Smart City Platform Specification: A Modular Approach to Achieve Interoperability in Smart Cities

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Abstract The development of our cities towards the Smart City paradigm is one of the challenges facing today's society. This means, among other things, continuously developing and adopting ICT technologies in order to create platforms on which governments, businesses and citizens can communicate and work together and providing the necessary connections between the networks (of people, businesses, technologies, infrastructures, energy and spaces) that are the base for the services of the city. The incredible vastness and diversity of applications that are emerging in this context generates an enormous amount of data of different types and from heterogeneous sources to be shared and exchanged. In this article we propose an approach and describe a methodology and a modular and scalable multi-layered ICT platform to address the problem of cross-domain interoperability in the context of Smart City applications.

Keywords Smart city · Interoperability · Specifications

1 Introduction

The world's urban population is expected to double by 2050, by 2030, six out of every ten people will live in a city and by 2050 this figure will run to seven out of ten. In real terms, the number of urban residents is growing by nearly 60 million people every year. As the planet becomes more urban, cities need to become smarter. Major urbanisation requires new and innovative ways to manage the complexity of urban living; it demands new ways to target problems of overcrowding, energy consumption, resource management and environmental protection; thus there is an increased

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demand for intelligent, sustainable environments that offer citizens a high quality of life. This is typically characterized as the evolution to Smart Cities as a key strategy to tackle poverty and inequality, unemployment and energy management. At its core, the idea of Smart Cities is rooted in the creation and connection of human capital, social capital and information and communication technology (ICT) infrastructure in order to generate greater and more sustainable economic development and a better quality of life; in this scenario, the Internet of Things (IoT) is a vital enabler of Smart Cities. As nodes of such a vast network get more and more intelligent, IoT becomes the backbone of smartification and the grounds of innovation. However, managing a plethora of heterogeneous connected devices is a laborious task that poses relevant challenges, demanding appropriate attention from industry, practitioners, and the scientific community alike.

Smart Cities have been further defined along six axes or dimensions [1, 2]: smart economy, smart energy, smart mobility, smart environment, smart living and smart governance. The linkages between economic, societal and environmental development are not scalable as cities expand and are difficult to predict precisely. Their beneficial evolution must therefore be facilitated by a combination of framework conditions and information and communications infrastructures. In this way a platform is provided on which governments, businesses and citizens can communicate and work together, and track the evolution of the city. We have seen that what makes a city a Smart City is the use of ICTs, which are used to optimise the efficiency and effectiveness of useful and necessary city processes, activities and services. This optimisation is typically achieved by joining up different elements and actors into a more or less seamlessly interactive intelligent system. In this sense, the concept of a Smart City can be viewed as recognising the growing and indeed critical importance of technologies (especially ICT) for improving a city's competitiveness, as well as ensuring a more sustainable future, across networks of people, businesses, technologies, infrastructures, consumption, energy and spaces. In a Smart City, these networks are linked together, supporting and positively feeding off each other. The technology and data gathering used in Smart Cities, should be able:

- constantly to collect, analyse and distribute data about the city to optimise efficiency and effectiveness in the pursuit of competitiveness and sustainability
- to communicate and share such data and information around the city using common definitions and standards so they can be easily re-used
- to act multi-functionally, providing solutions to multiple problems from a holistic city perspective.

Overall, ICT enables a Smart City to:

- make data, information, people and organisations smart
- redesign the relationships between government, private sector, non-profits, communities and citizens
- ensure there are synergies and interoperability within and across-city policy domains and systems (e.g. transportation, energy, education, health and care, utilities, etc.)

- drive innovation, for example through so-called open data, living labs and tech hubs.

ICT initiatives based on these characteristics aim to connect existing and improved infrastructure to enhance the services available to stakeholders (citizens, businesses, communities) within a city, thus IoT naturally becomes the nerve centre giving life to Smart Cities and opens up a vast road of promising potentials for innovation.

Nowadays, each city mainly carries out a multitude of heterogeneous solutions related to the different vertical application domains (e.g. Mobility, Buildings, Energy Grids) and the most common approach is that where each solution is a closed proprietary implementation not able to communicate neither with other solutions nor with the other city stakeholders (municipality, citizens).

Therefore, in order to exploit the Smart City vision potentials, we need to drive the solutions towards two fundamental concepts: open data and interoperability.

Open data is definitely an important enabler of urban smartification contributing to innovation with citizen and business value-added applications and services. Recent developments towards [3] opening up data in the process of urban "smartification" have demonstrated that making machine-readable information freely available can foster citizen empowerment, enhance public services through participation, leverage new business models, and ultimately change the paradigm on which governments operate. However, many issues still remain to be appropriately addressed so that open data can be explored to their full potential. Most infrastructure data in a city is still locked away and incompatible data formats and access methods, and various semantic interpretations of data consequently prevent open-data stakeholders to offer citizens and business value-added applications and services.

Interoperability is still at a very early stage. Most technology waves go through a similar innovation cycle—often referred to as the innovation S curve. There is a rapid explosion of innovation, many new systems and solutions appear on the market, and companies scramble to promote their approach. During this phase, standardization is hard and often gets overtaken by events. As the rate of innovation levels off (top of the S curve) standardization efforts are possible—they are usually led by companies with strong market positions as they try to impose their own proprietary solution. At the moment, the IoT space is still somewhat chaotic but there is a possibility for high level frameworks that provide some degree of standardization.

In this scenario the work described in this article is going to tackle the issues related to the two concepts mentioned above by providing a reference framework of modular specifications for stakeholders willing to implement ICT platforms with the aim of exploiting the Smart City vision potentials and therefore provide new services for citizens.

The most innovative aspects of the proposed approach are related to the Information and the Semantic interoperability levels. The usual issue, speaking of interoperability by use of shared data formats, is how to find the correct balance between too prescriptive specifications (which guarantee interoperability, but risk to inhibit innovation) and more elastic specifications (which have a lot of potential deficit with respect to real interoperability). This problem becomes more urgent in a context, like

Smart City, with a lot of interacting heterogeneous systems. In order to overcome it, the approach proposed by the chapter is to have a very light and elastic format (at Information Level) able to represent a very large set of data, moving at Semantic Level the strict definition of the data. The underlying idea is that this light approach can be easily applied also on existing systems with just small intervention on them.

Thus, the work is structured as follows. Section 2 describes the state of the art as well as the general background of interoperability and the replicability view for Smart Cities, Sect. 3 briefly outlines the reference model, the methodology and some aspects about use case definition, the following sections go in details about the different levels of the interoperability stack (Functional, Collaboration, Communication, Information, Semantics) od the reference model, highlighting the main original contributions of the proposed approach; the conclusion section sums up the main pillars and concepts of the proposed approach and outline future directions.

