CO-149

PERSPECTIVES ON URBAN MODELS INTEGRATION, USAGE AND INTEROPERABILITY IN SDIS: STANDARDS, INITIATIVES AND CURRENT TRENDS

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1 INTRODUCTION

Management and decision making for urban spaces require access to, fusion, display and exploitation of data from a variety of sources and efficient processing mechanisms capable of handling large amounts of data. Standardized geospatial information technologies, including GIS and service-oriented architectures, are tools that empower such usages. This paper describes the state of the art in terms of standards and initiatives for urban models and proposes a vision of dedicated services.

This paper is structured as follows: Chapter 2 presents significant user requirements related to urban issues; Chapter 3 identifies relevant standards and proposes a vision of a service framework; Chapter 4 describes the INSPIRE approach and finally, Chapter 5 highlights some key ideas.

2 USER REQUIREMENTS

Urban models are required by a rapidly increasing number of applications. This chapter identifies key domains and their requirements in terms of 2D and 3D data. This information was gathered during the (currently ongoing) development of the INSPIRE Building data specification [1].

2.1 Spatial planning

Spatial planning is concerned with the distribution of people and activities in spaces of various scales. Spatial planning policies aim at understanding and controlling urban sprawl as well as creating more sustainable and compact cities.

They require urban data at different scales:

- Aggregated data (e.g. land cover, current land use as shown on Figure 1) to denote the morphological characteristics of cities. Data over several years or decades is also necessary to identify evolution patterns.

Figure 1 - Urban atlas of Madrid, combining land cover and land use data

- Building data at a larger scale (typically at cadastre scale) to define development plans and monitor their implementation; such data can be used to compute density ratios or check compliance with urban planning regulations. 3D models can be derived out of such data for decision-making purposes.
- Transportation data is critical as the availability of transportation infrastructures generally drives urban development.
- Several European initiatives (Corine Land Cover, GMES Urban Atlas, EEA Urban Sprawl study [2]) identified a strong requirement for harmonized land cover and land use data.

2.2 Emergency management – Environment

Various physical phenomena, either natural or human-induced, have an impact on urban spaces: e.g. natural disasters (floods, fires, earthquakes, etc.), diverse environmental pollutions (air, water, noise). They have many major consequences on:

- Safety, as human lives and economic assets are threatened;

- Natural environment, with impacts on human health and quality of life;

- Energy resources, leading to a shortage of such resources and increased greenhouse gas emissions.

Urban data and simulation models are required to measure the impact of urban spatial structures on physical phenomena. Topographic data are used as inputs to propagation models. They are also essential for the evaluation of physical phenomenon effects on urban spaces, for instance, heat loss of buildings (cf. Figure 2), or assessment of risk vulnerabilities (e.g. to flood, cf. Figure 2). Identification and graphical representation of phenomenon impact zones are also based on similar urban data.

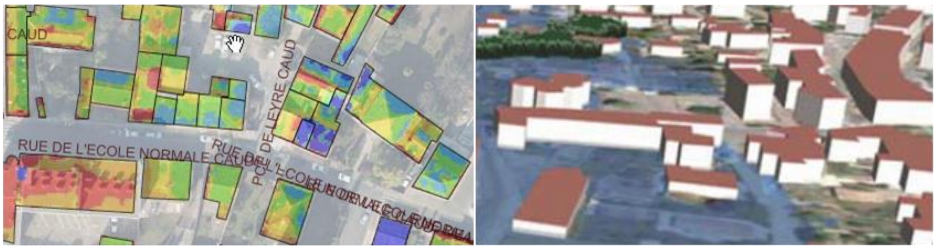

Figure 2 - Infrared image representing heat loss of roof surfaces (left) and 3D model with flood vulnerability zones (right)

Data is also used for emergency preparedness and response efforts, e.g. in communication plans intended to increase risk awareness and in maps for search and rescue efforts.

While more detailed input data improves the quality of end results, it also implies to manage a larger amount of data and generally increases processing times. It also involves additional costs. Current studies are, whenever possible, based on “simple” 2D data (e.g. on 2D location, height, usage and construction date information for building-related studies). However, some cases require full 3D data. In general, the trend is towards 3D models enabling finer-grained analyses.

Several European Directives (Noise, Flood, Energy Performances of Buildings) have led to a requirement for harmonized data over Europe.

