CPWD-PR_005_Open_Sensor_Platform

# Open Sensor Platform

Developed by TAFT - OSP

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**This Document Has Been Prepared Under the Auspices of the**

## City Protocol Task Force

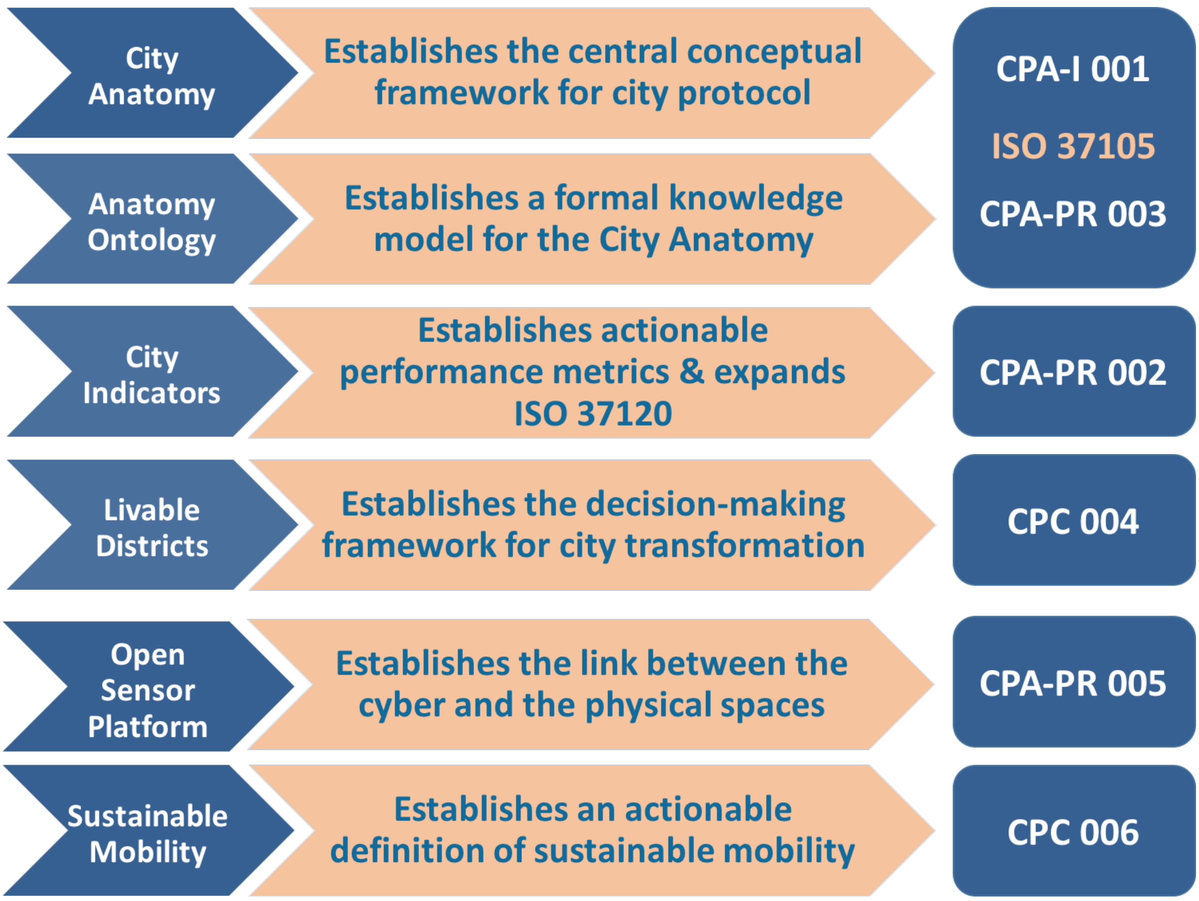
City Protocol is a collaborative innovation framework that fosters city-centric solutions to improve efficient service delivery and overall citizen quality of life. City Protocol seeks to define a common systems view for all cities regardless of size or type, embracing protocols that will help cities deploy solutions across service areas. City Protocol aims at working across cities of different realities by interconnecting them and ultimately creating an “internet of cities”.

In order to accomplish this goal, City Protocol adheres to a common vocabulary to express ideas. That vocabulary emanates from a seminal work, **City Anatomy,** that establishes the foundational platform for the approach to our work (CPA-I_001-v2_City_Anatomy.pdf).

## Executive Summary

### 1. Statement of Need

Information and Communication Technologies are in continuous growth and change, and many cities use them to enhance or improve the environment, interactions (functions, economy, etc.) and governance. By gathering and integrating data about city systems, city officials can optimize urban metabolism and performance, keep citizens informed and engaged, and facilitate the development of new businesses. Sensors and actuators are commonly used to respectively gather data and interact with the physical space of cities. Their implementation requires a platform capable to manage a sensors/actuators network and the flow of information that they generate.




This document completes the foundation of the City Protocol effort, as summarized in the figure above. The Open Sensor Platform (OSP) is both a simple conceptual model that identifies and describes the basic functions needed to sensoring the physical space as well as an actionable Software as Service (SaaS) model to gather data and actuate over platform devices when required. It thus defines the needs and provides the means to sense and actuate upon the physical space of any city and to evaluate **indicators with data**. The OSP facilitates the information needed to understand, assess and manage all systems and elements of the **anatomy**, information that is ordered, related and named according to the **ontology**, and that is essential to identifying and solving city **livability** challenges, such as mobility. Through this process, citizens can be engaged in decision making and project prioritization, with government mediating between stakeholder conflicting interests and caring for appropriate and integrated financial schemes to enable city transformation and modernization.

## 2. Purpose, Deliverable Description and Objectives

The aim of this document is to provide a software as service (SaaS) model to:

- extract, manage and share city indicators information, making it open and accessible to any interested party
- isolate sensors and actuators from the applications that use them, thus facilitating the development of multiple and varied applications
- break down vertical solutions, thus avoiding the dependence on suppliers and the proliferation of isolated systems often deployed even for the same city service
- facilitate data sharing from any sensor among different applications, assuring openness and transparency
- set common services such as catalogue of sensors/actuators, monitoring, and quality of service that are needed by all city applications to avoiding repetitive development
- allow protocol translation between sensors/actuators and applications
- ensure the completeness of the sensors/actuators catalogue with a core system

that manages and maintains equipment in the public space.

The above objectives are framed with an evaluation of the field testing carried out in several cities of different sizes and for a broad range of physical space targets. The feedback obtained from these cities should guide other cities in such sensing implementations.

OSP facilitates the organization of city services in an integrated manner as a set of functional layers that include data collection, knowledge management and data intelligence. Data collectors provide in agreed formats normalized data gathered from several sources (e.g., IT Systems, transducers, network elements, social networks, etc.). This information is stored and managed in a knowledge layer and offered to a higher level Intelligent Service Layer (e.g., in accordance with TU SG20 Y.CS-platform Working Group).

