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CITI-SENSE Citizens' Observatories Architecture*

Hai-Ying Liu[1], Arne J. Berre[2], Mike Kobernus[1], Mirjam Fredriksen[1], Richard Rombouts[3], Andrei Tamlin[4], Tom Cole-Hunter[5], Leonardo Santiago[6], Alena Bartonova[1]
[1]NILU, [2]SINTEF, [3]Snowflake, [4]U-Hopper, [5]CREAL, [6]ATEKNEA

[1]Hai-Ying.Liu@nilu.no

Abstract

This paper introduces the architecture of the CITI-SENSE Citizens' Observatories based on the ISO 19119 reference model. It describes the various parts of the architecture including boundary services with sensors and apps and data management services with the CITI-SENSE data model. It also describes the Web Feature Service (WFS) storage support and the reusable visualisation widgets used for both apps and web portals in various Citizens' Observatories.

Keywords: Citizens' Observatories, Crowdsourcing, Citizen science, Systems Architecture

1. INTRODUCTION

Citizens' Observatories (CO) are emerging as a means of empowering citizens to participate in environmental monitoring and enabling them to observe and understand environmental-related issues by publically reporting and commenting on them (Liu et al., 2014; Liu & Kobernus 2016). Meanwhile, the availability of relatively cheap, internet-connected, programmable, sensor-laden smartphones and the explosive growth of personal communication devices vastly increases the potential for people-centric data-collection applications (Jovaševic-Stojanovic et al., 2015; Broday et al., 2017). As a result, the idea of participatory sensing has emerged, in which both non-professionals and professional users participate in gathering and sharing (local) information and knowledge about various aspects of their environment (Grossberndt & Liu, 2016; Liu et al., 2017). Participatory sensing requires deployment of CO technologies, i.e., a set of Information and Communication Technologies (ICT) that provide various citizens with the instruments to collect, analyse and visualise data (Liu et al., 2013). Such data can be used for policy-making, as an evaluation instrument, and as a means to improve the quality of life of citizens, in particular with respect to environmental and health issues (Castell et al., 2014; Liu et al., 2014; Zamen et al., 2014).

In this study, we present the common architecture of a CO being translated into practice through the CITI-SENSE project. CITI-SENSE is an EU FP7 project that focuses on developing a sensor-based CO community with an interest in urban air quality, noise and thermal comfort (Castell et al., 2014; Engelken-Jorge et al., 2014; Liu et al., 2014). The goal of CITI-SENSE is to give citizens the tools to 'sense' and 'appraise' their environment and at the same time to raise awareness about urban environmental quality issues, thus allowing the communication of valuable environmental information between various stakeholders. The project aims to inspire people to relate to their natural environment in a systematic and scientific way and to motivate citizens to become active stewards of a healthy environment. To achieve this objective, CITI-SENSE aims to initiate an intensive dialogue between technical, scientific and lay people on various social aspects of environmental information: its production and its use (Bartonova, 2015). The project thereby defines a framework in which researchers, authorities and citizens can cooperate to (Kobernus et al., 2015): (i) raise environmental awareness in society; (ii) enable dialogue between citizens, communities, organisations and authorities; and (iii) gather, exchange and utilise data from a variety of sources for the benefit of the whole society.