2.3 Infrastructures – New projects

New public facilities have to be smoothly integrated in the urban fabric, in a manner that fits their purpose. Inconveniences to inhabitants have to be minimized (e.g. motorway or jail) and potential use has to be maximized (e.g. optimizing location of a new tramway line).

For new projects, multi-scale data is a key requirement:

- Medium scale (e.g. 1:25,000) topographic data is used in preliminary location studies (cf. Figure 3);

Current state With noise barrier With tunnel

Figure 3 – Impact simulation of noise reduction infrastructures

- Cadastral data (e.g. 1:1,000) is required for managing land purchases;

- 3D models (cf. Figure 4) serve several purposes: decision-making processes with elected representatives, communication and public discussions, technical discussions with contractors.

Figure 4 - Planning building demolition

- Fine-grained data for detailed thematic analyses.Harmonized models and standard formats supporting the exchange of consistent data between stakeholders, including citizens and their representatives, is also a major requirement.

2.4 Communication – Public awareness

Communication efforts are very diverse in nature, e.g. for tourism, public awareness, etc. Some may involve the use of geospatial data, at different scales:

- City-wide medium scale topographic data (e.g. 1:25,000 or 1:10,000), usually with an emphasis on transportation data;
- Larger scale data with a focus on a place of interest;
- 3D models to provide a realistic representation of a place of interest (cf. Figure 5);

Figure 5 - 3D model of Mont-Saint-Michel

Data presentation must be visually realistic and generally includes textual and graphical descriptions. Data exchanges must be based on widely implemented formats.

2.5 Synthesis

Heterogeneous, multi-scale, multi-thematic, consistent 2D and 3D data (topographic, cadastral, land cover and use, transportation, detailed building information) are requirements common to almost all use cases. Today, access, processing, combination and display of this data are usually cumbersome. There are requirements for standardized, efficient and flexible information systems, including methods and tools for data aggregation.

3 TOWARDS DATA INTEROPERABILITY USING STANDARDS

Interoperability may be defined as “the ability of two or more systems or components to exchange information and to use the information that has been exchanged” [3].

Systems that can exchange data are syntactically interoperable: they share a common structure, with agreed-upon data formats and communication protocols. Syntactical interoperability is a prerequisite for further interoperability. The ability for systems to automatically interpret the exchanged information is known as semantic interoperability. The same meaning can be derived from the data at both ends. This implies that the systems share a common information model, where each element of the model is precisely defined.

In a world where software vendors have implemented products tailored to the needs of specific communities and/or customers, standardization is the most efficient and global solution to interoperability problems. Several organizations, industry consortiums and communities are involved in standards development activities related to urban matters:

- ISO/TC 211 – Geographic Information/Geomatics is in charge of standards for geospatial information;
- Open Geospatial Consortium (OGC) focuses on standards for geospatial services;
- The buildingSMART alliance (formerly International Alliance for Interoperability, IAI) focuses on developing standards for the construction and facility management industries;
- Web3D Consortium is concerned with standards for 3D data exchanged over the Internet;
- Khronos Group creates open standards for the authoring and acceleration of parallel computing and graphics media;
- ISO/TC 204 – Intelligent transport systems standardizes information, communication and control systems in the field of surface transportation.

The use of standards that allow joint exploitation and combination of various geospatial and CAD data is a requirement for developing interoperable systems and is an increasing demand from user communities.

3.1 Standards defining core modelling and encoding of geographic information

ISO/TC 211 has established a set of standards in the 191** series. Some of them, listed below, define abstract conceptual schemas for describing the fundamental components of features as elements of geographic information. They define the elements to be used when modelling urban data.

- ISO/TS 19103 – Conceptual Schema Language, defining the use of the Unified Modeling Language (UML) for specification of geographic information.
- ISO 19107 – Spatial schema, which defines 2D and 3D geometrical and topological data types;
- ISO 19108 – Temporal Schema, concerned with temporal aspects.
- ISO 19109 – Rules for application schema, which specifies rules for modelling application schemas. Application schemas model the content and structure of data required by an application.
- ISO 19123 – Schema for coverage geometry and functions. Coverage examples include rasters, triangulated irregular networks, point and polygon coverages.
- ISO 19125-1, defining a common architecture for simple feature geometry (i.e. 2D geometry with linear interpolation between vertices), as a profile of ISO 19107.
- ISO 19136 – Geography Markup Language (GML), which specifies the XML implementation of a number of conceptual models defined in the ISO 191** series of standards. GML was developed by OGC and then brought to ISO/TC 211. ISO 19136 corresponds to the OGC GML 3.2.1 Encoding Standard.