OSP, in its current development, does not allow for knowledge management capabilities at the data collection layer, e.g., within data collector elements. This feature will be implemented in the future to enable actions that require a decision-making process with processing times lower than its latency (e.g., traffic lights changes when an ambulance arrives at 80 km/h).

## 3. Description of Target Users

The target users of this document are: (1) Task Teams working on protocols dealing with open data management and data portal software; (2) City leaders and officers accountable for informed decision making; and (3) Commercial organizations and Knowledge institutions involved in R&D+i and commercial activities related to data management (*e.g.*, data traffic, collection, processing, visualization and analytics).

## Contents

## 1. Introduction

Cities are sources of information related to many variables that can be observed, measured and acted upon to improve the quality of life of citizens, enhance city functions, increase the performance of the economy, make city metabolism more efficient, and facilitate continuous evaluation and participatory governance (*i.e.*, a livable city; CPC_004_Livable_Districts_and_Cities.pdf).

City systems, elements and interactions identified in the City Anatomy (CPA-I_001-v2_City_Anatomy.pdf) and its ontology (CPA-PR_003_Anatomy_Ontology.pdf) can be monitored, evaluated and improved with a set of anatomy-based indicators (CPA-PR_002_Anatomy_Indicators.pdf).

The best way to obtain context information of city functions and metabolic elements (*e.g.*, transport, waste and water management, environmental health, etc.), and to optimize performance, is to deploy and use sensors and actuators. The adoption of a single and common platform to and from which all sensors or users respectively send or receive information has several advantages. For example, such a sensor platform could interconnect heterogeneous devices and applications (*i.e.,* would support breaking internal city silos) and challenge the concept that a service or application is connected to a single sensor.

A network of multi-connected sensors and applications should speed up the provision or deployment of services since they usually require information from multiple sources which might already be available within the sensor platform. To keep the flow of information and actionable KPIs, cities will benefit from a thin client or lightweight cloud-based open sensor platform specifically designed, implemented, field tested and maintained by cities and regions that is consistent with CP foundations (ISO/NP 37105).

## 2. Sensor Platforms

### 2.1 State of the art

Current sensor platforms have appeared as a result of attempts to improve the process of sensing the physical space with minimal errors. Supervisory Control and Data Acquisition (SCADA) systems or Wireless Sensor Networks are good examples of such platforms. They rely on different technologies that aim at gathering city information and monitoring city variables.

Clasic SCADA systems have had an increasingly important role in monitoring and controlling city services and infrastructures[1,2,3]. Initially designed for the automation and control of industrial processes, they compile data from several sensors located in close proximity or in more remote locations, and send these data to a central computer that manages and controls it. A clasic SCADA system has the following components:

- Devices to catch and receive signals (sensors and actuators)
- Programmable Logic Controllers (PLCs)
- Communication networks and their components
- An industrial measurement and control system that consists in one or more central or master servers.
- One or more data gathering units and control units or remote controllers.

[1] Al-Hader M, Rodzi A. The smart city infrastructure development & monitoring. “Theoretical and Empirical Researches in Urban Management 4.2 (2009): 87 94

[2] Brenna M, Falvo MC, Foiadelli F, Martirano L, Massaro F, Poli D, Vaccaro A. Challenges in energy systems for the smart-cities of the future. Energy Conference and Exhibition (ENERGYCON), 2012 IEEE International. IEEE, 2012

[3] Vlacheas P, Giaffreda R, Stavroulaki V, Kelaidonis D, Foteinos V, Poulios G, Demestichas P, Somov A, Biswas AR, Moessner K. Enabling smart cities through a cognitive management framework for the internet of things. Communications Magazine, IEEE 51.6 (2013): 102-111

- Optimized Data Base.
- A collection of software properly customized.

The main advantages of clasic SCADA systems are the reliability and performance of the control and data acquisition systems. However, they are usually proprietary (*i.e.*, closed) systems, focused on managing the processes of a factory, an airport, etc., and not originally designed to share data with other platforms or to interoperate easily with third parties.

On the other hand, state-of-art Wireless Sensor Networks (WSN)[4,5] allow sensors to establish direct communications between themselves (i.e., following a peer-to-peer communication model) wherever they are acquiring data and to report them to a platform using a decentralized architecture. Current WSNs are a good choice to set up sensors in a given area either as a complement to, or replacement of, existing clasic SCADA systems. However, they were usually based on proprietary solutions and associated with manufacturers of the different devices that comprise the WSN. This fact favored vertical solutions, making interoperability more difficult. Nowadays, new WSN systems are deployed under Open Source with standard interfaces at different OSI levels. Simultaneously, new SCADA deployments evolve towards a similar standardized interface scenario.

Internet of Things (IoT) initiatives can minimize the drawbacks of old WSN by enhancing the openness and interoperability of WSN as the simplest and most efficient way to connect an unlimited number of devices and gather their data. Although many standardization bodies (*e.g.*, ETSI, ITU-T, ANSI, CENELEC,

[4] Lewis FL. Wireless sensor networks. Smart environments: technologies, protocols, and applications (2004): 11-46

[5] Raghavendra CS, Sivalingam KM, Znati T. eds. Wireless sensor networks. Springer Science & Business Media, 2004

IEC/ISO, etc.) have been working on the topic of IoT and Machine to Machine (M2M) interconnection, a common definition and standards for sensor interfaces and data is still lacking. This is hindering the goal of a more global and homogeneous operation of IoT systems. However, works on IoT and Y.CS-platform on ITU SG20 shows a clear path towards a confluence of standards.

The Open Geospatial Consortium (OGC) Sensor Web Enablement[6] is a good example of standardization of a sensor management platform. OGC has participated in the development of a group of web standards to access sensors and their observations. These standards enable discovering sensors, observing each one with the measurement processes involved, knowing the tasks assigned to the different devices, and accessing observations and the publication/subscription alerts of all sensors. Although these standards facilitate interoperability between platforms, they are too unwieldy to implement into simple devices since they have limited consumption and computation power. The OGC approach does not consider requirements when providing data from the collection elements to the knowledge layer functions.

Taking into account this background and the rise of WSN and IoT technologies, especially in the context of the increasing level of sensing in cities[7,8,3], a number of approaches emerged recently that simplify the control of the myriads of sensors expected to be placed for controlling real-time urban services. The most relevant proposals available are presented and explained in the following subsection.

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[6] Botts M, Percivall G, Reed C, Davidson J."OGC® sensor web enablement: Overview and high level architecture." GeoSensor networks. Springer Berlin Heidelberg, 2008. 175-190

[7] Filipponi L, Vitaletti A, Landi G, Memeo V, Laura G, Pucci P. "Smart city: An event driven architecture for monitoring public spaces with heterogeneous sensors." Sensor Technologies and Applications (SENSORCOMM), 2010 Fourth International Conference on. IEEE, 2010

[8] Mitton N, Papavassiliou S, Puliafito A, Trivedi KS. "Combining Cloud and sensors in a smart city environment." EURASIP Journal on Wireless Communications and Networking 2012.1 (2012): 1-10

## 2.2 Available Platforms

Two different philosophies with radically opposite perspectives exist in the field of Sensor Management Platforms. On the one hand, there are several commercial and proprietary platforms that offer vertical approaches while providing a complete solution from the sensors and any intermediate hardware to the software that monitors and controls them. However, these are only prepared for specific use cases and they do not provide interconnection and interoperability capabilities with other platforms.