2 Problem Definition and Research Context

2.1 The Interoperability Problem in the (Smart) Cities

The Smart City paradigm is gaining momentum in the recent years as a holistic approach to the digitalization and convergence of the complexity of services and infrastructures resting on the same territory; for this reason, the Smart City is often thought as a system of systems.

Furthermore there are evidences [4, 5] that in recent years many investments have been implemented, for example by multi-utilities operating in the cities, for creating digital infrastructures while many Smart City projects have been developed with the aim of the vertical integration within existing services with the result of improving digitalisation, collecting more data through new IoT technologies and offering new services [6] to the citizens. The result is a lack of horizontal data flows, between vertical applications and between service suppliers and the city administration and citizens: in short interoperability is lacking between applications that have been developed like self-consistent silos, able to exchange data from the field up to the decision support systems and the dedicated control dashboards but unable to interoperate with other systems.

Two kinds of barriers should be broken in order to favour interoperability: barriers between the higher levels of the silos that hamper the monitoring and the exchange of the data between the top of different systems (e.g. global indicators about traffic, parking, public transportation and urban planning related to an area); barriers between the field level of the silos, that hamper the possibility of fully reuse existing data collection infrastructures for different services (e.g. the same sensors for parking, traffic, security, environmental monitoring). This chapter has its main focus on the first group of barriers.

2.2 Interoperability, Definition and Researches

Even though there is a general agreement on the need for enabling horizontal data flows it is less clear how this objective can be realistically pursued.

In literature the discussion about how the integration between independent systems can be achieved has been largely addressed since 1990 in the domain of Enterprise Interoperability (see [7] for an overview), and, the theme of interoperability was dealt with by a large number of successive European projects, starting from the IDEAS project (2002), then continuing in the INTEROP (2002), ATHENA (2004), Abilities (2006), COIN (2008) projects, just to name a few of the most important ones; [8] summarizes some of the main points that have been identified during these research activities. These efforts have also led to the drafting of a European document for interoperability between digital public services [9]. Coming from the world of enterprise systems, the interoperability concept has been adopted in the domain of public infrastructures and Smart Cities with the same definition: "the capability of two or more networks, systems, devices, applications, or components to exchange and readily use information, securely, effectively, and with little or no inconvenience to the user" [10].

In the field of Enterprise Interoperability, characterized by the continuous evolution of the business processes and products, the research focus is addressing the means for enabling interoperability and the concept of sustainable interoperability: the crucial point, in fact, is assuring the capability of the systems to interact while they and the external ecosystem evolve over time, with new technologies, new services, new requirements, new categories of data and applications [11].

Meantime the Smart Cities seem growing thanks to both digitization of existing services and composition of new services upon the existing ones; the number of potential new applications and services (and data flows to deploy) is rapidly increasing [12, 13]. Thus, in this case, the interoperability hampering factors seem to be the number of already existing solutions with different institution and organisations in charge, architectures in concurrence with the lack of convergence in the field of standardization initiatives.

2.3 Approaches and Means for Achieving Interoperability

A look at the landscape of existing initiatives can give the sense of the strength of the feeling that exists on this subject in the Smart City community. The wide landscape of the initiatives can be split into the following categories: Models, Tools (technologies and platforms), and Standards.

With the word "**models**" we mean analysis frameworks defining high level requirements for Smart City Platforms. Such kind of frameworks aims at providing shared languages for describing system basics and interoperability levels, for categorizing platform and comparing different architectures.

Some examples of such frameworks are:

1. The SGAM [14] (Smart City Architecture Model): an interoperability oriented analysis framework in the smart grid context, built by the Smart Grid Coordination Group (which join CEN, CENELEC and ETSI). It enables identification of data exchange interfaces, standard classification and mapping of different architectures on the same reference model. Even if it is thought for a different field, smart grids—similarly to Smart Cities- are made of complex ecosystems of inhomogeneous and independently born applications and services, as a consequence they present similar interoperability issues.
2. The SCIAM [15] (Smart City Infrastructure Model): it uses the same SGAM interoperability levels, changing the set of application domains. At the moment it is a proposal and needs to be consolidated.
3. GSCAM [16] is another proposal for extending the SGAM to the Smart City context (Generic Smart City Architecture Model), which adds to the SGAM new dimensions applicable to the domain.
4. Moreover, the main European SDOs are trying to replicating the success of the SGAM with a similar initiative: the SF-SSCC (Sector Forum on Smart and Sustainable Cities and Communities) [17], built on the previous Smart and Sustainable Coordination Group.

Other interesting models are presented within initiatives with more operative objectives, like those at the base of:

- SMArc [18] (Smart, Semantic Middleware Architecture Focused on Smart City Energy Management), a middleware proposal for Smart Grids
- U-City (Ubiquitous Eco-City Planning, in Korea), a project aiming to create a ubiquitous city model [19]
- ITU-T, a proposal about the Smart Sustainable Cities [20].

If the previous models give us the language, more technological **tools** are available. Let us give a look just at some of them, choosing only among existing open tools and splitting them into three main categories:

1. General purpose development framework. One of them, very active in the Smart City application context is FIWARE [21], managed by an open community, it provides public and royalty-free set of APIs and the related open source reference implementations.
2. Smart City Platforms. For examples Open City Platform [22] is a cloud platform aiming to sustain cloud service offer by public administration; KM4City [23] is an open source system providing customizable dashboards for managing the city; E015 [24] has a different approach and presents a set of guidelines for enabling the definition of interoperable Smart City services.
3. IoT Middleware platforms. Some examples: Kaa IoT Development Platform [25] is a middleware platform which allows building complete end-to-end IoT solutions; OM2M [26] is an autonomic ETSI-compliant M2M service platform; OpenIoT [27] is a middleware open source platform for getting data from a cloud of sensors.

But, in order to have the sense of the incredible complexity of the situation, a look at the landscape of Internet of Things technologies (so just the third point of the previous set) made by Matt Turk is really instructive. The conclusion of the author, looking at this landscape, is that “there is no dominant horizontal platform and not enough mature, cheap and fully reliable components just yet” [28].

The last important point about Smart City interoperability is the set of standards. A really interesting work about the categorization of Smart City related standards was made by the British Standard Institution (BSI) [29]. In its report BSI identified 100 Smart City standards (only considering inter-domain standards) split into three levels (technical, process and strategic standards).

