emergencies located in urban areas. Figure 9 identifies services and interfaces based on best practices and open standards. This architecture is based on operational and development systems that deliver a COP for oil spill response using open standards.

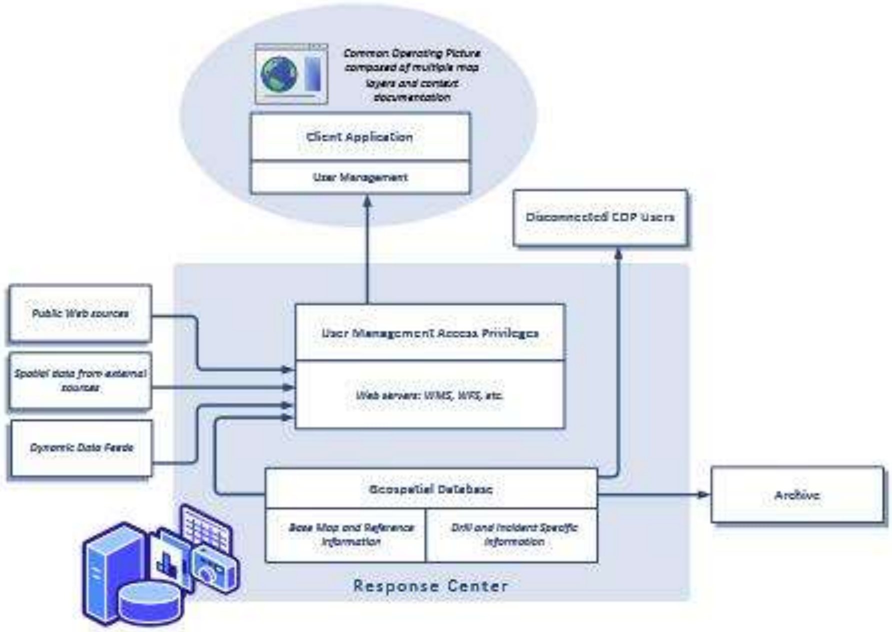

Figure 9. COP Service-Oriented Architecture

5.3 RECREATION INDICATOR

Outdoor recreation space Calculation of area for urban spaces is a mature GIS-based capability. Key to best use of urban space is to have a richer semantic understanding of these spaces. Also it's important that both indoor and outdoor spaces are counted in the semantic bucket of interest. "Square meters of public outdoor recreation space per capita" is indicator 13.2 in the Recreation category of ISO 37120. Calculating this indicator and related space calculations is easy using a CityGML model. Additional studies can be accomplished, e.g., some indoor spaces would provide the same benefits as outdoor public spaces.

Calculation of the area can be done from any open-standards client requesting a query to WFS-equipped database holding the CityGML model and/or could be calculated by request to a WPS that performs the algorithm. Additionally studies of spatial "flows" are important in understanding recreation space. Two additional OGC standards are relevant to spatial flows.:

- The OGC IndoorGML standard is for navigation and routing of indoor spaces. Knowing the available spatial flows for indoor mobility in different modes is key to such a study.
- The OGC Moving Features standard captures the movement of pedestrian and vehicles through spaces. The advance of mobile computing and inter-connected sensors (including sensors and GPS transponders in cell phones and notebook computers) brings

with it a rapid rise in applications for moving feature data. Crowdsourcing of data about pedestrian and vehicle movement in urban environments is a great source for spatial flow studies to improve the quality and safety of urban living.

5.4 ENERGY INDICATOR; RENEWABLE ENERGY SOURCES

"The percentage of total energy derived from renewable sources, as a share of the city's total energy consumption" is indicator 7.4 in the Energy category of ISO 37120. The Solar Atlas of Berlin is based on the Berlin CityGML model is an operational system based on open standards so that the approach can be easily set up in any city based on a CityGML model. Open standards-based are the foundation for integrating BIM, geospatial and smart meters for urban energy performance optimization conducted by the European SUNSHINE project (http://www.sunshineproject.eu/)

5.5 ENVIRONMENTAL INDICATOR; NOISE POLLUTION

"Noise Pollution" is indicator 8.7 in the Environment category of ISO/DIS 37120. This indicator can be assessed using established methods based on OGC standards. 3D visualization of noise mapping based on regulations in Europe have been achieved using the INSPIRE Building Model based on the OGC CityGML standard.

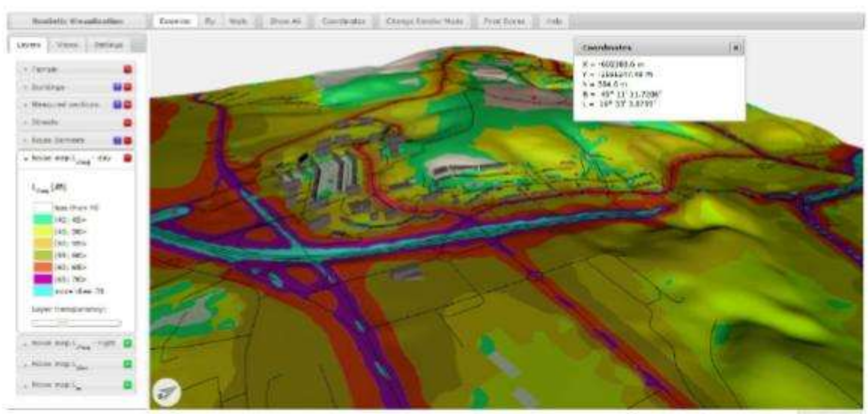

Figure 10. Web 3D visualization of noise mapping using OGC standards

5.6 URBAN ECONOMIC ANALYSIS

Urban economic modeling and effective spatial planning are critical tools towards achieving urban sustainability. However, in practice, many technical obstacles, such as information islands, poor documentation of data and lack of software platforms to facilitate virtual collaboration, are challenging the effectiveness of decision-making processes. Li et.al. reports (http://www.geog.ucsb.edu/~good/papers/549.pdf , May 21, 2013) on their efforts to design and develop a geospatial cyberinfrastructure (GCI) for urban economic analysis and simulation. The urban GCI implements several OGC standards: WMS, WFS as well as WPS. The WPS is used in a chained flow of geoprocessing services to support effective spatial policy analysis and decision-making.