User communities can take advantage of this framework of standards to develop application schemas that follow the rules and reuse the components defined in the abstract standards. An XML Schema encoding following the GML grammar can then be derived from the application schema and serve as the basis for data exchange. This approach was followed during the development of CityGML and INSPIRE data specifications, as described in sections 3.2 and 4.

3.2 Thematic standards for urban modelling

ISO/TC 211 has started to standardize different thematic aspects of geospatial information. Several standardized conceptual schemas have been defined, in accordance with ISO 19109. The following standards are relevant to urban space modelling:

- ISO 19144-2 – Classification systems – Part 2: Land Cover Meta Language (LCML) defines a metalanguage for expressing land cover classifications. Land cover classifications can be used to distinguish built-up areas from non-urban zones.
- ISO 19152 – Land Administration Domain Model (LADM) is a standardized conceptual schema for cadastre data. Land administration data can also play an important role in urban models.

ISO/TC 204 has developed ISO 14825 - Geographic Data Files (GDF) as a conceptual and logical data model and exchange format for geographic databases for transportation applications. GDF has a strong focus on road transportation information.

Other organizations have developed and maintain standards for urban and building models. The Industry Foundation Classes (IFC), defined by buildingSMART, is a Building Information Modelling (BIM) data schema covering a wide range of information elements required by software applications throughout the lifecycle of a building. IFC now contains 600 classes enabling the exchange of building design, construction and maintenance data. IFC 2.3 was adopted as ISO 16739 in 2005. Version 2.4 is currently in development and will feature an improved modelling of external spaces and better support for geographic coordinate reference systems.

OGC published CityGML 1.0 in 2008. CityGML specifies a standardized application schema for 3D city models, from which a GML 3.1.1 encoding is derived. CityGML is therefore both a conceptual model and an encoding, enabling syntactic and semantic interoperability. Its key features [4] are:

1. Thematic modelling: the model covers a wide range of city objects, including but not limited to buildings, transportation facilities, water bodies, vegetation, terrain, land use, city furniture, etc.

2. Modularization: each thematic model is packaged in a separate UML module.

3. Multi-scale modelling: CityGML supports five levels of details (LOD). This mechanism facilitates the integration of 2D (at LOD0) and 3D datasets at different scales representing the same real-world entities. The same feature can be represented with different geometries at each scale. CityGML also provides an aggregation and decomposition association between objects that can be used to indicate that an object at a lower LOD has been decomposed into two or more objects at a higher LOD. These LODs also enable applications or simulation models to process the data at the most suitable scale.

The five LODs are illustrated on Figure 6 and defined as follows:

- LOD0: regional view. An orthoimage or a map may be draped over a Digital Terrain Model, together with regional land use, water bodies and transportation information ;

- LOD1: city view. Buildings are modelled as flat-roofed blocks;

- LOD2: city district, project view. Buildings are modelled with distinct roof structures and semantically-classified boundary surfaces. Vegetation objects, city furniture and more detailed transportation objects may also be modelled.

- LOD3: architectural models (outside), landmark. Detailed wall and roof structures, balconies, bay and projection structures are modelled, as well as high-resolution textures, detailed vegetation and transportation objects.

- LOD4: architectural models (inside). Interior structures are modelled.