On the other hand, platforms that enable connections between heterogeneous sensors from multiple vendors also exist, although they are significantly fewer in number. They represent a much more interesting development, because they promote an open and horizontal environment that allows users to interact with as many sensors as possible, regardless of the type and the manufacturer. However, there are still limitations that must be addressed to have fully open and interoperable platforms. For instance, none of the above approaches includes requirements between knowledge layer functions and data collection elements. Similarly, the lack of a common standard ontology for sensors hinders semantic interoperability and sometimes justifies the use of proprietary (i.e., closed) solutions.

### 2.2.1 Open platforms

***Sentilo***[9] is an open source sensor and actuator platform designed to fit in the Smart City architecture of any city looking for openness and easy interoperability. It is built, used, and supported by an active and diverse community of cities and companies that agree in the power of also using open standards and free software. It represents one of the most deployed open platforms (in use currently in Barcelona and Dubai).

[9] http://www.sentilo.io/wordpress/

In contrast, too many smart cities still rely on their own proprietary and vertical solutions. To avoid vertical solutions, Sentilo is designed as a cross platform with the objective of sharing information between heterogeneous systems and easily integrating legacy applications. It offers the following features:

- front-end for message processing, with a simple REST API
- administration console for system configuration and managing the catalogue
- memory database, designed to attain high performance rates
- a non-SQL database for more flexibility and scalability
- universal viewer, provided as a public demo that can be used as a starting point for specific business visualizers
- basic statistics module that records and displays basic platform performance indicators
- extensible component architecture, to enlarge the platform functionality without modifying the core system. Sentilo starts with an initial set of agents, one for exporting data to relational databases and another one to process internal alarms based on basic rules.

***SOFIA***[10] is a middleware that provides seamless interoperability between multiple devices and systems. It offers a semantic interoperability platform to allow the exchange of real world information between smart applications. It includes a standard definition of concepts (Things) in the domain of the applications, making SOFIA a suitable platform for Internet of Things. In addition, it is open source, multi-language and communications agnostic. An evolution of this middleware is provided by Indra under the name of Sofia 2, with the following features:

[10] SOFIA Website, Indra Systems. Available online at: [http://sofia2.com/docs/ SOFIA2%20-%20SOFIA2%20as%20Interoperability%20Platform.pdf]. Last access: September 2015.

- Big Data Interfaces (Hadoop) for storage and data warehouse
- Temporary reasoning capabilities
- Integration with back-ends
- Storage and geographical queries
- Addition of pluggable security mechanism
- Multiplatform:
    - REST interfaces: smartphones, devices, etc.
- Platform simplification:
    - SSAP (Source SAP) communication protocol with a JSON-based protocol: lighter than XML and suitable for devices
    - Simplification in the development of ontologies and query language
- Horizontal scaling:
    - By adding elements that scale horizontally at every level (data grids, storage, processing)

***OpenIoT CUPUS***[11]. The CUPUS middleware is a content-based publish/subscribe offering. It is designed to enable pre-filtering of sensor data streams close to data sources, *e.g.*, on mobile devices, so that only data of interest and value to various subscribers is pushed into the publish/subscribe cloud. The filtering process is not guided locally on mobile devices but from the cloud, based on global data requirements. Moreover, the CUPUS cloud distributes push-based notifications from the cloud to largely distributed destinations (mobile devices) in near real-time. Although it cannot be considered as a full open sensors platform, it is a relevant software component to be taken into account as part of any platform.

***IBM Mote Runner***[12] provides a platform, simulation environment, and development

[11] https://github.com/OpenIotOrg/ openiot/wiki/CUPUS. Last access: September 2015.
[12] http://www.zurich.ibm.com/ moterunner/. Last access: September 2015

tools for wireless sensor networks (WSNs). Applications can be written in Java/C# using Eclipse and deployed on simulated motes (on the host PC) or physical motes (IRIS). Firmware is included in the distribution allowing the mote application to run on hardware such as the IRIS, RZUSBSTICK, and AVRRAVEN motes. Therefore, it cannot be considered a complete software platform because it provides limited functionalities and a short range of sensor types.

***IoTSens***[13] and ***Telefonica M2M***[14]. Both advertise themselves as open platforms for *smart* solutions. IoTSens platform is provided as a service Software by an SME[15] in Spain, so it does not really rely on an open community. Analogously, the integration and deployment of Telefónica M2M solutions, which rely on open source components compliant with the FI-WARE ecosystem[16] depend on Telefonica[17] who manages the service.

### 2.2.2 Commercial platforms

***SenseIoT***[18] is a platform that allows users to upload and monitor data, receive alarm messages when some parameters values established by the user are reached, and visualize information. This platform manages vertical sensor-based solutions and simplifies the connection between the information and application layers. Managed by the company Sense, it also has its own developers' platform called *CommonSense*, which is user-friendly and offers a free code to retrieve data. Nevertheless, depending on the expected use of the application, it will generate additional costs based on the amount of data stored in the SenseIoT database, the

13 http://www.iotsens.com/en. Last access: September 2015
14 https://m2m.telefonica.com/. Last access: September 2015
15 https://www.adc.es
16 https://www.fiware.org/. Last access: September 2015
17 http://www.telefonica.com/
18 http://www.sense-iot.com/. Last access: May 2015

period of time (in months) it remains stored, and the number of calls on these data. The time that the data will remain in the platform since the last update also impacts the cost of the service for users. A free account is available with a limited size of data to upload, limited calls per month and a month of remaining time for the data since the last upload.

The main purpose of SenseIoT is to offer as many facilities as possible to anyone who wants to monitor any parameter measured by sensors, and to visualize and work with the sensed data. The platform doesn't offer the possibility to share data, requiring the data provider and the developer to be the same entity, and thus limits the development of applications by third parties.

***SeeControl***[19]. This IoT Software platform service enables web-based applications that, with the proper authentication, enable users to visualize data through several interactive tools (*i.e.,* computational operations, analysis of historical measurements, etc.). The web-based applications provide limited customization possibilities. In contrast to SenseIoT, SeeControl does not offer a free account and the cost depends on the functionalities available, the information rate, the size of data, etc. For instance, the capability to send orders to the devices (actuators) is available only for the most expensive option.

SenseIoT and SeeControl are neither horizontal nor interoperable platforms. Each information system or sensor is connected with a single application, and if something changes in the information layer, changes must be applied on the application layer and vice versa, hampering the maintenance of the services.