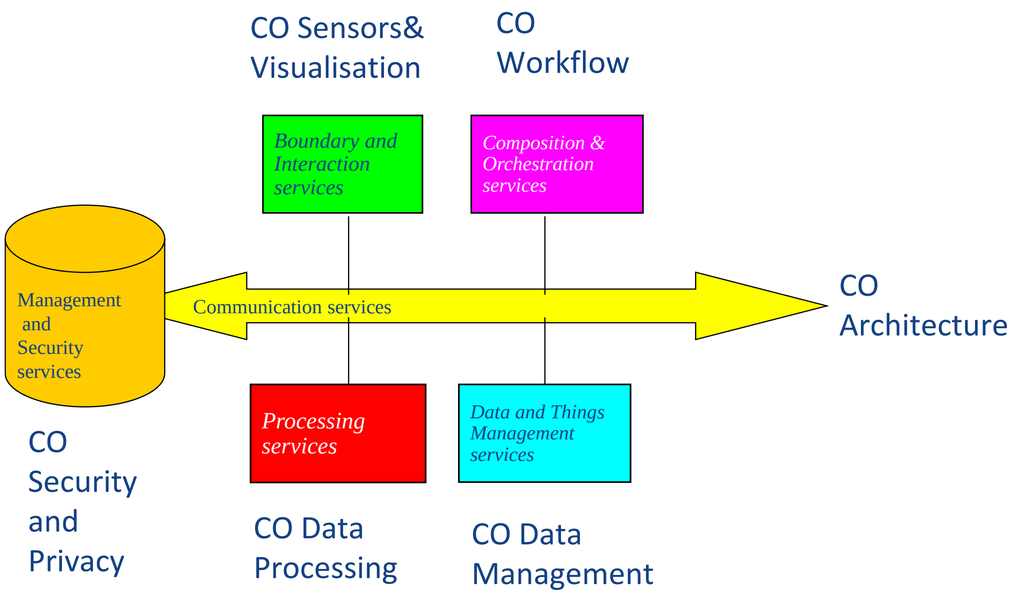
In this paper, the CITI-SENSE CO architecture will be described in the following sequence: (i) reference model based on ISO 19119; (ii) boundary services with sensors and apps; (iii) data management services with the CITI-SENSE data model and the Web Feature Service (WFS) storage support; (iv) adaptable visualisation widgets used for both apps and web portals in various Citizens' Observatories.

2. ARCHITECTURAL REFERENCE MODEL BASED ON ISO 19119

The CITI-SENSE architecture is described according following the six service categories defined in ISO 19119 Geospatial service architecture (Figure 1): (i) CO security and privacy; (ii) CO data processing; (iii) CO data management; (iv) CO architecture; (v) CO sensors & visualization; and (vi) CO workflow.

Currently, the CITI-SENSE architecture is designed to support a number of different sensor platforms and apps; these provide flexibility for dynamically-introduced new technologies which collect human and sensor based observations (Liu et al., 2018). The common storage representation is based on the CITI-SENSE data flow model which is established as a profile of the standardised (OGC, ISO) WFS service conformant with the Global Earth Observtion System of Systems (GEOSS) infrastructure. Observations can be accessed and transformed to different data formats (e.g., XML, JSON, CSV, etc.) and visualised through different visualisations widgets. HTML5 is used for the portability for both web portals and apps. Current experiments are evaluating big data scalability with respect to data volume and velocity/speed. A mapping to and representation with Linked Open Data in Resource Description Framework (RDF) is under trial. Furthermore, data will be quality assured from testing to operational use prior to its becoming available through the GEOSS Infrastructure.

Figure 1. Citizens' Observatories components related to ISO 19119 services.