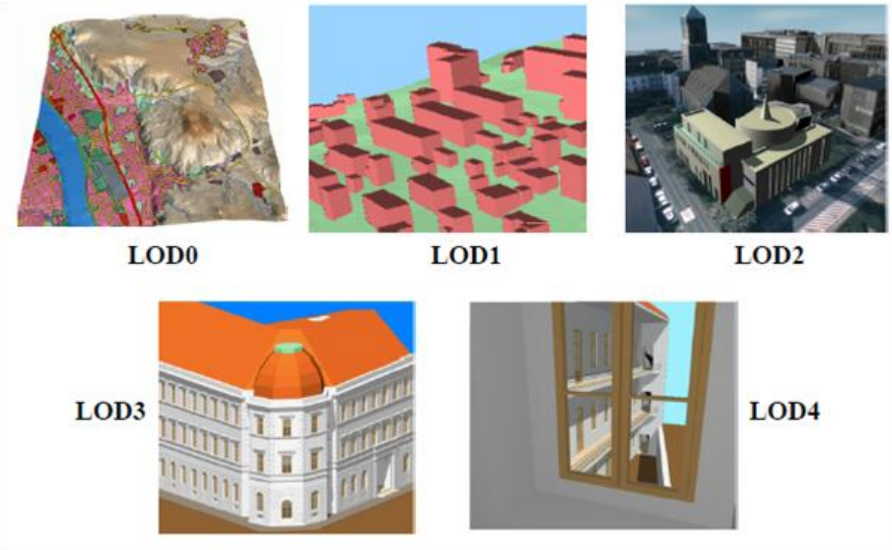

Figure 6 - CityGML's five levels of details

4. External references: objects in external databases may be referenced from the building or city object to which they correspond. They can be used to propagate updates from the source database to the 3D city object. They also help in linking different information models, while keeping them separate, as each has its own purpose. A building may for instance be related to an object in the cadastral database.

5. Application Domain Extension (ADE) is a key mechanism of CityGML. Users can formally extend the base UML model with domain-specific information, e.g. an extension for utility networks or describing noise rates on city objects, and encode it in an XML Schema. Several ADEs have been developed for topics such as Noise (in relation with the European Noise Directive), Tunnels or Bridges. An ADE extending CityGML with more detailed semantics from the IFC standard is also being developed as the GeoBIM ADE .

CityGML's modularity, thematic structure, extensibility and external referencing mechanism sustain richer urban models integrating data from a variety of sources and enabling links with other application domains.

3.3 Common 3D graphics standards

A variety of graphics formats have been standardized for visualizing 3D data in software applications:

- VRML (adopted as ISO 14772) supports the exchange of 3D graph scenes. 3D vector objects are encoded as geometries to which a texture can be applied. A geographic extension, GeoVRML, was also developed

- X3D is a modular 3D graphics format based on XML, developed by the Web3D Consortium (which also maintains the VRML specification), with four profiles of increasing complexity. The “full” profile includes a georeferencing capability. X3D is also available as ISO 19775 (architecture and abstract capabilities), ISO 19776 (encodings) and ISO 19777 (API).

- COLLADA is an XML-based exchange format for 2D and 3D objects, maintained by the Khronos Group. The format supports object texturing, animation but has only a limited support for semantics information. Google Earth uses COLLADA as its internal format for the description of 3D objects.

- Universal 3D (U3D) is a compressed file format for 3D computer graphics, standardized by Ecma International. This format has been implemented in Adobe and Bentley (Microstation) products.

- Keyhole Markup Language (KML), developed by Google, is an XML visualization format for encoding geospatial data and the associated portrayal information. KML 2.2 became an OGC Standard in 2008. Google Earth user interface includes KML viewing and editing capabilities. KML files can reference COLLADA-encoded 3D objects in their own coordinate systems.

Figure 7 compares the capabilities of the 3D standards (Legend: Empty: not supported; 0: basic; +: advanced; ++: comprehensive). X3D, U3D, KML and COLLADA are graphics formats while IFC and CityGML, with their support for semantics, appear to be well suited for the exchange of the geometric and semantic characteristics of urban models.

Standard Feature	X3D	U3D	KML	COLLADA	IFC	CityGML
Geometry	+	+	0	+	++	+
Topology	0	0		0	+	+
Semantics	0			0/+	++	++
Georeferencing	+		+		(IFG) +	++
Appearance (textures)	+	+	0	++	0	+
Linking / embedding	+		++	++		++

Figure 7 - Comparison of 3D standards

3.4 Towards interoperable SDIs for urban environments

A Spatial Data Infrastructure (SDI) may be defined as the set of technologies, policies, standards, human resources, and related activities necessary to acquire, process, distribute, use, maintain, and preserve spatial data, in a transparent way for the end-user. Using urban models in an efficient and flexible way implies to go beyond providing modelling, exchange or processing functions operating on them. Their integration in Spatial Data Infrastructures has to be considered, with access to sensor observation data and spatial analysis functions coupled to models conveying thematic expertise.