[19] http://www.seecontrol.com/. Last access: May 2015.

# 3. Optimal Requirements for an Urban Sensor Platform that Responds to The Values of the City Protocol Society

## 3.1 Technical

***Open Source***. The code has to be open and accessible according to the open-standard principles adopted by the CPS. Openness is required for adaptation to the realities of each city, and to changing needs.

***Interfaces***. The interface between the platform and the sensors/actuators network, and the interface between the platform and applications receiving/using data and sending commands to the field, have to be as simple as possible. It is universally accepted that Internet protocols best suit these requirements. Among them, the API/REST protocols are the simplest and most convenient when low latency needs with the highest degree of robustness are not required. The OSP should allow the adoption of other protocols because in some implementations of very specific sensors/actuators this might be required.

Interfaces are key elements since public procurement forces the coexistence of proprietary and open applications. Accordingly, in an open platform it is imperative to develop at all levels standard interfaces between different applications and/or devices (see ITU SG20 Y.SC Platform Draft).

***Performance***. Instrumenting (sensing) the complex physical domain of a city, with all of its functions and interactions, will ultimately involve a large number of devices sending data at high rates. Therefore, the architecture of the platform has to be a simple and scalable high capacity system to ensure performance in a data intensive and diverse city environment. In other words, a thin client or lightweight cloud-based model that is consistent with CP foundations (ISO/NP 37105) is the preferred option.

***Resilience and service continuity***. An urban sensor platform, like any other information system, must incorporate all the necessary redundancies to maintain data provision to all its clients. The specifications of the redundancies and support systems will depend on the criticality of the linked services and applications. Redundancies for scenarios of communications failure, system instability, etc., should be considered. Thus, the platform should be designed for self-configuration/adaptability to ensure service continuity.

***Security***. The whole environment where the OSP operates should have the adequate level of security to avoid attacks, and minimize the consequences of misuse and errors. The fact that the sensor network would in most cases involve the internet (*i.e.*, it would not be a corporate private network) makes security a priority in the sensor/actuator layer, in the OSP itself, and in the applications layer. Identification, authentication and authorization measures must be in place together with protective mechanisms for denial of service (DoS) attacks.

***Modularity***. The platform design has to allow the addition of modules for new services. The growth of this modular structure should be simple in design and in implementation. All modules must use standard interfaces at all levels between different applications and/or devices (see ITU SG20 Y.SC Platform Draft).

### 3.2 Functional

***Efficient information broker***. The main task of the OSP is to link sensors/actuators with any client application and distribute data among all city information systems. This data throughout has to be highly efficient. One of the easiest ways to minimize communications between all platform elements is to rely on a publication/subscription scheme which can be coupled with pooling mechanisms to collect the information needed by systems and applications.

***Maintenance of sensors/actuators catalogue***. The OSP must also maintain a catalogue with updated information associated to sensors/actuators that is necessary for management and maintenance (*e.g.*, brand, model, type, manufacturer, installation date, documents, maintenance data, etc.). The OSP has incorporated maintenance functionalities either at individual sensor/actuator level or tools for massive maintenance activities like incorporating new sensor/actuators systems for a given city project. The catalog must be organized as a dataset with the potential to be used by Open Data Applications (e.g., UNE 178 301 - 2015 in Spain).

***Bidirectional use of data***. The design of the OSP should allow bidirectional flow of information: receiving data from the sensors/actuators, and distributing data across the city information systems; or receiving commands from the applications and sending them to the sensors/actuators.

***City field testing***. Cities are urban labs and as such are the ultimate field testing environment where initiatives can be evaluated and demonstrated under real working conditions. Thus, any OSP should have been tested in different cities, for different purposes and in different scales. It should also have a multi-tenant enabled architecture to facilitate implementation in regions deploying smart initiatives.

***Additional requirements***. There are other functionalities that an OSP could have and that could also be available in other functional blocks of IoT platforms and applications (*e.g.* historical data, visualization/dashboards with GIS, administrative tools, machine learning and data analytics modules, etc.).

# 4. The Open Sensor Platform of the City Protocol Society

## 4.1 Sentilo

Most of the requirements for an open sensor platform listed above (Section 3) are fulfilled or in the process of implementation by Sentilo. Its architecture (*see* Figure 1) isolates applications developed to exploit the city information and the layer of sensors deployed across the city to collect and broadcast this information.