5.7 ANALYTICS

The science of Cities Analytics refers to the discovery and communication of meaningful patterns in data, particularly "big data." Big data refers to massive volumes of data that typically include both structured and unstructured data that are thus difficult to process using traditional database and software methods. In Smart Cities, processing of sensor feeds using big data analytics will be useful for many purposes.

The new science of analytics is integral to a "New Science of Cities," the title of a book by Michael Batty (https://mitpress.mit.edu/books/new-science-cities, October, 2013). As stated on the publisher's web page for the book: "In The New Science of Cities, Michael Batty suggests that to understand cities we must view them not simply as places in space but as systems of networks and flows. To understand space, he argues, we must understand flows, and to understand flows, we must understand networks—the relations between objects that comprise the system of the city. Drawing on the complexity sciences, social physics, urban economics, transportation theory, regional science, and urban geography, and building on his own previous work, Batty introduces theories and methods that reveal the deep structure of how cities function.

Use of WPS to “wrap” cloud computing has been successful for big data analytics and is directly applicable to the analytics considered in the new science of cities.

5.8 CROWDSOURCING

Crowdsourcing and Volunteered Geographic Information (VGI) can increase accessibility by making the data open with open standards. Many of the existing crowdsourcing applications are “stovepipes” from the sensor to the browser. Application of OGC standards is key to making this truly open data. The concept of using a Web Feature Service in combination with a Sensor Observation Service (SOS) for handling humans as sensors has been accomplished in past OGC initiatives. A developed data model for VGI for Sensor Web was presented and illustrated with examples from Twitter, Flickr and from mobile devices directly (OGC Testbed 10).

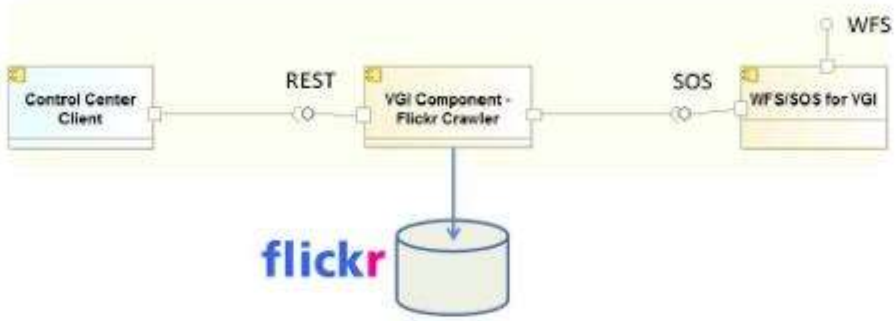

Figure 11. OGC testbed example of integrating Flickr with OGC Services

SensorThings extends the OGC Sensor Web Enablement standards to Internet of Things environment. SensorThings brings the robust semantics to this new emerging world of sensors truly everywhere.

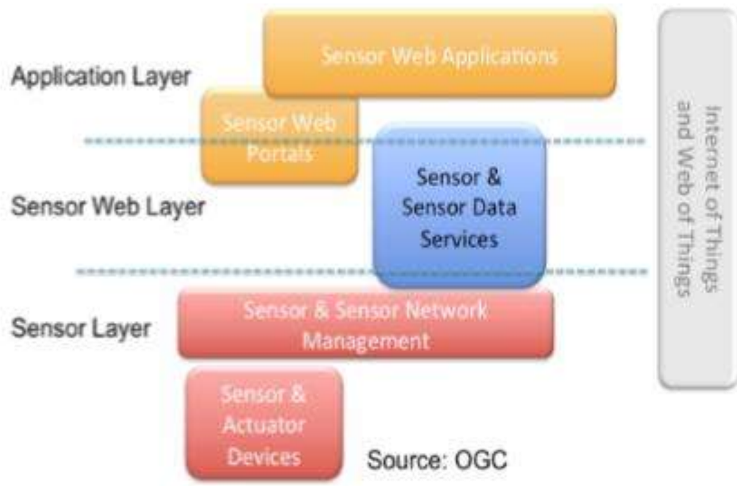

Figure 12. Scope of SensorThings standards

There are many great new projects providing deployed sensors in cities, e.g., for noise and air quality and weather at a city block level of resolution. One approach is to work with these projects to make their data available through open interfaces and therefore accessible for the wider benefits of an Open Smart Cities approach.

5.9 OPEN DATA FOR SMART CITIES

Open Data is a key enabler for informed public and for informed city officials. Public ability to access and use data has grown with the growth of the Web. Spatial open data and open data from many cities is bringing new opportunities for people to assess the situation from their perspective and thereby provide better input to collective decision making. OGC works with the open source geospatial promoters, e.g., OS Geo, LocationTech, Apache, etc. Open data from for example, Open Street Map and Location Tech provide data that have been of great value to systems based on open standard services from OGC.

6.0 CONCLUSION

Effective integration of human, physical, and digital systems operating in the built environment holds the promise of improving the quality of life of urban residents, improving the governance of cities and making cities prosperous, inclusive, sustainable and resilient. Location is a primary method for organizing Smart City services and communicating anything about location requires standards. This paper describes one key step in the process of building an open standards based framework from the enterprise, information, computational and deployment viewpoints.

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FIGURES