OGC provides several Web services specifications that aim at facilitating the implementation of spatial data infrastructures:

- Data discovery through CS-W catalogue services;

- 2D and 3D data download with Web Feature Services (returning 2D or 3D GML data) and Web Coverage Services (for imagery and coverage data);

- Access to in-situ sensor observations using a Sensor Observation Service (SOS);

- Web Map Services for data visualization (as a 2D map image);

- Efficient visualization of 3D data as graphics representations using emerging candidate specifications Web 3D Service (serving X3D data – potentially tiled) and Web View Service (serving 3D views as images). Use of mainstream graphics formats (like X3D or KML/COLLADA) as transfer format between servers and clients provides a capability for improved visualisation performances and integration within mainstream client applications. Other solutions like WebGL (developed by the Khronos Group), taking advantage of OpenGL graphic hardware capabilities, allow acceleration of 3D data display in web browsers.

Figure 8 shows a proposed framework of OGC discovery, fusion, geospatial portrayal and view services for 2D, 3D and imagery data as well as sensor observations, taking into account previous test activities [5, 6]. GeoBIM data could also be included in the infrastructure, provided that appropriate discovery, access and view service interfaces are made available.

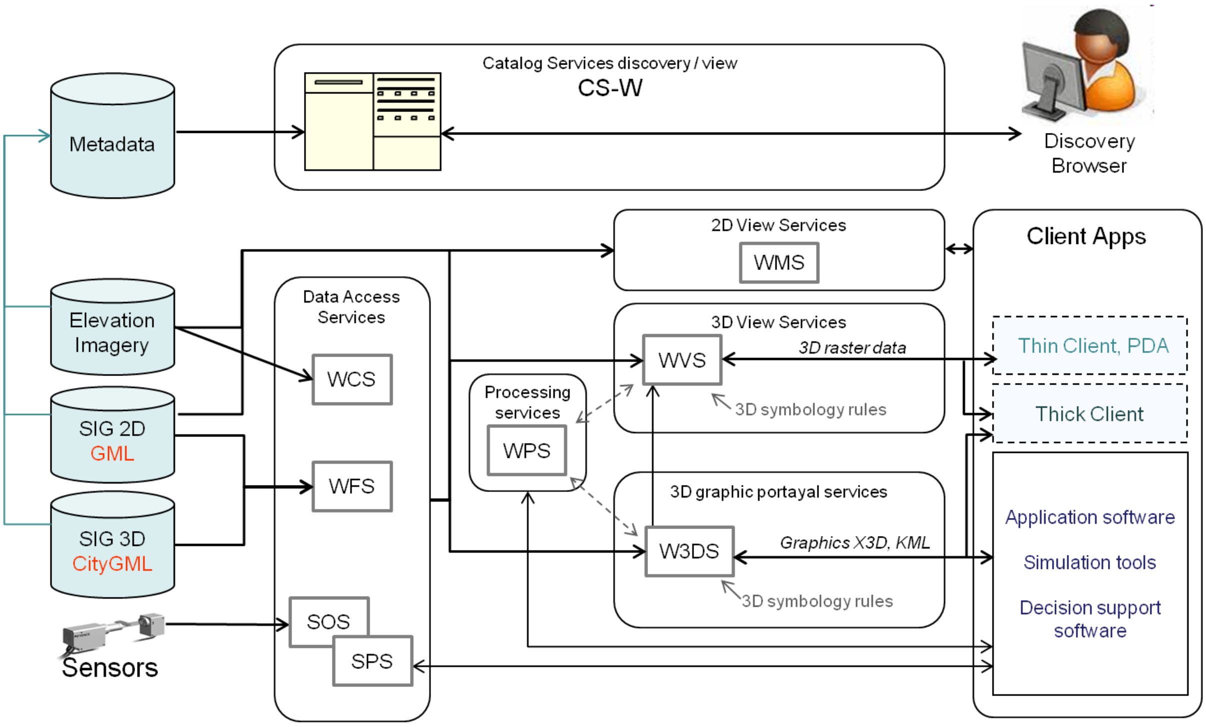

Figure 8 - Proposed OGC services framework

4 INSPIRE approach for an European SDI

4.1 Context

The INSPIRE Directive, adopted in 2007, aims at making more and better spatial data available for the preparation and implementation of environmental-related policies. Its expected beneficiaries are the European Commission, public bodies in the Member States and the citizens.