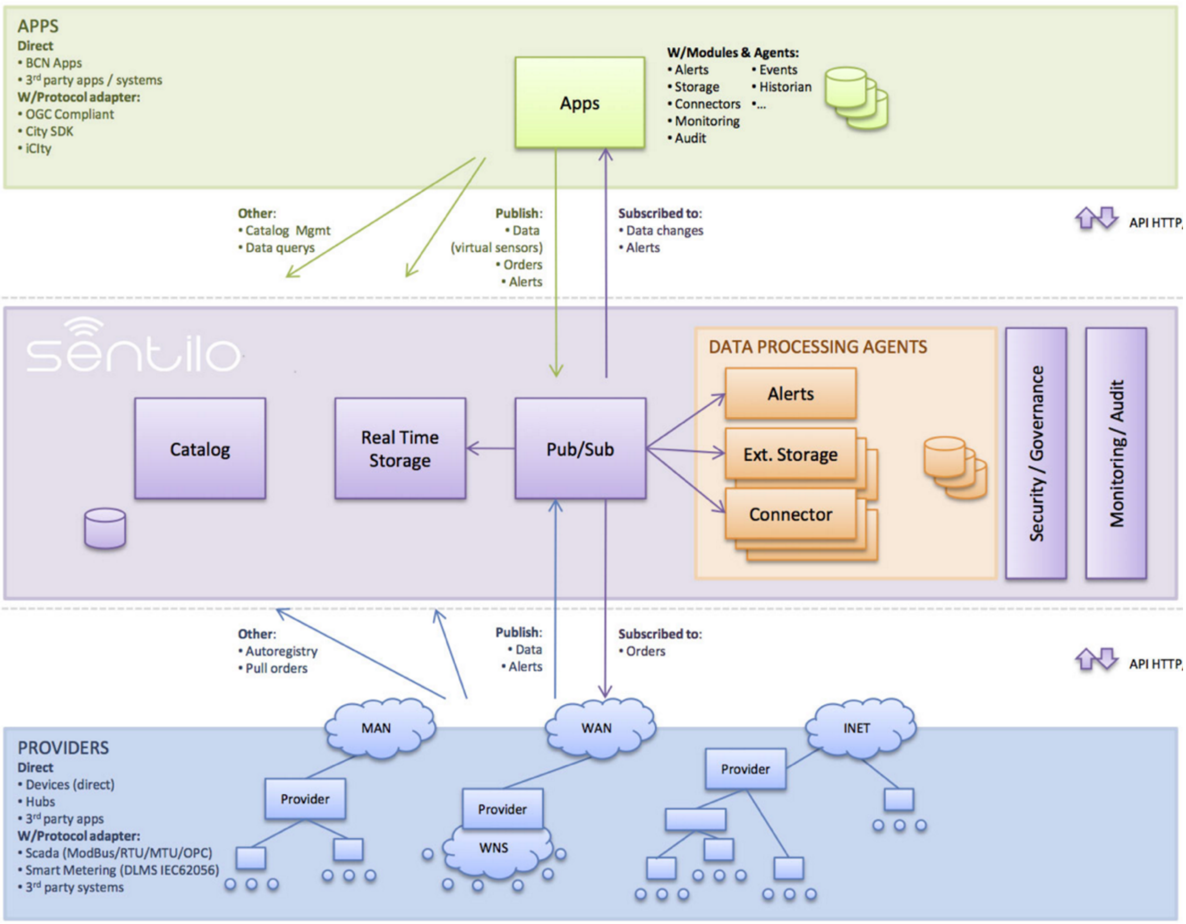


*Figure 1. Architecture of Sentilo*

The architecture shown in Figure 1 supports an open source sensor and actuator platform designed to fit in the Smart City architecture of any city that desires openness and easy interoperability. It has been built, used, and supported by an active and diverse community of cities and companies who believe that using open standards and free software is the first smart decision a Smart City should take. [20]

Sentilo represents a good example of a cross platform that is well aligned with the model of best practices that City Protocol stands for because it:

- is a City-led product and service that stem from city practice and needs;
- provides a way to extract, manage and share city indicators information, making it open and accessible;
- isolates sensors and actuators from the applications that use them, facilitating the use of multiple and varied applications;
- facilitates sharing information between heterogeneous systems and easily integrating legacy applications;
- breaks down vertical solutions, thus avoiding the dependence on suppliers and the proliferation of isolated systems often deployed even for the same city service;
- facilitates data sharing from any sensor among different applications, assuring openness and transparency;
- offers common services needed by all applications avoiding its repetitive development: catalogue of sensors/actuators, monitoring, quality of service, etc.;
- allows protocol translation between sensors/actuators and applications; and
- ensures the completeness of the sensors/actuators catalogue, thus facilitating the core sensing processes for managing and maintaining all equipment in the streets and other public spaces.

The Sentilo architecture depicted in Figure 1 enables the set of key features listed below:

- High performance: the platform is designed focusing on performance to process thousands of messages in a very fast response time.
- Modular and extensible: Defines a component architecture in order to enlarge the

[20] The complete set of Sentilo information and software can be found at http://www.sentilo.io/wordpress/. A description of the Sentilo development and implementation at Barcelona can be found at http://connecta.bcn.cat/connecta-catalog-web/.

platform functionality without modifying the core system.

- Horizontal scalability: allowing an easy distribution of load.
- Cross platform: Designed as a cross product not focused in any concrete business requirement, fleeing from vertical solutions.
- Open Source: In order to share contributions and improvements and create an ecosystem of companies around it.
- Simple REST Interface: it provides a simple, easy to use and intuitive interface.
- Universal viewer: Provided as a public demo that can be used as a starting point for specific business visualizers.
- Basic statistics module: Records and displays basic platform performance indicators.
- Catalogue and administration console: Intended to manage the devices installed in the street and its users (providers and applications).
- Strong partnership: the leadership of Barcelona, the support provided by the CPS, Dubai and the participation of other cities, regional administrations and companies ensures the applicability of the platform and its continuity.

The benefits obtained by using Sentilo are:

- Escape from ICT vertical solutions organized in silos.
- Reduce dependency on specific technologies, solutions or providers.
- Avoid isolated compartments where the applications cannot access data from other applications.
- Minimize duplicity and multiplicity of data and infrastructures.
- Lower investments and maintenance costs.

Finally, Sentilo has a roadmap for improvement and to better align its characteristics with the optimal features described in Section 3. This roadmap includes: (i) monitoring of sensors for incidents and faulty operations; (ii) security enhancements;

(iii) agent monitoring; (iv) and a push mechanism for retrying failed tasks. Other improvements in the pipeline are to increase availability, display structured data, integrate additional cartography systems, management system for sensor incident and maintenance, integration with external monitoring systems.

## 4.2 Current Implementations

Sentilo has been adopted, is in the process of implementation or has been implemented by several cities of different size (Barcelona, Dubai, Terrassa, Cambrils and Reus), and also at the regional level with a multy-tenant architecture (Diputació de Barcelona). This document (a Proposed Recommendation) will be promoted to the status of Recommendation when a substantial number of implementations have been completed and evaluated. In what follows, several implementations are provided and illustrated to support the technical advantages previously described. The preliminary field feedback is provided in Section 5.

### 4.2.1 Barcelona City Pilot

Barcelona is an important global city and a major European metropolis with more than 1.6 million inhabitants and an extension of 100 km$^2$. It is the main city of the sixth largest metropolitan area in the European Union. It services 36 municipalities and 3.239.337 inhabitants, with a total metropolitan extension of 636 km$^2$. This area is also the fifth largest industrial agglomeration in Europe.

Barcelona City Council deploys smart city projects by promoting public-private partnerships. One of the key achievements of Barcelona's strategy has been the definition of an IT architecture for the city, the so-called Urban Platform[21]. This

[21] Awarded by Siemens and the C40 Cities Climate Leadership Group (C40) with the City Climate Leadership Award 2014 on the Intelligent City Infrastructure category

platform is shown in Figure 2 and it aligns with the concept of a city being a system of interrelated systems (The City Anatomy[22]).