Because of the previous complexity, NIST set up the IES-City (Internet of Things-Enabled Smart City Framework) initiative, involving ENEA and other international organisations. The aim is to distil a common set of architectural principles (Pivotal Points of Interoperability—PPI) from the comparison of existing architectures. PPI are very basic (e.g. to convert XML to JSON, to use REST APIs, etc.), but they show a way for facing the problem: finding common principles upon which new architectures should be designed.

2.4 The Still Open Issues

The work conducted by IES-City initiative [30] is a first important step to create environments facilitating the reuse and the automated and interoperable interaction between different systems and applications; nevertheless it is not enough. If we state that the public administrations can play a key role in breaking the barriers between the Smart City subsystems, they should be provided with a common global set of standards and guidelines to be used in their call for tender.

This chapter presents an approach to this issue: concretely it consists in the definition of a set of modular, general specification (the Smart City Platform Specification) for implementing horizontal ICT platforms, in order to enable interoperability among the vertical silos.

The idea of specifications comes from the need of the city administrations for avoiding the “vendor lock-in” and to clearly state the data that the public service providers are required to supply.

In parallel, an ICT platform would allow to get and monitor data from different utilities and urban service providers (Fig. 1).

The specifications consider also the following requirements:

- split in modules, according to interoperability levels (Functional, Communication, Information, Semantic, Collaboration levels) [31];
- focus on the interfaces;
- the city viewed as system of heterogeneous systems (building, lighting, …) with different aggregation levels (sources, local platforms, Smart City Platform);

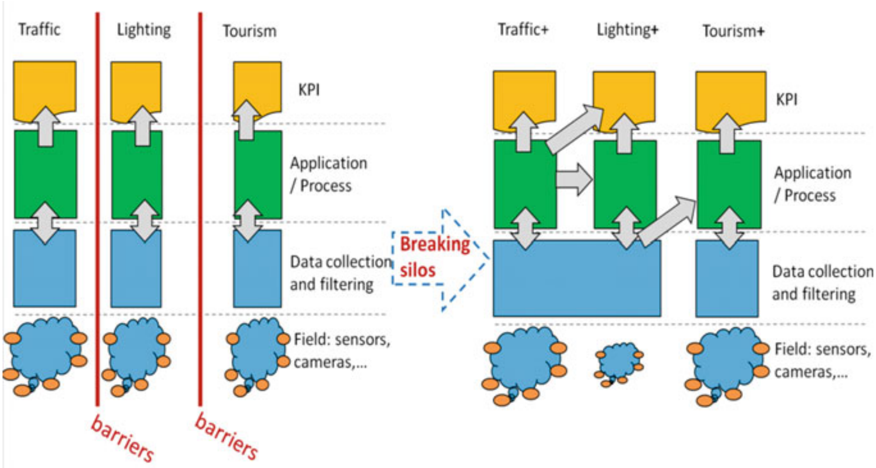

Fig. 1 Breaking down the silos barriers for creating smart cities, from [13]

- scalability and composability: the specification modules have been thought to be used also separately and to be adaptable to contexts and domains not known at their design time.

3 The Reference Model for the Smart City Platform Specification

The starting point for solving the "silo" problem, explained in the previous section, is a close look to real world applications and the consequent identification of a clear methodology. For this purpose, a reference model was defined based on a "customization" of the SGAM, considering also the SCIAM proposal and the other examined models.

All these models present some common elements:

1. At their base there is a data acquisition layer, made of sensors plus the physical infrastructure for connecting them.
2. Over the acquisition layer there is a layer where data are aggregated, inserted in (often distributed) databases and some elaborations (e.g. data fusion, statistical analyses, decision support) are performed.
3. On the top there are the Applications that exploit the collected and elaborated data for offering services to the users.

The previous scheme represents the usual data cycle in a single domain application: the application gets the data from the field, collects and elaborates them and uses the results for providing applications to the users. But, in order to get

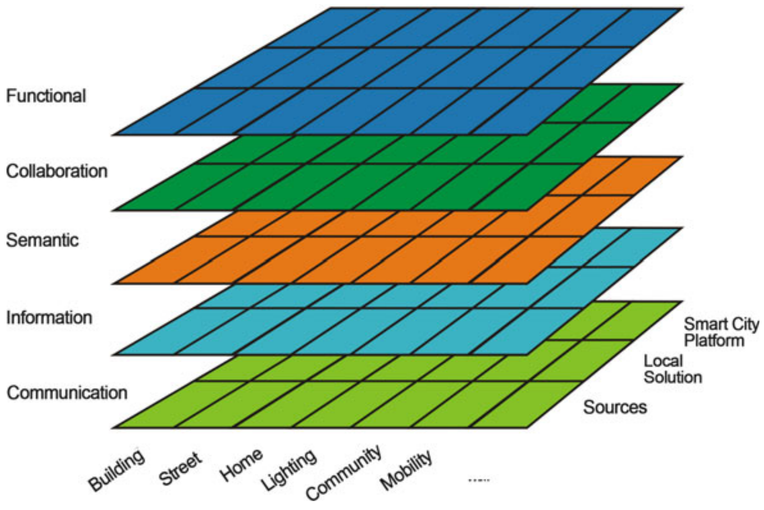

Fig. 2 Reference model for the smart city platform specification

inter-application interoperability, a higher layer has to be added, enabling data exchange between domain centric applications (i.e. the aforementioned silos). Considering a SGAM-like vision, the ICT layers of our model (the z-axis) are the following (see Fig. 2): Sources/Field (sensors and related infrastructure, layer 1), Local Platform/Solution (collection, elaboration and user services, it joins layer 2 and 3 of the previous list) and Smart City Platform (the inter-application interoperability layer we add).

The y-axis of the SGAM-like model represents the interoperability levels. Re-elaborating these levels on the base of the Enterprise Interoperability Framework [8], the levels that have to be addressed for answering to interoperability issues are:

- **Functional**: key concepts, actors, architectural model, component and functionalities;
- **Collaboration**: information expressing the collaborations among the different actors and the configuration of the interoperable communications;
- **Semantic**: semantic of the common language, for sharing the data meaning, avoiding ambiguity;
- **Information**: the common language data format, involving both data models and syntaxes;
- **Communication**: definition of data exchange interfaces, including transport protocols.

We adopted these levels for the definition and organization of the Smart City Platform Specification (SCPS).

The last axis (the x-axis) represents the application domains and it has to be intended as an "elastic" axis, since the domains can change depending on the city context.

The resulting model is represented in the following figure.

We firstly used this reference model to deeply analyse (by UML diagrams and textual description) different use cases, intended as a set of smart applications from city (e.g. smart lighting, smart building, waste water treatment plant) in order to identify: actors, exchanged data and the related processes and, at the end of the analysis, requirements for SCPS definitions. Then Functional, Collaboration, Semantic, Information and Communication aspects of the use cases have been clearly described, helping in identifying the specification requirements.