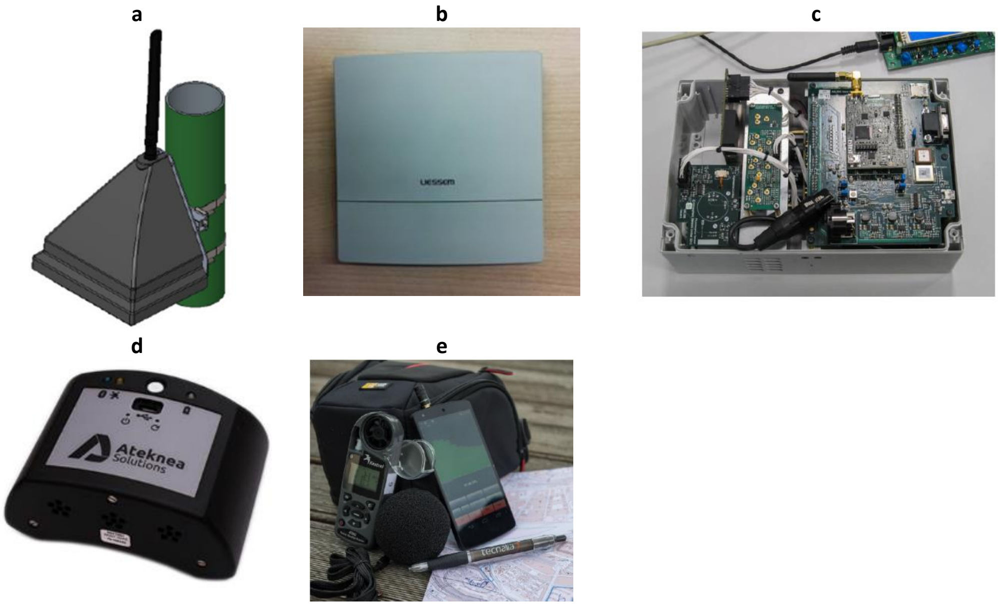


3. BOUNDARY SERVICES – SENSOR PLATFORMS AND APPS

3.1. Portable and Static Sensor Platforms

The impact of mobile technologies on the CO, specifically in the areas of environmental quality monitoring (air pollution and noise emissions), has the potential to improve data coverage through the provision of near-real-time high-resolution data over urban areas. In CITI-SENSE, two classes of sensor platforms have been developed and used in case studies – portable and static sensor platforms. These sensing technologies had to be simple and affordable for citizens and the scientific community to use in order to observe atmosphere-related variables. The complexity of the citizens' involvement with the sensors was a critical consideration when designing the case studies and selecting the different sensing systems (Castell et al., 2017; Fishbain et al., 2017). The static sensor platform providers in CITI-SENSE are Geotech, Obeo and Atmospheric Sensors (Figures 2a, 2b and 2c, respectively). Ateknea provides a portable sensor platform for air quality (Figure 2d). In addition, Kestrel 4000 and smartphone microphones (with a windscreen) are sed for monitoring thermal comfort and noise in public spaces, respectively (Figure 2e).

Figure 2. Sensor nodes used in the CITI-SENSE project: static sensors from (a) Geotech, (b) Obeo (radon), and (c) Atmospheric Sensors; and (d) Ateknea portable sensor; (f) Kestrel 4000, Smartphone Nexus 5 and microphone with a windscreen.