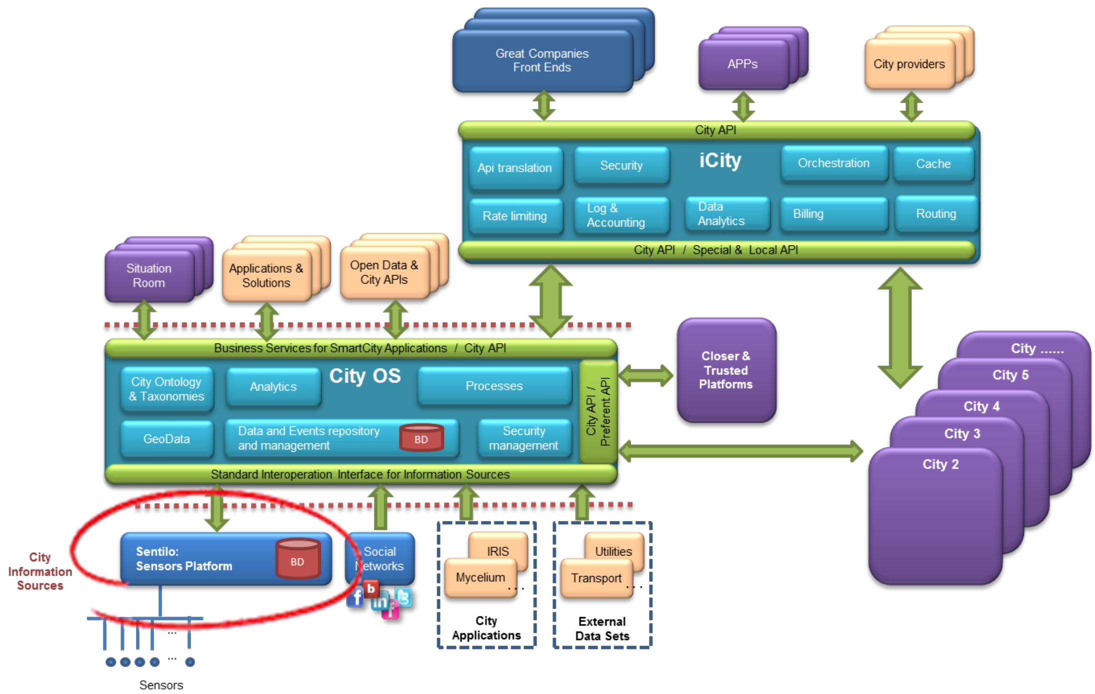


*Figure 2. Barcelona Urban Platform*

Barcelona approaches urban transformation in a holistic way in which decisions can be made thanks to transversal solutions that break the service delivery silos in which cities are traditionally organized. Moreover, the city has become a true urban lab for pilot services and projects in fields such as irrigation, street lighting and energy consumption monitoring among others.

Sentilo's first conceptualization was released in November 2011, and the first operational version was released in June 2012, developed by Open Trends company. Barcelona has already deployed with Sentilo the following network of sensors: noise (60+) for acoustic comfort; waste containers and trucks (800+); parking (550+); energy in public buildings and solar irradiance. An example of

[22] Vision aligned with the CPA-I_001_City_Anatomy, deliverable of the ANCHA TAFT

Barcelona's sensor network is depicted in Figure 3.

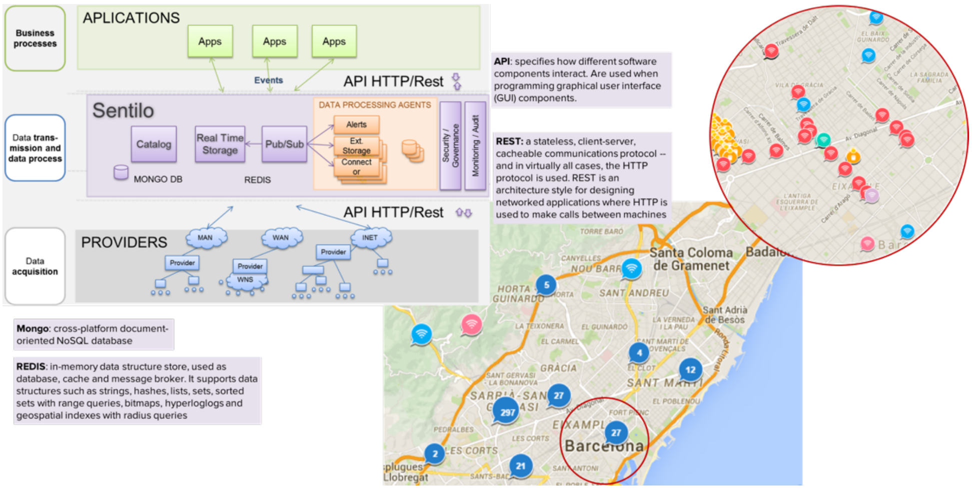


*Figure 3. Illustration of the Open Sensor Platform implementation in Barcelona*

This Open Source project has raised the interest of other Catalan cities (*e.g.*, Terrassa, Cambrils, Reus, etc.). The Province of Barcelona has adopted a multi-tenant architecture of Sentilo to serve its network of cities and towns.

Current Proof of Concept (PoC) initiatives include watering public lawns and gardens, water ph, traffic, people movement and air quality. Two pilots on surface parking and waste containers have been deployed while those concerning noise, energy consumption and energy generation are underway.

### 4.2.2 Dubai City Pilot

Dubai Municipality (DM) is the municipal body under the Government of Dubai with jurisdiction over city services such as major infrastructure (buildings, parks, drainage & irrigation), environment, waste management, health and public safety services in the Emirate of Dubai, United Arab Emirates. It was founded in 1954 by the then Crown Prince of Dubai, H.H Sheikh Rashid bin Saeed Al Maktoum, and is regarded as one of the largest government institutions in terms of services rendered and projects executed. The Dubai Municipality is the leading driver of growth and evolution of the Emirate of Dubai with over 11,000 employees working in 34 departments.

In his capacity as Ruler of Dubai, Vice President and Prime Minister of the United Arab Emirates, His Highness Sheikh Mohammed bin Rashid Al Maktoum, has issued a number of new laws that enhance the organizational structure and legislative framework for the Dubai Smart City project. The new laws aim to enhance the progress of the Smart City initiative and encourage innovation in this sector by fostering collaboration between the public and private sectors. The new laws also complement the strategic vision announced two years ago with the aim of transforming Dubai into one of the world's smartest cities and utilizing technology for the benefit of people.

Dubai Municipality is playing a lead role in achieving this vision by embarking on a number of Smart City initiatives and programs. One such initiative is to build a comprehensive platform to consolidate sensor and actuator data spanning services across most departments within the organization including environment, public health & safety, buildings, planning & engineering, waste disposal, drainage and irrigation to name a few.

Sentilo was chosen as the preferred platform due to its openness and interoperability using simple REST API. A PoC exercise is underway to interface the Air Quality Monitoring (AQM) system, managed by the Environment Department, with Sentilo, which has been setup and configured as shown in Figure 4. The AQM system aims to set a benchmark in the reduction and prevention of air pollution in line with DM’s strategic objective of “Ensuring health & safety of residents, environment protection and maintaining natural resources in a sustainable manner" through its environmental control strategies as well as the Smart Environment objectives.