INSPIRE covers spatial data in digital format, related to Member States' territories, under the responsibility of a public body and related to one of the 34 themes of Annexes I, II, III of the Directive.

Annexes I and II mostly cover reference data, i.e. topographic data (hydrography, transport, elevation, land cover, geographical names…), administrative data (administrative units, cadastral parcels…), orthoimages, geology, protected sites. Annex III focuses on more thematic data, e.g. production and agricultural facilities, governmental services & utilities, buildings, land use, soil...

The INSPIRE Directive is complemented by Implementing Rules, which address technical components:

- Metadata, to increase discovery of existing data sets.

- Interoperability of spatial data sets: to facilitate data combination, as required in many use cases. Data has to be structured according the same rules, i.e. according to same data specifications

- Network services (i.e. discovery, view, download, transformation and invoke services), to provide access to data on the Internet.

These Implementing Rules (IR) have to be based on international standards or, if standards are missing or irrelevant, on best practices. The "interoperability of spatial data sets" IR was established following a three-step approach, as shown on Figure 9.

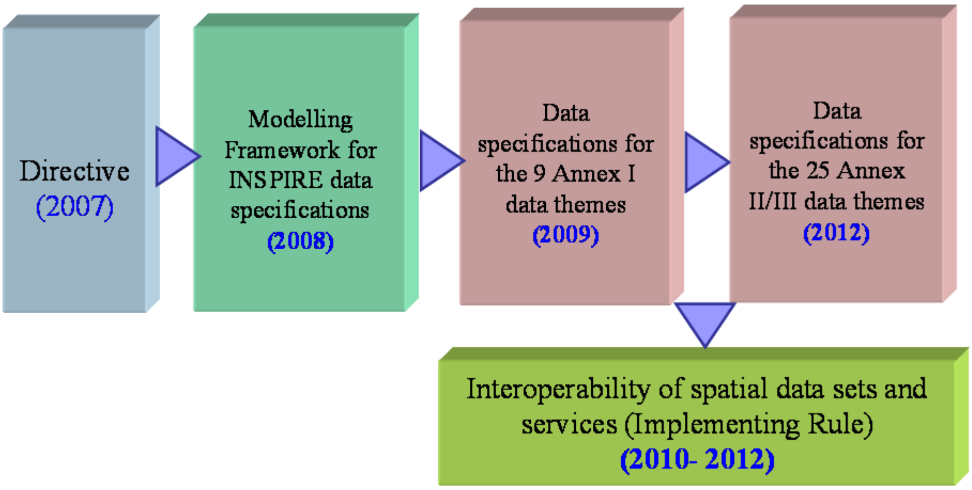

Figure 9 - Interoperability of spatial datasets IR 3-step approach (Source: Data Specifications Drafting Team)

4.2 The Common Modelling Framework

A common modelling framework was first defined, to ensure consistent development of all INSPIRE data specifications. It addresses both structural (i.e. modelling and encoding concepts) and methodological aspects.

4.2.1 Modelling and encoding concepts

Modelling and encoding concepts are described in two documents:

- The INSPIRE Generic Conceptual Model, which defines base modelling concepts to be used by most Thematic Working Groups (TWG), in charge of developing the data specifications;

- Guidelines for the encoding of spatial data.

Both provide grammatical rules that describe the structure of forthcoming INSPIRE datasets and are therefore cornerstones for syntactic interoperability. These rules are taken from ISO/TC 211 standards, and are, if required, tailored to INSPIRE specific requirements. INSPIRE conceptual schemas are described in UML following ISO 19103 and ISO 19109 and documented according to ISO 19110 (feature catalogues). They are encoded as ISO 19136-compliant GML application schemas.

The Generic Conceptual Model also defines a common vocabulary, originating from ISO/TC 211 standards, e.g. ISO 19103 (basic types) and ISO 19107 (geometrical and topological types). Some INSPIRE specific structures are also defined, e.g. an INSPIRE Identifier data type and a Generic Network Model, to be used in themes such as Hydrography or Transport networks.

The INSPIRE Modelling Architecture is shown on Figure 10.