Together with the reference model, the methodology and the template defined by the IEC 62559 [32] were used for use case analysis. The template, which contains the fields for describing the use cases, was filled by domain experts with the information about the identified applications (e.g. including smart building, smart lighting, smart home, and smart waste water treatment). On this basis inter-application data exchanges were modelled allowing us to recognize recurrent data structures and to fix specification requirements.

In particular, some common points emerged:

1. The different spatial data can be aggregated, in one of the following levels:
    - Items: punctual data (e.g. at single sensor level);
    - Facility: data related to the whole monitored facility (an entire building, street, …);
    - Aggregation of facilities: data from an application that collects them from a group of facilities;
    - City: monitoring data from the whole city;
    - Region: data related to infrastructures extended beyond a city (e.g. energy infrastructures).
2. Similarly, the different data can be aggregated, at spatial level, in one of the following way:
    - Static: anagraphic data (e.g. geographical localization of a facility);
    - Instantaneous: instantaneous measurements from sensors;
    - Average: average data, elaborated starting from instantaneous ones, in a fixed time range;
    - Total: sum of instantaneous data in a fixed time range
    - Forecast: forecast (future) values (e.g. weather forecast).
3. The exchanged data present a set of common properties that can be shared at data model level (e.g. the timestamp, the spatial coordinates, the reference time period, the updating frequency, etc.).

In the following section we detail the five levels of the SCP Specification.

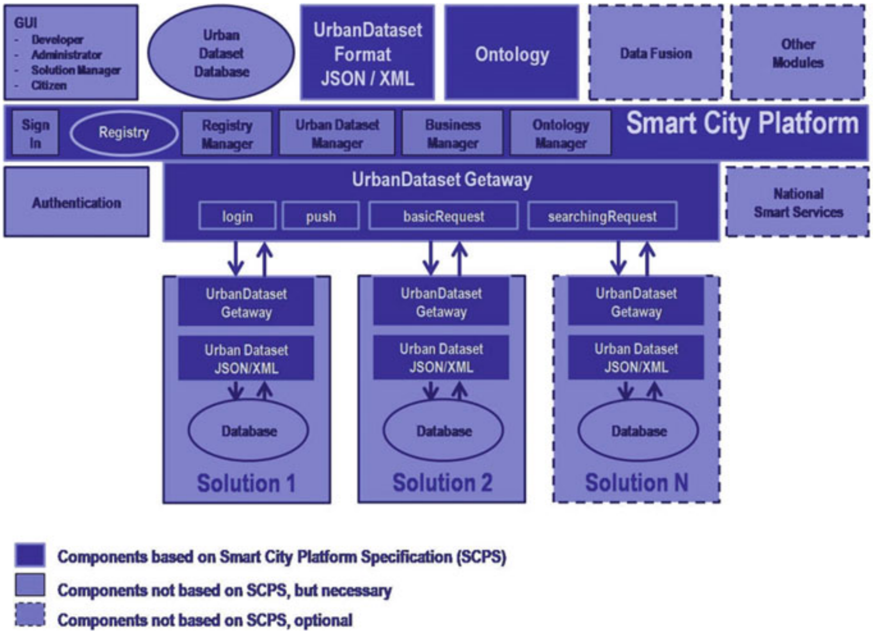

Fig. 3 SCP reference architecture

3.1 The Functional Level and the Architecture

The core of the Functional Level is the description of the Smart City Platform Architecture, its components and functionalities, and the interactions with the connected solutions: Fig. 3 depicts its schematic representation that includes:

- a horizontal Smart City Platform;
- a series of vertical Solutions (i.e. local platforms for the management of a single application context);

where, ideally, the data collected by the city will "rise" vertically, from the solution management in its own application context, up to the integrated ICT platform. In the figure, we represent in blue the basic components that must adhere to the proposed Smart City Platform Specification: these components will be described later in this chapter. We defined the components with a modular approach: each of them is independent from the others, and the adoption of the specifications can be carried out gradually, choosing step by step what to implement. For example it is possible to start adopting only the data format, and only afterwards adding the other components according to own priorities.

The Architecture shown in Fig. 3 depicts how each vertical Solution, managing specific application contexts, exports, from its local database, the information in the "Urban Dataset" JSON/XML format and sends them to the horizontal Smart City

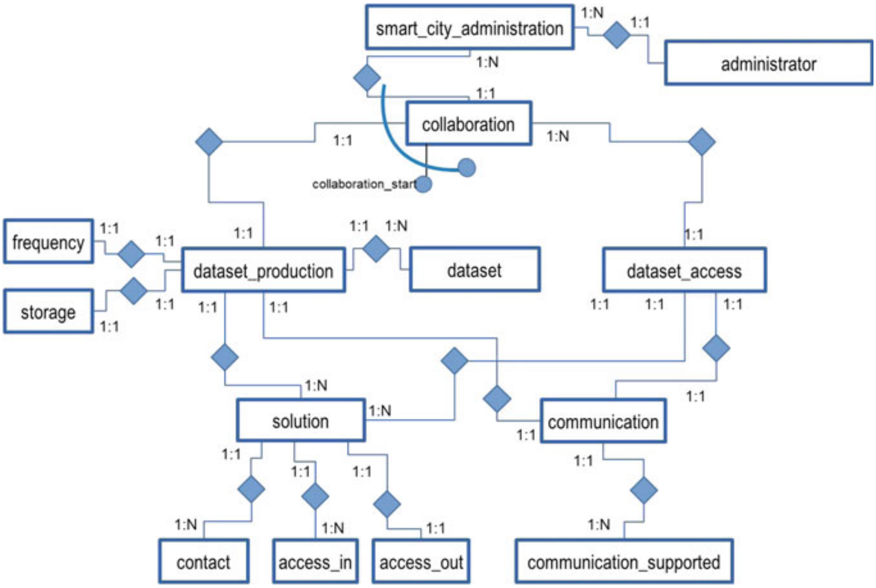

Fig. 4 Schema E-R registry

Platform through the transport service "Urban Dataset Gateway". The Smart City Platform has to handle the dataset production and access (Fig. 4).

Moreover, the Functional Level provides a description of:

- key concepts and the Components (there is a 1–1 correspondence between the key concepts and the main Components of the Architecture);
- users;
- macro-functionalities (through Use Case Diagrams).

The following are some Key Concepts:

An **Urban Dataset** (UD) is a set of data exchanged between the city's vertical solutions and the Smart City Platform, according to the SCPS, characterized by a univocal and centralized semantic description (the Ontology component), and by common formats defined by the Abstract Data Model and Syntactical Implementation (JSON and XML).