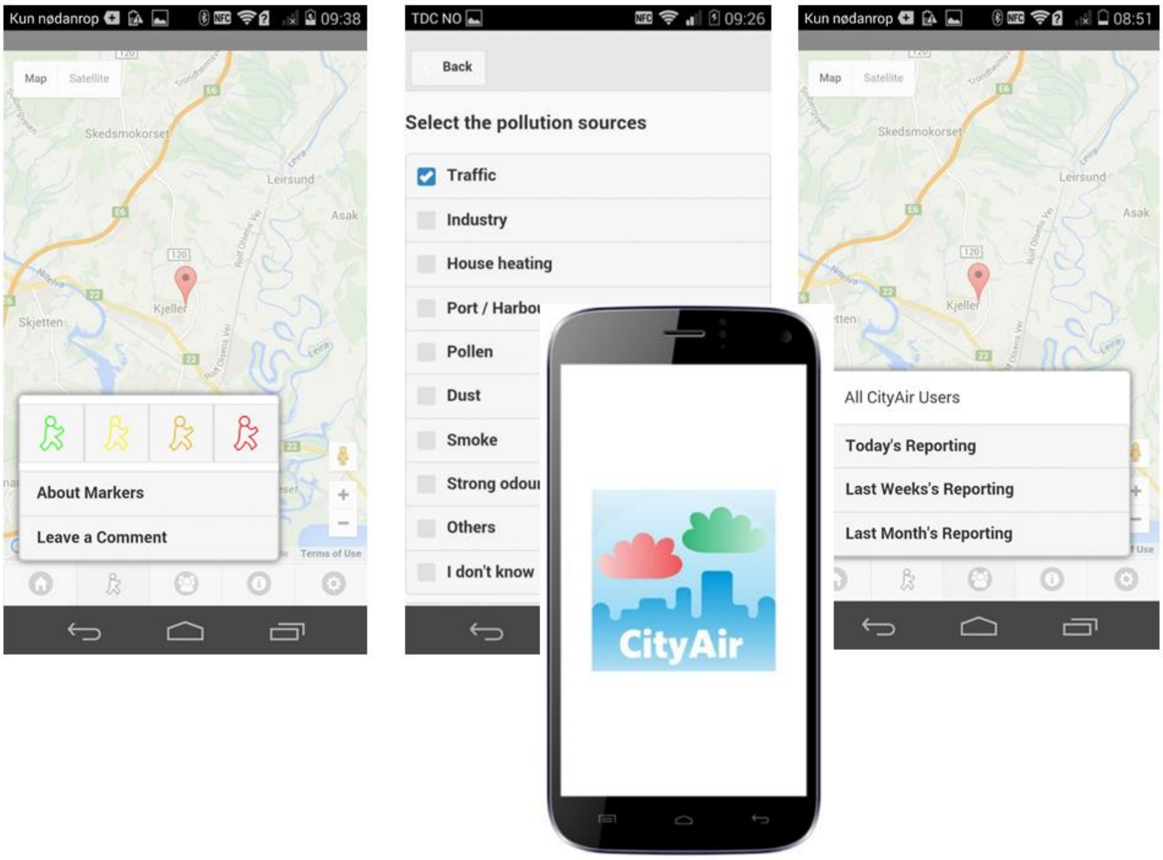


3.2. Mobile Apps

Several smartphone apps supporting multiple languages have been designed and implemented in CITI-SENSE for various CO location participants. This was done to support communication and sharing of air quality related data and information, as well as to facilitate the collection of sensor readings from smartphones that are running the apps and are paired with portable sensors. The apps have been designed to sense geolocation and acceleration data using GPS and accelerometer sensors that are built into smartphones. Transmission of data from portable sensors to the apps is performed automatically over an encrypted Bluetooth channel. The data collected by the apps on smartphones are relayed to the dedicated CITI-SENSE Spatial and Environmental Data Services Platform (SEDS) via Global System for Mobile Communications (GSM). Data from the static sensors are transmitted to the CITI-SENSE server via SIM cards. Static sensors' data are used for constructing dynamic land-use regression and data fusion models. Air quality maps derived from these models are made available to the public through the CO web portal and the apps using visualization widgets developed in the project (Liu et al., 2018).