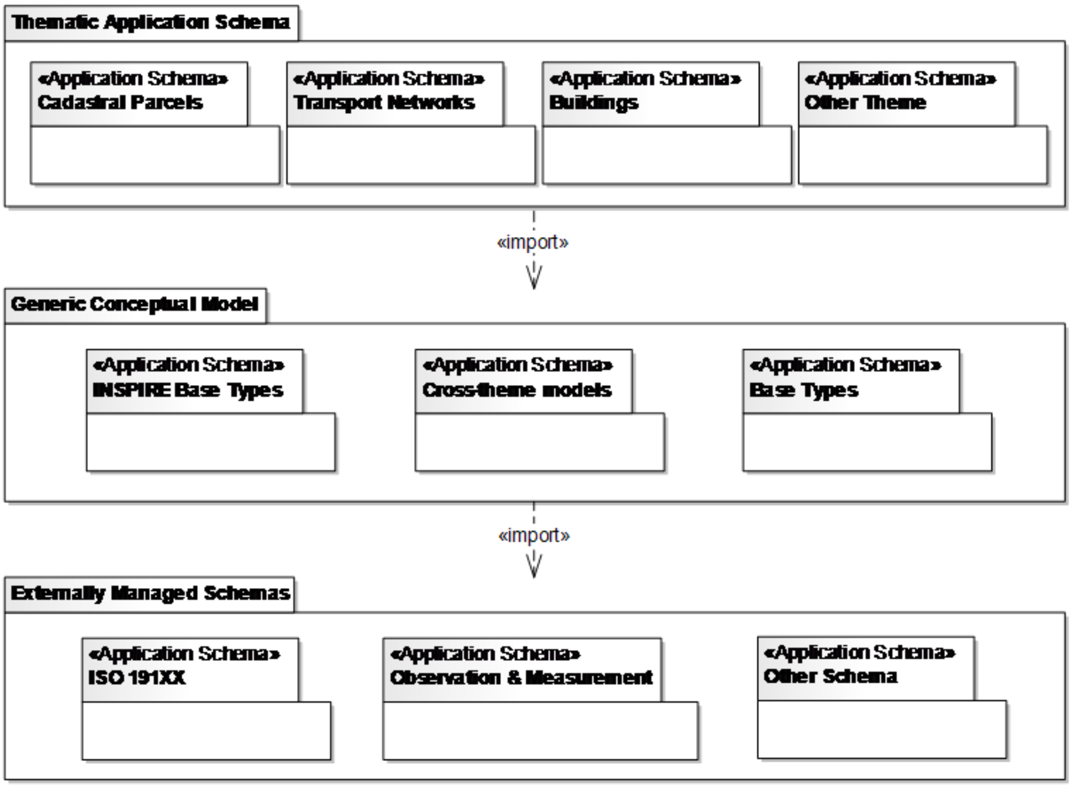

Figure 10 - INSPIRE modelling architecture (source: Data Specifications Drafting Team)

4.2.2 Methodology

The INSPIRE methodology (cf. Figure 11), described in “Methodology for the development of data specifications”, has two main purposes:

- Ensure that the data specifications address user requirements related to environmental issues;
- Ensure that existing data can conform to the data specifications; INSPIRE is indeed about interoperability of existing data, and not about capturing new data. The as-is situation must be taken into account.

Previous harmonisation initiatives, e.g. thematic standards, were also taken into account.