The **Ontology** is the component defining the semantic structures of the Urban Datasets, as well as classifying them into categories and sub-categories. The Ontology is an independent component, external to the Smart City Platform, to allow a shared use with other SCPS-based platforms, in the way that a process of convergence is at the base of every communication.

The data **Transport** Service allows to send and receive Urban Datasets, and it is defined in the SCPS by defining a single Web Service: Urban Dataset Gateway. The Web Service is provided with three patterns (push, request/response, publish/subscribe), a common definition of service interface and two implementations (REST and SOAP) based on the same interface.

The **Registry** is a database that manages the information related to the collaborations between Smart City Platform and Solutions, from the point of view of who produces and accesses the Urban Datasets.

There are four kinds of **Users** defined for the Smart City Platform:

1. *Developer*: it deals with administering the platform from the technical point of view and the software components that implement the platform;
2. *Administrator*: it manages the horizontal platform (typically it is a representative of the municipality or multi-utilities that manages the city/district) handling the collaborations between Smart City Platform and the different vertical Solutions;
3. *Solution Manager*: responsible for the vertical Solution platform connecting to the Smart City Platform; it accesses to the data describing the situation of its Solution (personal data, web services access credentials and parameters, Urban Datasets to be produced or accessed and data sent view);
4. *Citizen*: unregistered generic citizen user who accesses the services offered by the platform.

These four kinds of users can access to the functions of the SCP. The SCPS Functional Level provides also four use case diagrams to describe the main steps for the set-up, instantiation and use of the SCP:

1. SCP configuration for City/District;
2. Solution configuration;
3. Interoperable Communication;
4. Solution deleting.

3.2 The Collaboration Level

The dialogue between the horizontal Smart City Platform and vertical Solutions, through the datasets exchange, implies the management of a remarkable set of information (e.g. the produced datasets, who produce them, who will access them, in which format the information will be represented, which data transport protocol will be adopted, etc.).

The **SCPS Collaboration Level** provides an approach to manage this set of information, through the description of:

- the definition of proper roles for each user of the Smart City Platform (developer, administrator, solution manager, citizen) and the way each of them interacts with the Platform through the Graphical User Interface (GUI);
- the Registry database, which allows recording and storing information about the Solution and the managed Urban Datasets, as well as the information regarding their production.

The collaborations are handled, in the Registry, defining four groups of information about:

1. Smart City Administration: administration of the Smart City Platform;
2. Vertical Solutions: registered Solution, reference contacts and credentials for the access to the transport data services (for the Smart City Platform that has to access to the vertical Solutions, and for the vertical Solutions that has to access to the Smart City Platform too);
3. Urban Datasets: declarations of which dataset (registered in the Ontology) will be produced by the vertical Solutions in a given collaboration, as well as the ownership of that datasets;
4. Complementary aspects: complementary information to the collaborations, such as the production frequency of an Urban Dataset, the related ownership and the access by other Solutions (if the UD is declared as OPENDATA, it will be accessed by everyone), the transport protocols, the formats used in the transmission, etc.

Each group of information has been organized in the following E-R scheme and their detailed description is provided with the related tables. It should be noted that the collaboration table is the core of the whole E-R schema since a **collaboration** describes the production of a specific Urban Dataset, by a specific vertical Solution, towards a specific Smart City Platform, in a given time period.

Collaboration between a vertical solution and the SCP is defined, in fact, as an agreement with the aim to produce a particular Urban Dataset. Between a solution and the SCP, there might be multiple collaborations (production of different Urban Datasets and/or production of the same Urban Dataset in different periods) and different accesses to the produced Urban Dataset. This collaboration provides a connection between the Smart City and the Dataset Production of a Solution, at a certain timestamp. Since this aspect is crucial and it is employed in several parts of the Smart City Platform, it is useful to have an ad hoc identifier to easily achieve this information without involving Registry accesses. In this respect, the identifier *collaboration_id* is created from the sequence of the identifiers of Smart City Platform, solution, urban dataset and timestamp of the reference period.

The *collaboration_id* is the link among the different SCPS specifications that can be used in a modular way but, in any case, they offer their maximum potential when used jointly. There are, in fact, two main moments in which the *collaboration_id* is treated:

1. In GUI navigation to search for available/accessible Urban Datasets, from which it is possible to obtain a *collaboration_id*;
2. Using the web service to produce or access a particular Urban Dataset (this will be evident in the web service interface, in the communication part).

3.3 The Information and Communication Levels

The data exchange is managed starting from the definition of two main aspects:

- **Information**: representation of the exchange data by defining an abstract model of Urban Datasets and related common formats (JSON and XML);
- **Communication**: description of the data transport through the architectural patterns and the web service interface.

These two aspects correspond to the homonymous sub-specifications which, we recall, can be adopted in a modular and gradual way.

The Information level defines a format able to make interoperable the exchange of Urban Dataset between heterogeneous systems or applications.

It is defined by:

- an Abstract Data Model;
- the syntactic implementation of the Model; currently, two reference implementations are available: XML (eXtensible Markup Language) and JSON (JavaScript Object Notation).

The Abstract Data Model gives a syntax-independent representation of the content that is mandatory for a document used to exchange Urban Dataset. Because the Smart City scenario is continuously evolving, it has been designed to be scalable during the time and across different contexts; in this perspective, it satisfies the following requirements:

- independence from syntaxes and communication protocols;
- ability to represent any kind of Urban Datasets coming from any vertical system or application;
- ability to represent new, unexpected Urban Datasets, which were not foreseen at platform design time and do not come from the initial use cases.

To meet these requirements the Abstract Data Model has a flexible structure (it is unaware respect to the Urban Dataset properties) and we also define a procedure to customize it without loss of interoperability. The result is an Abstract Data Model composed of the following three parts:

- **Specification**: it contains meta-information describing the Urban Dataset (e.g. the Urban Dataset specification reference, its properties,…);
- **Context**: it provides information needed for contextualizing the exchanged values (e.g. the time zone related to the timestamps);
- **Values**: it contains the measured data on the Urban Dataset properties, organized in key-value pairs.

The customization procedure consists in binding the Abstract Data Model to a specific Urban Dataset and its properties, following its semantic definition (in the SCPS it is given by an Ontology). The aim of this approach is to facilitate the mapping between different syntactical implementations used by different systems or applications and to enable interoperable data exchanges.

Actually multiple syntactic implementations are possible; currently, two **reference syntaxes** are available:

- XML, formally expressed by an XML Schema conformant with the XML Schema 1.0 Specification;
- JSON, formally expressed by a JSON Schema conformant with the JSON Schema Draft 06 Specification.