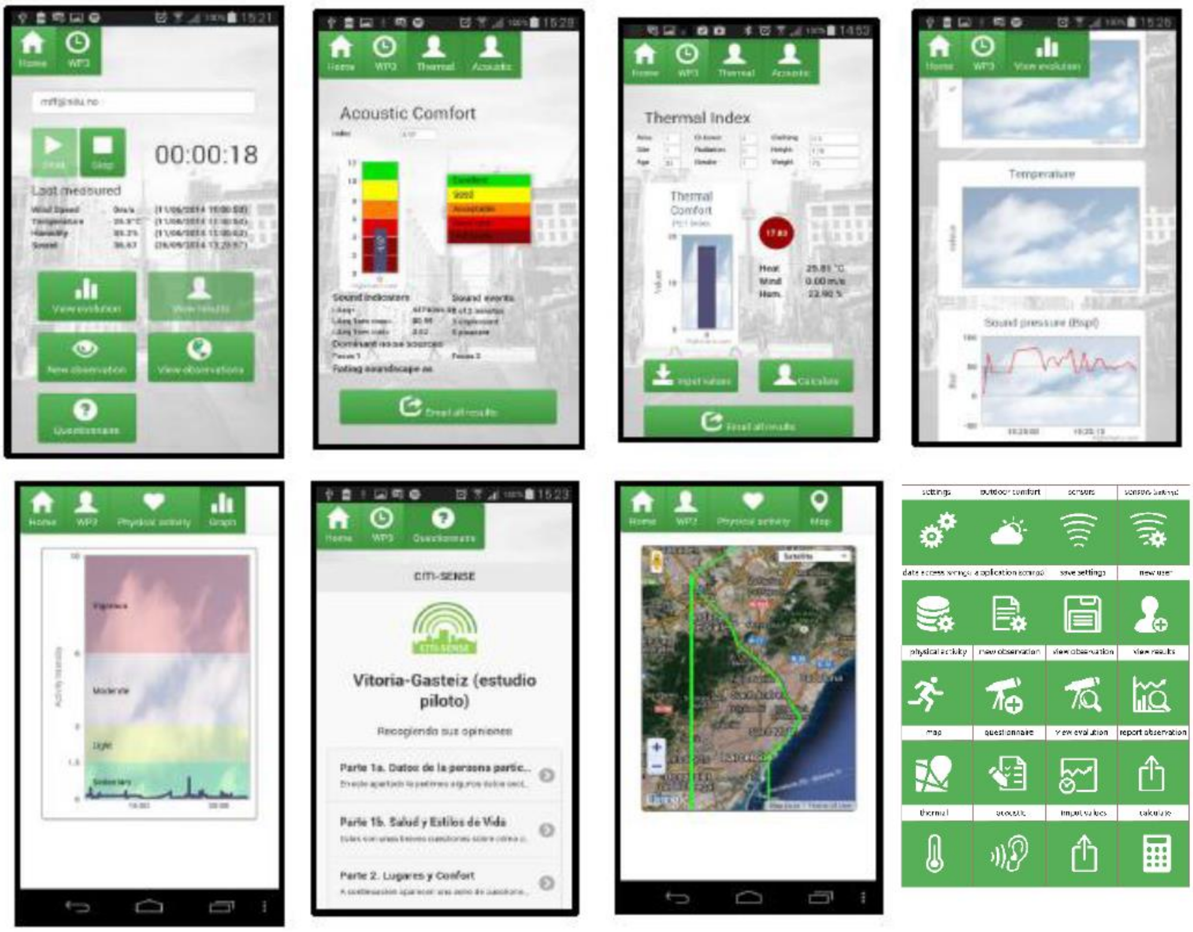
In addition to collecting objective observations, we created the 'CityAir' app (air quality perception smartphone application) which uses the Android and iOS operating systems to record subjective observations (Figure 3). The 'CityAir' app includes five simple questions – participant's gender, age, education level, the air quality level participants perceived during his/her daily activities in the city s/he lives/works/studies in, and the participants' views on the source of the air pollution in the location s/he made the observation. The response to these air quality-related questions can be visualized on a baseline map (i.e. data fusion map). Participants can use color-coded air quality levels to indicate how much pollution they perceive and what the source of the air pollution might be (See Figure 3). In this way, the baseline map can also be used to evaluate the citizens' air quality perception. Currently, CityAir App is available both at Google Play and the iTunes App Store.