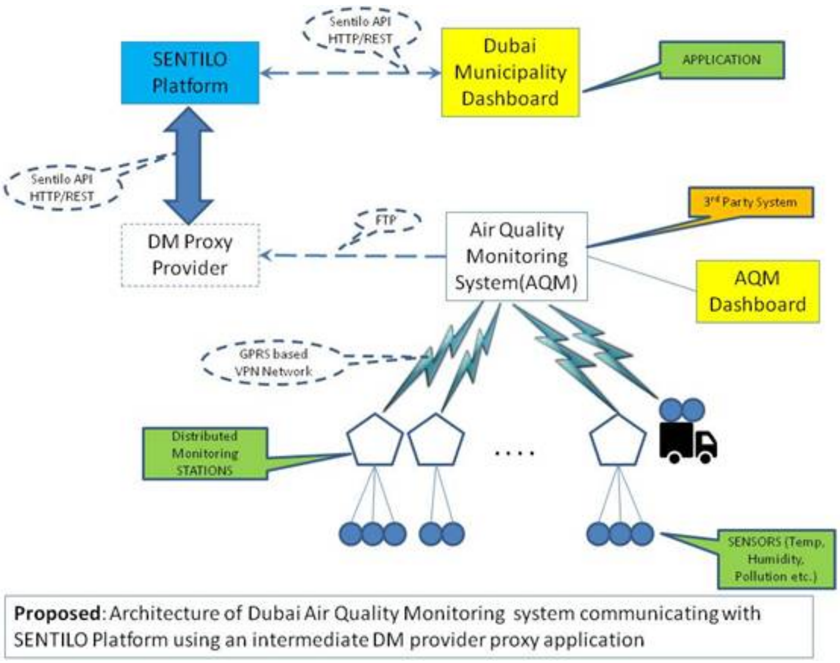


*Figure 4. Integration of Sentilo into Dubai's Air Quality Monitoring System*

Air Quality and environmental data from around the city of Dubai are collected using a network of 13 strategically placed distributed air quality monitoring stations at fixed as well as mobile stations, transmitting data periodically to a central AQM system. The system also features a pollution and health impact forecasting module indicating pollution levels using heat maps.

### 4.2.3 Terrassa City Pilot

Terrassa is a Catalan city located in the east central region of Catalonia, county of Vallès Occidental in the province of Barcelona. It has a total extension of 70.2 $km^2$ and a population of 215.000+ inhabitants. It is a prosperous and important city in Catalonia with an interest in using new technologies with the aim of improving public services, offering new ones and enhancing the quality of life of its residents.

The city of Terrassa has recently approved the Smart City Terrassa Strategic Plan developed with the participation and collaboration of city stakeholders with the purpose to integrate different municipal services. This strategic planning includes the improvement of the city communications network and adoption of standards for all IT municipal equipment. One of the priorities is to break the inner city silos and to facilitate the flow of information across all municipal services, administrative organization and towards the citizenry.

To help facilitate cross-sector cooperation and interoperability, and with the general purpose of establish a sensing platform, Terrassa has adopted Sentilo with the following specific objectives:

- Establish a unified equipment catalogue and a global monitoring system.
- Standardize and automatize all sensor related processes.
- Coordinate and unify all information systems across municipal areas and services.
- Establish a single common communication interface for all applications.
- Generate new municipal services from the improved flow of information.

Sentilo Terrassa is mainly a real-time dispatcher of data coming from the territory towards applications designed to manage it. The city has linked a management information system or dashboard to Sentilo to evaluate the implementation and facilitate the understanding of (i) static and dynamic data, (ii) routes for dynamic mobile components with geo-positioning information, and (iii) reports of congestion in the main roads of the city. Data include measures from the waste collection service, energy consumption, “indoor” parking, fleet of vehicles for general purpose public space services, and traffic. There are plans to incorporate new services and sensors to manage irrigation, monitor air pollution, manage public lighting, monitor noise, manage fleets of street cleaning vehicles, gauge counters, fleets of public transport and water cycle management.

### 4.2.4 Cambrils City Pilot

Cambrils is a Catalan coastal town in the county of Baix Camp, province of Tarragona. It is a very important tourist destination with a population of 32,500+ inhabitants in an area of 35.2 $km^2$. Population density doubles in summer. A new strategic planning process is under development to enhance performance, sustainability and security of municipal services, with the participation of all local government representatives, social and economic agents, and citizens. This open approach stems from *iCambrils*[23], a project for a digital, innovative, sustainable and safe Cambrils designed to guide the transformation of all city systems.

Two UrbanLabs, one for the fisherman district and another one for downtown (as respectively depicted in Figure 5) have been established to test, demonstrate and evaluate the *iCambrils* digital solutions and to experience change management within the administration and with citizens. It was decided that these digital solutions and transformations would be implemented and maintained by collecting, storing and management all information with Sentilo linked to a single open data portal for citizens and municipal services. This open information architecture, while integrating all city data, ensures that all equipment/sources of information are accounted for in a complete catalogue.

[23] http://www.cambrils.cat/ca/l-ajuntament/comunicacio/el-projecte-icambrils-urbanlab-finalista-en-la-categoria-de-millor-projecte-smart-cities-als-vi-premis-cnis-2016

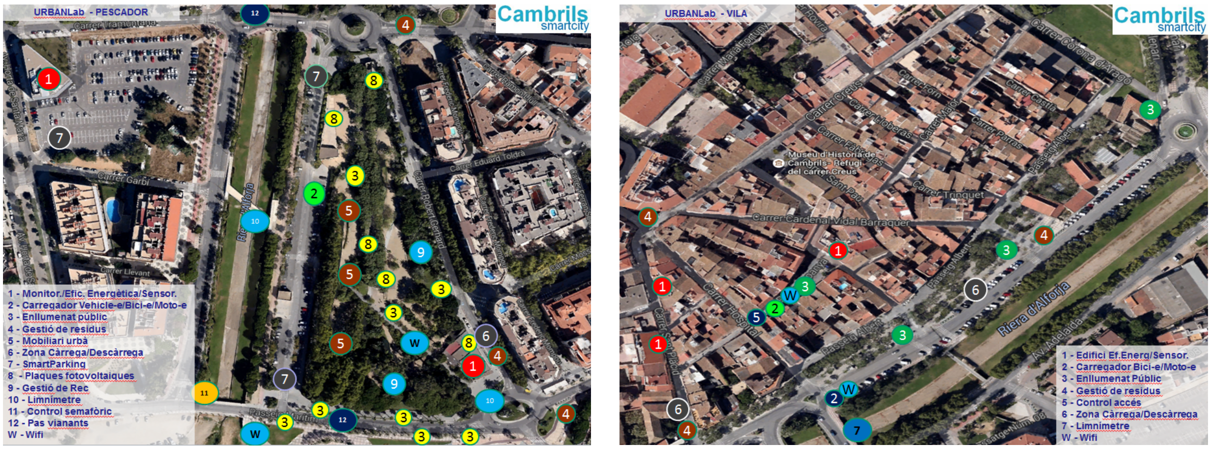


*Figure 5. Cambrils UrbanLabs*

Current Sentilo projects:

- Sensing and managing surface parking and load zones with sensors as well as occupancy management in parking lots with in/out monitoring.
- Energy consumption in buildings with temperature and humidity control.
- Monitoring of the two city bus lines.

### 4.2.5 Reus City Pilot

Reus is the capital of Baix Camp, in the Catalan province of Tarragona. It is known by its commercial activity. It has a population of 105.000+ inhabitants and a total extension of 52.8 km$^2$. Although the extension of the city corresponds to the 7.6% of the area of the whole county, more than half of the total number of vehicles in the area are located in Reus. For this reason and its commercial activity, the city must pay attention to parking.

The pilot of Reus consists in the use of the Sentilo to monitoring several surface and underground parking lots as well as the recharging sites for electrical vehicles. More information on the sensing Reus can be found in http://youtu.be/o64owomh6Bk and http://www.igsresearch.com/devel/riera11.