The following figure shows an XML fragment related to data measured on an Urban Dataset (this fragment implements the "Values" section of the Abstract Data Model). It is important to emphasize that the same structure is able to contain very different kinds of Urban Dataset properties and related values.

The Communication Level (or data transport) deals with two main actions that a vertical Solution can undertake to communicate with the Smart City Platform:

1. Production of an Urban Dataset: export, from a vertical Solution, of the urban datasets that will be received from the Smart City Platform;
2. Access to an Urban Dataset: vertical Solution access to the Urban Datasets that the Smart City Platform has previously published.

Note that, if the first action enables the retrieving of data from a Solution to the Smart City Platform and the second action enables transfer of data from Smart City Platform to a Solution, the coordinated set of the two actions allows the exchange of data from a vertical Solution to another vertical Solution through the Smart City Platform (Fig. 5).

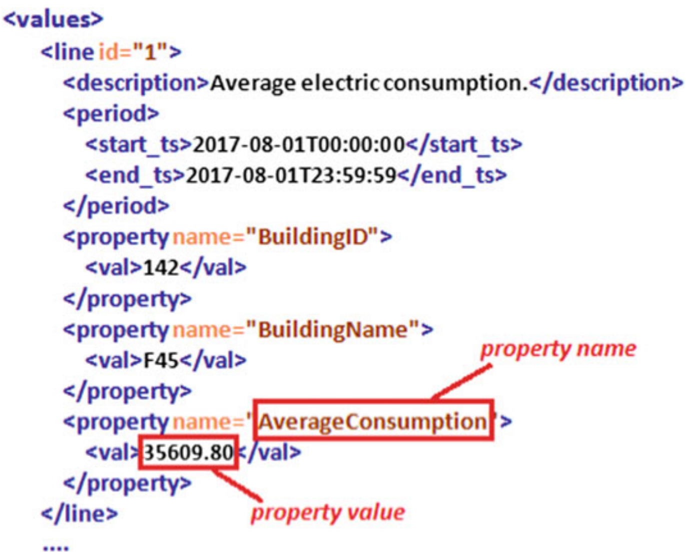

Fig. 5 Urban dataset XML fragment

The Communication, to perform the two actions above, must be defined through the configuration of three aspects:

1. The Architectural Patterns,
2. The Web Service Interface,
3. The Transport Protocol.

The SCPS Communication Level describes the set of possible configurations that the Smart City Platform and the Solution can agree on. SCPS Communication Level provides three architectural patterns [33] defined as Client-Server interactions:

- Request/Response: it allows a client to request an Urban Dataset to a listening server (e.g. a Vertical Solution, as a client, requires an Urban Dataset to the Smart City Platform's service, as a server, which responds with the Urban Dataset required);
- Push: it allows a client to directly send an Urban Dataset to a listening recipient (e.g. a vertical Solution, as a client, sends an Urban Dataset to the Smart City Platform's service that, as a server, receives the Urban Dataset);
- Publish/Subscribe: it allows the transmission of data between a vertical Solution "publisher" and N vertical "subscriber" Solutions, through the Smart City Platform that acts as a "broker".

These patterns can be used to implement the communication among the vertical Solutions and the Smart City Platform, depending on the needs inherent in the case to be managed.

We report, as example, the schema of the "Request/Response" pattern.

Note that, depending on the situation, the Client and Server roles can be interpreted by both a vertical Solution and the Smart City Platform.

The patterns can be realized through the implementation of the "Urban Dataset Gateway" web service, whose interface is defined with various methods (detailed descriptions are provided for each method and each parameter specified). For example, the "basicRequest" and "searchingRequest" methods implement the "Request/Response" pattern (see Fig. 6). Note that the description of the web service interface is independent from the implementations, based on the REST protocol in combination with the JSON format or SOAP (described through WSDL, descriptor of the service) in combination with the XML format (Fig. 7).

3.4 The Semantic Level

The core functionalities of the Smart City Platform aim to make efficient the exchange of information between the different interfaced application contexts. Clearly this leads to interoperability problems, due to the use of different languages, paradigms, software, data formats. A way to tackle this problem is the reduction or elimination of terminological confusion and with shared knowledge and terminology through the definition of a unifying framework that could serve as a basis for interoperability.

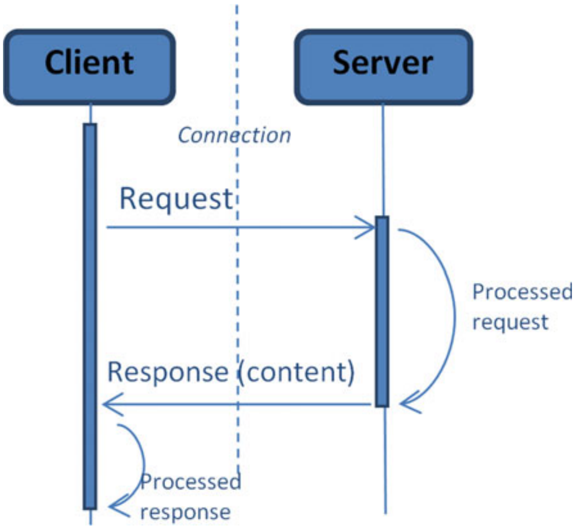

Fig. 6 Pattern request/response

Service	UrbanDatasetGateway
Methods	login (username, password)
	push (token, collaboration_id, dataset)
	basicRequest (token, collaboration_id)
	searchingRequest (token, collaboration_id, from_utc_datetime, to_utc_datetime, coordinate_center, radius)

Fig. 7 Methods of the urban dataset gateway

Ontology definition can help in this task, and could represent a common ground to face up some of the aforementioned issues, playing a relevant role in the communication management and solving semantic ambiguity. Modularity and reusability are two key characteristics that make ontologies a proper tool to be used inside the platform.

The use of standard technologies for the definition of Ontology, such as those defined by the World Wide Web Consortium (W3C), makes available a whole series of protocols and languages for communication. These tools favour the automatic discovery of the data structures and their meaning through the organization of the concepts in a hierarchy and the link with related information, making possible also the automatic generation of the relative documentation. An additional advantage using Ontology is the possibility to define, in a simple way, rules for generating new information autonomously with the appropriate software tools. In fact, there are different mechanisms and languages that allow to define rules to obtain new information starting from the information stored in the knowledge base.