Figure 3. Screenshots of CityAir (Air Quality Perception Smartphone App).



In addition, we have built the 'Sense-It-Now' smartphone app (Figure 4). It reads and displays/visualizes data from different sensors used in the CO of outdoor air quality in cities and the CO of environmental quality in public spaces, by providing HTTP (Hypertext Transfer Protocol) requests to the CITI-SENSE data server platform. HTTP is a request/response protocol, which means the communication is made by sending requests for some files to a web server that sends back a response. To date, the Sense-It-Now app supports the following four plugins: (i) Camera – Use of the phone's camera enables participants to upload pictures that they have taken during their daily activities where they live/work/study; (ii) Network – Access Wi-Fi and cellular network; (iii) Device – Access information about the device's hardware and software; (iv) Geolocation – Access location database using GPS (Global Positioning System) or network signals. Currently, the Sense-It-Now mobile phone application can be downloaded with this link: http://ftp.nilu.no/pub/tmp/senseitnow.apk.

Figure 4. Screenshot of the Sense-It-Now Smartphone App.

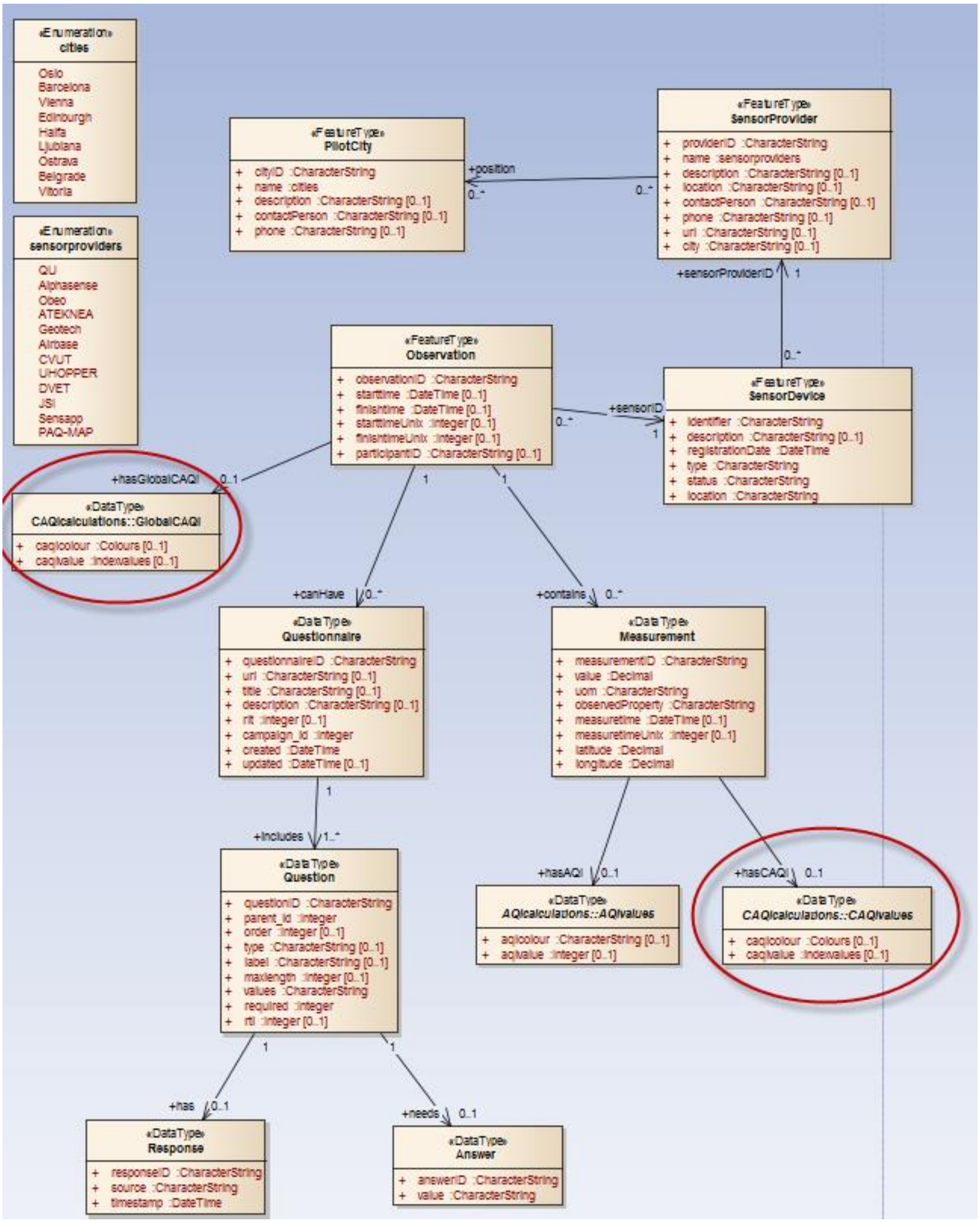


Both the CityAir and Sense-It-Now smartphone apps were developed using Cordova for the Android operating system. This open source framework uses a standardized web API (Application Program Interface, e.g., JavaScript, HTML5, CSS3) to develop applications for different mobile platforms.

4. DATA MANAGEMENT

Figure 5 shows the CITI-SENSE data management model for the CITI-SENSE SEDS platform. The data model is based on the General Feature Model of ISO/TC211 and OGC as it is being introduced in the standard ISO 19109 and also supported in ISO 19156 Observations and measurements.

Figure 5. CITI-SENSE data management model.