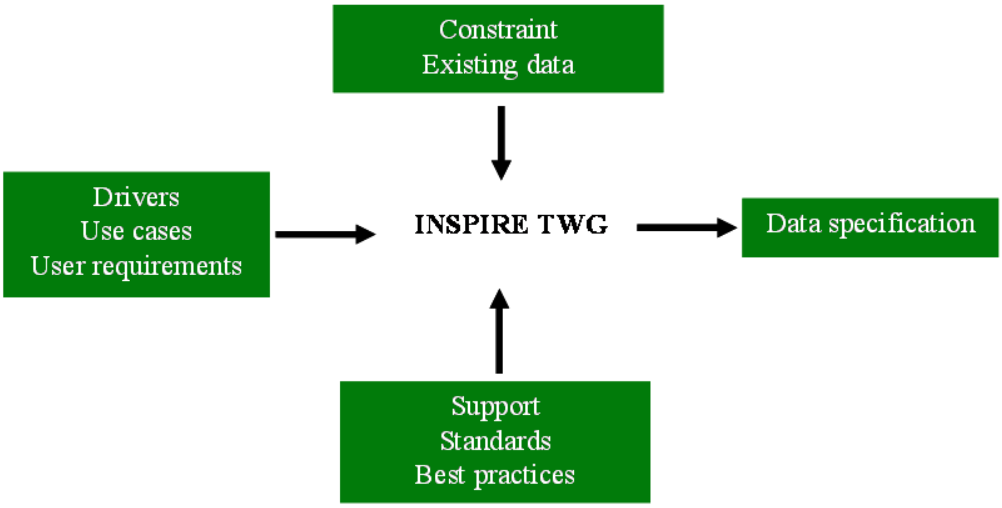

Figure 11 - INSPIRE methodology

4.2.3 The INSPIRE Data Specifications

The harmonised INSPIRE specifications support semantic interoperability by defining a common application schema. Some themes are relevant to urban issues. Cities are primarily composed of streets and other transportation networks, buildings and infrastructures. At smaller scales, land use and land cover themes are also relevant for describing the urban morphology. Spatial planners and other stakeholders will also need administrative, cadastral or statistical information. And lastly, elevation is a key piece of information about the urban terrain.

Some of these themes have already been specified (transport networks, cadastral parcels, administrative units, addresses); others are still under development (buildings, governmental facilities & utilities, land use, land cover, elevation).

These specifications provide a single application schema for the whole scale range relevant to the theme. Some themes are obviously required at large scale (parcels, buildings, addresses) to describe a neighbourhood, others are relevant at medium scale (land use, land cover, administrative units, statistical units, elevation, governmental facilities & utilities) to describe the city and others are relevant at all scales (transport). The INSPIRE application schemas are generally applicable to all scales.

The following standards have been or are being considered in the TWGs:

- The "Transport Networks" TWG has used specifications of the EuroRoadS project as reference materials. These specifications are based on the GDF standard.

- The Cadastral parcels specification and ISO 19152 have been developed in parallel and close cooperation to ensure that the outcomes of the two approaches are compatible.

- The "Land cover" TWG will specify a generic model allowing the use of European classifications (e.g. Corine Land Cover) and/or national and local classifications. This model is based on ISO 19123 and ISO 19144-2.

The "Building" theme, maybe the most relevant to urban matters, has identified many user requirements related to environmental issues. These use cases require multi-scale 2D and 3D data. The TWG is therefore considering defining two normative profiles: a core 2D profile and a core 3D profile based on CityGML (at LOD 1). To ensure consistency between the two profiles, most concepts of CityGML have been used in the 2D profile, e.g. the distinction between building and building part or the use of the external referencing mechanism. Moreover, as these profiles will presumably not meet all user requirements, the TWG is likely to propose a richer profile, as an example of possible extension.

5 CONCLUSIONS & PERSPECTIVES

Access to and exploitation of heterogeneous, multi-scale, multi-thematic, consistent 2D and 3D urban data and models is an increasing demand from all users, from decision makers to citizens, with requirements for data sharing and collaborative exploitation. As illustrated in this paper, using adopted and emerging standards to set up spatial data infrastructures taking into account the complexity of urban issues and requirements is proving relevant in INSPIRE. It should also be meaningful for other initiatives such as GMES or GEOSS .

CityGML and IFC appear well-suited for the encoding of semantically rich urban data. As identified in INSPIRE Building TWG, CityGML's multi-scale modelling, thematic modularity, external referencing and extension mechanisms are particularly relevant to consistently integrate 2D and 3D data in an information system and link it to other information systems. Thematic extension of base 3D models is an emerging requirement, and CityGML ADE development is a positive trend useful to the various user communities. CityGML's planned evolution towards new packages covering additional 3D topographic objects (tunnels, bridges …) is also a positive direction. CityGML could also leverage IFC concepts to enable integration of facilities management data with geospatial data. The GeoBIM ADE is a first step in this direction.

Integrating urban data in SDIs implies to specify service standards that can support the complexity and volume of the data and the performance requirements of client applications. Visualization services for 3D data are a key component of these SDIs, as Web Map Services were for 2D data. Use of widely implemented and efficient graphics formats, APIs and services is a requirement for satisfactory performances and smooth integration in mainstream client applications.

The involvement of user communities in this on-going standardization process is a key issue for the achievement of interoperable exploitation of 2D and 3D urban data in SDIs.

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