In the task of defining and creating the Ontology, the initial phase was focused on the analysis and exploration of existing ontologies that deal with the Smart Cities in various aspects. We started analysing the initiatives listed in the http://smartcity.linkeddata.es/ portal of the READY4SmartCities FP7 CSA [34] project, whose aim is to increase awareness and interoperability for the adoption of semantic technologies in the energy field to reduce consumption and CO2 emissions at the Smart City community level. The portal contains several ontologies for the most diverse services related to a Smart City. During the analysis phase we explored different projects that tried to achieve the objective of cataloguing and data integration through ontologies. The aim was to observe the state of the art in order to understand how to move in this area and what are the pros and cons of different approaches. Below are some of the identified solutions.

- The DIMMER project (http://www.dimmerproject.eu) integrates information on the topology of buildings with real-time data from sensors and users to analyse and correlate the use of buildings and provide information on their behaviour on energy consumption in real time. The defined Ontology is very simple and defines a relationship between services provided by a sensor, building and physical location.
- The City Protocol project (http://cityprotocol.org/), conducted by the city of Barcelona, whose goal is the creation of a common system for cities and the development of protocols that allow innovation through the interaction between different sectors and areas of city life. The project provides the definition of Ontology [35] that defines a fundamental structure of the city through the definition of basic and general concepts for the different types of activities of the city from both an infrastructural and social, economic and environmental point of view.
- Km4City Ontology: Ontology developed by the DISIT of the University of Florence [36] with the aim of integrating information on transport and mobility with the dataset provided by the municipality of Florence and the Tuscany region.
- The CITYkeys project (http://www.citykeys-project.eu/) aims to improve the exchange of information between the various subjects providing services within a Smart City. The project identified a set of KPIs (Key Performance Indicators) to help the city in implementing strategies by linking various services. CITYkeys does not define any Ontology, but helps collecting and detailing a wide set of indicators that can be used in the evaluation of impacts on Smart Cities.

The analysis led also to the identification of two existing ontologies that have been integrated in our platform for greater compatibility with the outside world:

- Ontology of units of Measure (OM) [37], it has a strong focus on units, quantities, measurements, and dimensions.
- PROV Ontology (**PROV-O**), provides a set of classes, properties and restrictions that can be used to represent and exchange information of sources, generated in different systems and different contexts

In its definition, the Ontology revolves around the concept of Urban Dataset (defined as a subclass of Entity of the PROV Ontology). This concept refers to any data, aggregated or not, that an application context is able to process based on the

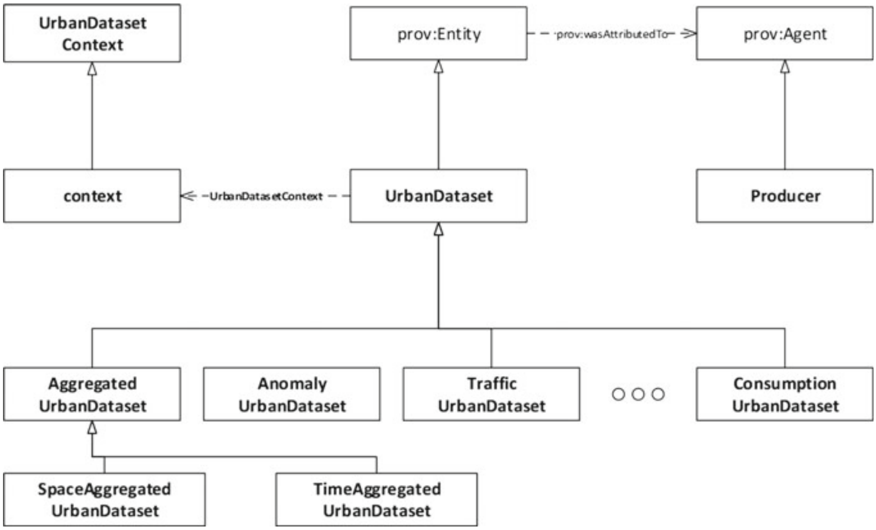

Fig. 8 Main concepts related to urban dataset

data collected by the sensors located in the Smart District. This is the crucial node of all communication and the main information that must be exchanged within the infrastructure.

Figure 8 shows the main concepts of the Ontology:

- **UrbanDatasetContext**: each Urban Dataset has its own context that serves to better describe and characterize the information (e.g. the context includes the geographic position to which data refer, language used for descriptions, time and time zone). Information from a context is modelled as a property.
- **Property**: when an Urban Dataset is generated, it is associated with other information (both specific and contextual) describing it, such as the creation time, the position of the sensor from which it is produced, its description or its identifier and the version (that is the specificationRef). This information is defined as a property of the Urban Dataset or a context.
- **Producer**: an important aspect of a data set is its origin, that is, who is the data provider. PROV Ontology, introduced earlier, in this case performs this function. In the specific case, Producer, subclass of "Agent", (see Fig. 8) describes the entity that creates the data. The property "wasAttributedTo" of PROV-O can be used to report the producer.
- **DataType**: this class was created to manage and list the canonical data types. As said, the OM Ontology is used to link Urban Dataset to the units of measurement of the international system.
- **ApplicationContext**: in addition to the specific properties, the Urban Dataset is also associated with a field that indicates the application context to which it refers (e.g. SmartBuilding for the case of anomalies in a building).

The individual properties of the different Urban Dataset are in turn the subclasses of Property:

- **ContextProperty**: groups all the property instances used to describe the context (e.g. coordinates, language, time in which the data was collected, etc.);
- **UrbanDatasetProperty**: groups all the property instances used to describe specific properties of the Urban Datasets (e.g. the number of anomalies, the number of occupied parking spaces, the average energy absorption, etc.).

Finally, an Urban Dataset often contains data that can be attributed to a particular application context (e.g. smart building, smart mobility, etc.). For this reason, the existence of a property that relates an instance of Urban Dataset with an applicative context has been foreseen in the Ontology. The Ontology has been formalized in the OWL language and made available online and downloadable at the link http://smartcityplatform.enea.it/specification/semantic/1.0/ontology/scps-ontology-1.0.owl.

3.5 The Original Contribution of the Approach

The SCPS with respect to existing development framework and platforms:

- does not impose a reference technology or the use of an existing implementation;
- looks only at the interfaces at the higher ICT level (z-axis in Fig. 2), leaving completely free the implementation of each vertical application;
- is highly customizable, since:
  - the developers can choose the subset of the specification they want to implement (favouring incremental approach)
  - the flexibility of the format enables to exchange a huge kind of data. So the set of data can be defined on the base of the vertical applications that need to be connected.