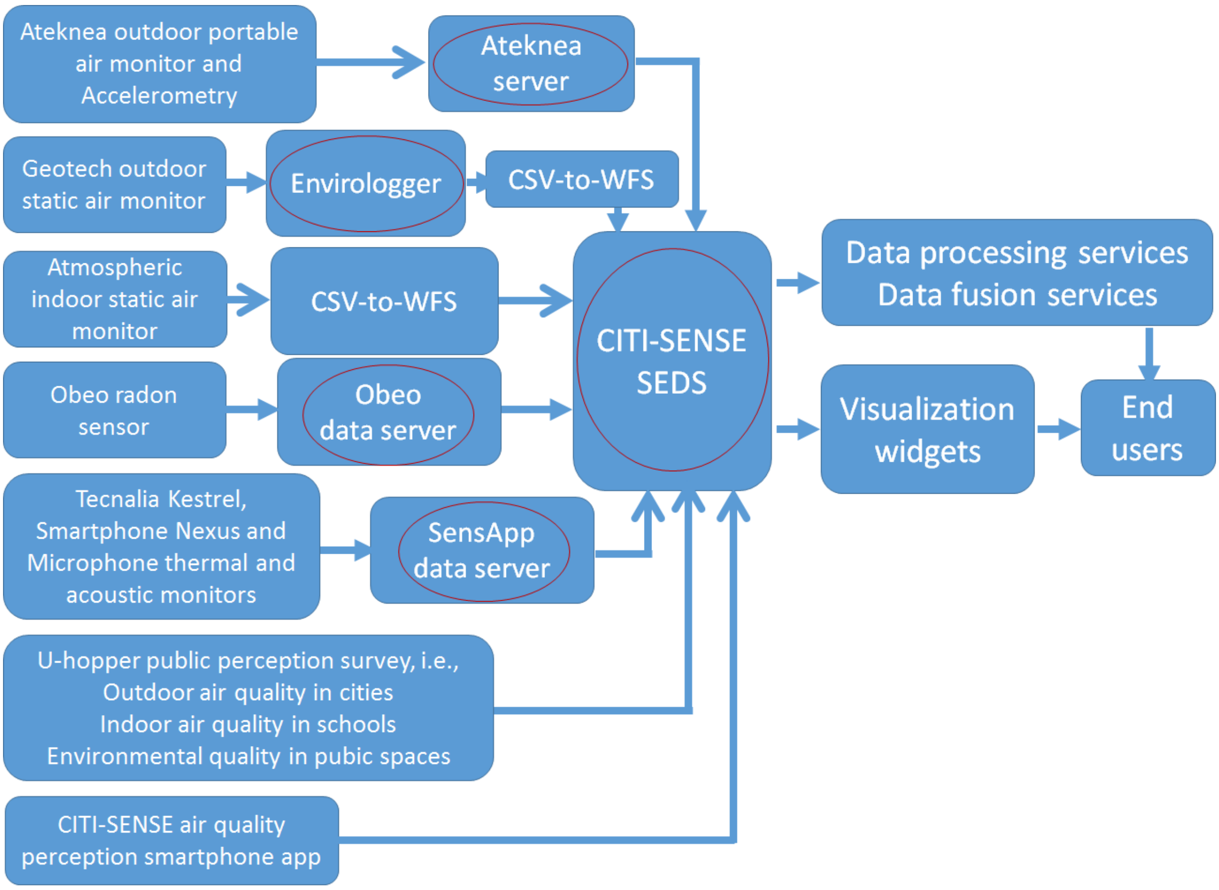


We used the Web Feature Service (WFS) ISO 19142:210 standard rather than the more specific model of the OGC Sensor Observation Service (SOS) in order to ensure flexibility. The CITI-SENSE data model equates the response of the questionnaire to an observation. It also associates pilot cities with sensor providers. In the latest CITI-SENSE data model, aggregated Air Quality Index (AQI) values are associated with observations and measurements.

5. DATA FLOW MODEL

The concept of the CO in CITI-SENSE relies on the implementation of the information chain “citizens –> sensors and sponsor platforms –> data server platform –> products and services.” Figure 6 summarizes and visualizes various items in the data flow developed along these lines in the CITI-SENSE projects.

Figure 6. CITI-SENSE Citizens’ Observatories data flow model.



In CITI-SENSE, we have three data server platforms, including the Ateknea data server, the Obeo data server and the SensApp data server connected to the CITI-SENSE SEDS by pushing data through the provided WFS API. Two servers (Geotech/Envirologger and Atmospheric) are connected through pulling data from their ftp/CSV representation for ingestion into the WFS. Ultimately, all data generated from the CITI-SENSE project is stored in the CITI-SENSE SEDS for common access. Through the WFS interface, the SEDS data is also compliant with the GEOSS infrastructure, and selected datasets will be made available through GEOSS towards the end of the project.

6. VISUALISATION WIDGETS AND PORTALS

6.1. Visualization Widgets

A number of reusable visualization widgets have been developed in CITI-SENSE in order to provide graphical depiction of data acquired by the CO and to simplify data interpretation. The widgets have been designed with three requirements in mind: (i) Configurability. Allowing developers to easily configure the widgets for visualizing various aspects of measured data (e.g., range of measured values, color schemes for visual interpretation of data, etc.); (2) Reusability. Allowing developers to easily reuse the same widget for multiple measurements; and finally (3) Embedding. Enabling website content managers to easily plug widgets into 3rd party web portals and mobile applications and as such promote the CITI-SENSE data for the community. To realize these goals, the CITI-SENSE widgets were developed using modern HTML5 techniques.

The CITI-SENSE visualization widgets implement various forms of visual representations, such as maps, time series and charts. These representations allow one to depict appropriately specific aspects of sensors' data (e.g., temporal variability, spatial distribution, etc.). Both single sensor and aggregated multiple sensor visualizations are provided by the widgets. For a single sensor, one can visualize the sensor's measurement in real-time using a configurable gauge chart, draw a timeline of historical measurements using a line chart, or display the measurements on a map. For visualization of multiple sensors' data, the widgets provide the ability to define filters for discovery of sensors given a specific criteria (e.g., sensors in a given city, static or portable, specific sensor provider, etc.). The widgets leverage the rich filtering capabilities of WFS for data retrieval. As in a single sensor case, widgets allow construction of aggregated charts and maps based on multiple sensors (e.g., Figure 7).