## 5. Preliminary Field Feedback

The field feedback received from the cities involved in the adoption, implementation and evaluation of Sentilo reflects their differences in size and in sensing scope. It should be noted that the UrbanLabs initiative supported by the Catalan Government has facilitated the cultural change needed for the creation of cross-functional teams and the integration of all city information (*i.e.,* breaking the inner silos) in small size cities located in Catalonia,

To facilitate the current assessment and to highlight the main elements that have been identified, either as enablers or roadblocks for the successful implementation of the platform, comments received have been grouped in three areas: strategic planning, resources and platform implementation, and communication and cross-functional teams.

### 5.1 Strategic Planning

The implementation of a sensor platform that integrates all verticals requires the political determination to enact a governance model that is transversal in nature for the whole city hall organization. A strong and visionary leadership is thus needed to navigate the transition from a siloed organization into an integrated public administration. A critical strategic element for a successful implementation is that this integration purpose also guides the initial phase of project definition and planning by engaging all stakeholders and public administration personnel responsible for city infrastructures (communication and mobility networks, water, energy and matter), services, information managers and administration.

It is also essential to identify and quantify the direct economic benefits that such integration and platform implementation will have for the city (citizens and governance), and also the enhanced services that will be provided with a common and more sustainable technology base. To this end, a key element of success has been the reallocation and unification of all affected public administration resources (which otherwise would function as disperse silos). A clear example of the benefit of this process is a single data repository, accessible for any administrative process, service provision and for citizen empowerment. The administrative resistance triggered when implementing an open sensor platform that breaks inner city silos is downplayed by the fact that Sentilo has been conceived, designed, developed and tested by a city administration, with proven enhanced performance of city operations.

From a technology perspective, connectivity and integration have not been issues for the implementation of Sentilo. The only bottleneck is to have a working communication network in place, with a properly established city information architecture. The cities involved think that their new integrated approach to innovation also changes the way technology providers relate to them, much in the same way that technology supporting teams within the local administration have become more cross-functional. Sentilo has been an excellent tool to manage change towards integrated city services if proper resources and communications strategies are also in place.

These systems should consider how they will interconnect with other platforms because most real implementations in cities will imply the coexistence of more than a single platform (i.e., city systems are interconnected with systems from other administrations and/or private actors). In real use scenarios, the interconnection and interoperability with external systems requires the development and adoption of open standard interfaces. It is imperative to converge these platforms towards the ITU's

Y.SC Platform concept. In the case of Sentilo, the convergence process is straightforward since Y.SC Platform is based on the same concepts as Sentilo.

## 5.2 Resources and Platform Implementation

A key element that has been identified by the CPS is the need for city-to-city collaboration to learn how other cities address similar challenges. City resources are generally scarce, and collaboration with other cities can help in the customization process or when new modules are needed. The benefits of this collaboration can be critical in small cities without a previous technological base or the support of a nearby IT cluster since the small scale nature of the project would not attract proper financing nor facilitate public-private partnerships. In these cases, a regional collaborative action is pivotal for the success of Sentilo and for establishing a repository of information on a shared cloud.

In terms of equipment, sensing platforms need sensors and actuators that work properly, where malfunctioning can be detected. Without those physical elements working properly, Sentilo will not deliver the information needed for adequate decision making. Thus, technical characteristics and robustness for reliable operation and maintenance have to be accounted for. Another important element is how we want to measure the physical space to get the information needed. Measurements could be discontinuous at periodic times or continuous to also allow calculation of accurate mean values over time. In some cases, these options and optional measuring techniques cannot be decided for a given measurement because there is a standard or legal protocol that has to be followed.

There is the possibility that for a given target variable the market does not offer a suitable device at a reasonable cost. In this case, local companies can become excellent providers to co-define technical specs and reach a consensus on price. To avoid post-implementation legal issues and disputes, specs should be made public together with the protocol adopted to verify compliance. More expensive and homologated devices could be used to certify the proper operation of the customized sensor. In this regard, specs of devices should be included in public bids whenever appropriate to avoid litigations at any stage of project development, acceptance and operation.

It is also recommended, as a first step, that cities carry out a pilot with fewer sensors to evaluate the cost-benefit of the sensing project in a real scenario. It is recommended that cities engage several sensor manufacturers (and operators if this is the case) in the pilots and evaluate them by asking, at a minimum, the following questions:

- Do sensors measure correctly and consistently the target variable?
- Which are the services and/or functions that are improved by the measurements? What new relevant information is obtained that was previously unavailable and that mostly impact the service and/or function?
- How does this information impact citizens directly? How can this impacting information be explicitly perceived as a service improvement by citizens? How can this new sensing technology enhance citizen engagement and participation?
- What is the cost-benefit of the new sensor implementation and how will it be communicated internally to facilitate service integration and culture change in the administration? What is the increase in operational costs? What are the technical and economic uncertainties?

A careful implementation plan has to be in place and carefully communicated when the pilot yields the expected results. Massive sensor implementations in periods less than one year are not recommended, as such implementations must be properly managed and strategically planned, as discussed previously. Best results have been obtained by accommodating sensor implementation with other planned public works to reduce costs and minimize disturbances in the public space of the city. To this end, identifying and establishing synergies with any planned public or private city project helps.

The cultural change required to break the inner city silos while implementing Sentilo can best be accomplished by avoiding technological roadblocks caused by minor issues like the lack of proper drivers to connect the platform with existing systems. The benefits of the open sensor platform can be best communicated and demonstrated with an open data portal where information can be made accessible and shared. An example of an open data portal adopted by some CPS member cities is CKAN.[24]

### 5.3 Communication and Cross-functional Teams

Cities face many challenges and resource allocation has to be carefully evaluated and communicated. Engaging citizens in the strategic planning, and communicating with them and local administration personnel on a continuous basis about project implementation and usefulness, is a critical process. Posting this information as well as any feedback received in the city portal is the best option since both this media and the content of the information are based on digital technologies and both most likely will continue to be connected when reporting sensor-related information after the implementation is over.

Training technical staff within the local administration about cross-platform document-oriented and non-relational databases (*e.g.*, MongoDB) or structured storage

[24] http://ckan.org/

systems that support not only strings but also abstract data types (*e.g.,* Redis) is also a key element for a successful implementation since they are uncommon in many of the previous technology platforms operating in municipalities. Building cross-functional teams is a necessary follow up for proper sensor platform management and quality assurance of operations in an environment where technology providers have a large experience in vertical solutions, can assure service delivery and can become an opposing force to vertical integration. Collaboration between technology providers and users helps both the local administration and the private sector.

## 6. Acknowledgments

Thank you to the cities of Barcelona, Dubai, Terrassa, Cambrils and Reus for their implementation and evaluation of this Open Sensor Platform. We would like to acknowledge the support received from Jim Aloisi, Editor, and the Technical Steering Committee to carry out and complete this proposed recommendation.

## 7. Copyright Statement

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