Moreover, the SCPS approach to the data format definitions is based on two principles, aiming to join the flexibility with the capability of checking conformance to the specification:

1. *Need for minimum set of constraints on the Information Level*: this has been got by the definition of a general, huge and elastic data model able to contain a wide set of measured data, coming from different contexts and managed by different applications. This data model can be imagined as a table, which names of columns are defined case by case. So at this level only the conformance to this general light format is checked.
2. *Moving of conformance checking on the semantic level*: this has been got by defining the semantic structure of the data model within the Ontology, so assuring not only the semantic interoperability thanks to shared meaning, but also a part of the formal validation of the data format.

Moving on a more political and organizational level, another interesting point is the recognition of the key role played by the Public Administrations in the effort to activate the city's change. It resulted in the identification of the public calls for tenders as a powerful leverage for applying common interoperability principles between Smart City Applications.

4 Conclusions and Future Directions

Nowadays, each city carries out a multitude of heterogeneous solutions related to the different vertical application domains (e.g. Mobility, Buildings, Energy Grids) and the most common approach is the one where each solution is a closed proprietary implementation which is not able to communicate neither with other solutions nor with the other city stakeholders (municipality, citizens). Meanwhile the Smart City holistic vision is rapidly spreading out thanks to the digitization of existing services and the creation of new services upon the existing ones. In fact, what makes a city a Smart City is the use of ICT in order to optimise the efficiency and effectiveness of useful and necessary city processes, activities and services. This optimisation is typically achieved by joining up different elements and actors into an interactive intelligent system. For that reason, in order to break the silos and break the barriers in the ecosystem of urban solutions, we need to drive them towards interoperability concepts.

In this scenario we started from the analysis of real contexts and the processed and exchanged data in the Smart Cities; this analysis made it possible to identify multiple aspects related to interoperability among systems and to group them into 5 groups/levels; then a concrete solution was given for each of the 5 levels, providing a precise specification; the 5 resulting specifications are modular, connected but independent of each other: this makes it possible to establish a process of gradual convergence towards full interoperability among the city's vertical solutions with the aim of exploiting the Smart City vision potentials and therefore provide citizens with new services, fostering competitiveness and avoiding the 'vendor lock-in' given by proprietary implementations.

As a result, we proposed an approach inspired by the SGAM Model, an interoperability oriented analysis framework in the smart grid context, which enables the identification of data exchange interfaces, standard classification and mapping of different architectures on the same reference model.

Re-elaborating the SGAM in a Smart City scenario five levels have to be addressed in order to face the interoperability issues: Functional, Collaboration, Semantic, Information, Communication.

The Functional Level describes the Reference Architecture, the Key Concepts, the Users and the macro-functionalities through Use Case Diagrams. The Reference Architecture assumes a schematic representation which includes a horizontal Smart City Platform and a series of vertical Solutions where the data move from the Solution management in its own application context up to the Smart City Platform.

The Collaboration Level manages the set of information that characterizes the cooperation between the SCP and any solution, through the description of the basic functionalities needed for the interaction with any user and the registry database which is the repository of the solution and of the managed Urban Datasets, as well as their relationships. The collaborations are handled, in the registry, as a set of information organized in the following four groups of information: Smart City Administration, Vertical Solutions, Urban Datasets, and Complementary. Each group of information is explained in a data model through the definition of the appropriate E-R scheme and detailed descriptions of the related tables.

The Semantic level deals with the definition of an Ontology which provides reduction or elimination of terminological confusion by means of shared knowledge and terminology. Ontology definition plays a relevant role in the communication management and solving semantic ambiguity. Modularity and reusability are two key characteristics that make ontologies a proper tool to be used inside the platform. In particular, the Ontology is essential for the right interpretation of the information of the Urban Dataset structure. The Ontology has been formalized in the OWL language and made available online.

The Information Level defines the format able to make interoperable the exchange of significant information about the city, namely the Urban Dataset, among heterogeneous systems or applications. The format has been thought to be self-consistent (it is mandatory to be compliant with the SCP specifications but it can be adopted also outside the framework) and it is defined by an Abstract Data Model and the syntactic implementation of the model in XML (eXtensible Markup Language) and JSON (JavaScript Object Notation). The Abstract Data Model gives a syntax-independent representation of the content that a document, used to exchange Urban Dataset, must have. Because the Smart City scenario is under continuous evolution, it has been designed to be scalable during the time and across different contexts.

The Communication Level (or data transport) defines the actions that a vertical Solution can undertake in order to communicate with the Smart City Platform, which are: the production of Urban Datasets (information which a solution exports towards the Smart City Platform) and the access to Urban Datasets (a solution retrieves information that the Smart City Platform has previously published). Therefore, if the first action enables the retrieving of data from a Solution to the Smart City Platform and the second action enables transfer of data from Smart City Platform to a Solution, the coordinated set of the two actions allows the exchange of data from a vertical Solution to another vertical Solution through the Smart City Platform. The communication, to perform the two actions above, must be defined through the configuration of three aspects: the Architectural Patterns (Request/Response, Push, Publish/Subscribe), the Web Service Interface and the Transport Protocol.

All these features of the SCP specifications are modular; it means that each stakeholder can implement not necessarily all of them but also a subset of them.

Thus, as already stated, since the absence of a univocal and ‘holistic’ standard, what we have proposed here is a high level reference framework aimed at enabling interoperability in Smart Cities, i.e. able to include all the multiple aspects of the Smart City with a coherent vision. For the future this means the need to face the issue of standardization, confronting emerging initiatives or even proposing the SCP Specification as a contribution to the construction of standards and it requires the engagement of the main national/international standardization initiatives (as the IES-City initiative led by NIST) in order to achieve a convergence on all the technological issues related to the proposed model.

This convergence process through open specifications is the opposite of an imposition of a single centralized and proprietary solution; in fact it allows existing solutions to join without having to be replaced by another technology and allows interested parties to contribute on specific aspects of the overall design.

Nevertheless it is not enough. If we state that the public administrations can play a key role in breaking the barriers among the Smart City subsystems, they should be provided with a common global set of standards and guidelines to be used in the call for tender.

At the moment the specification are being experimented in a laboratory context, implementing the communication among existing testbed applications (for example smart buildings within ENEA site and another existing WebGIS application, and so on). The first results are very encouraging. Moreover the approach has been shared with an important group of stakeholders (including city, industry and research representatives) in an ENEA initiative called Italian Convergence Table and it has received a very positive welcome. The next step will be the experimentation in a real urban context. In this phase it is expected to get a credible evaluation of the approach and to be able to identify possible criticalities in it and to modify the specifications in order to solve them.

Lastly, SCP Specifications do not aim to solve all the issues related to communication in the Smart City field, but the potential impact, at the national or European level through a first convergence path based on interoperability, can be noticeable in socio-economic terms and in the efficient energy management, pursuing an improvement in the quality of life of the citizen.

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