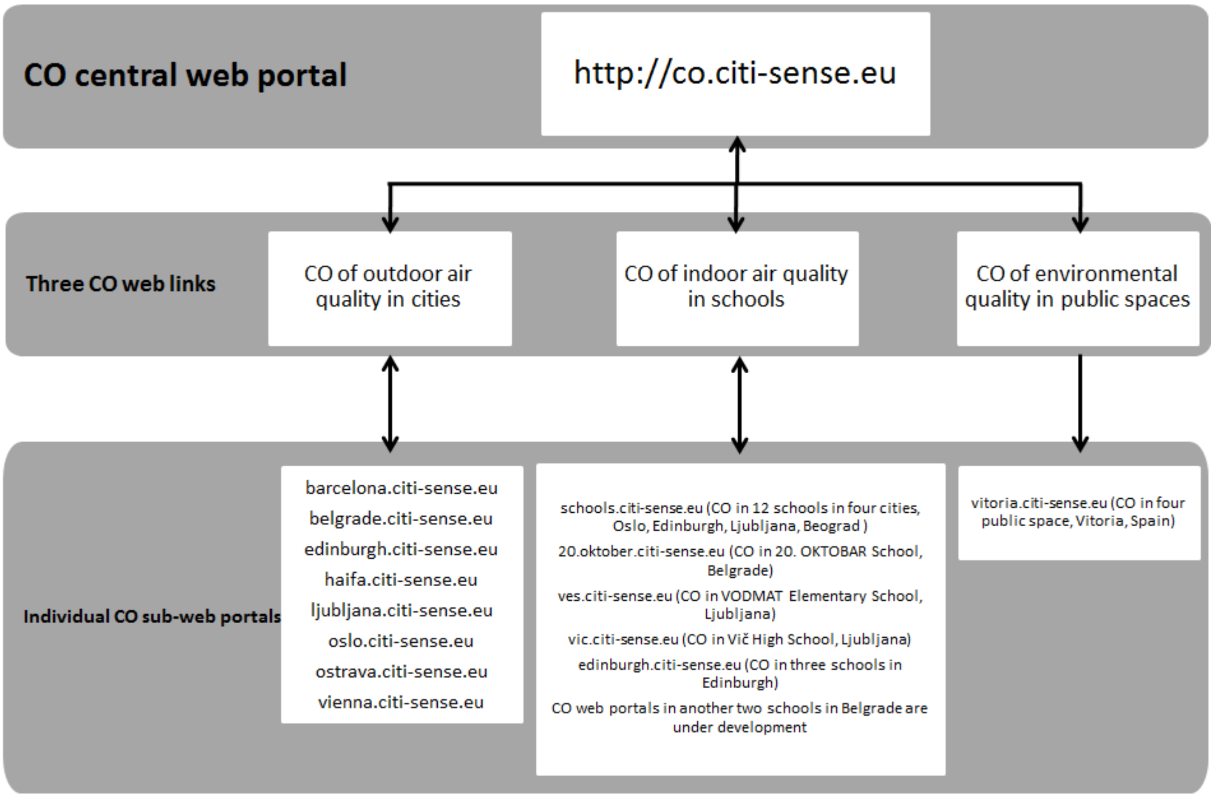
Figure 7. Example of a map visualization using Ateknea app in Barcelona

6.2. Web Portals

We have further developed a multi-level CO 'central' web portal (co.citi-sense.eu). The first level of CITI-SENSE CO central web portal is intended to be the gateway to all available products and services and to provide free access to all public data generated from the project (Figure 8). It can be considered both as an integration and a comparison hub for the data from the three types of CO: (i) CO of Outdoor Air Quality in Cities; (ii) CO of Indoor Air Quality in Schools; and (iii) CO of Environmental Quality in Public Spaces. It can also provide access to individual location-based CO. Furthermore, collaboration and synergy with GEOSS will ensure that the CO central web portal has the potential to become a major data/information resource in the future. Tools such as Citizens' Voice and Observations can enable citizens to upload their subjective and objective observations, while a discussion forum enables citizens to exchange their data, information and knowledge (Liu et al., 2018). An Air Quality Perception Survey will present and visualize the results generated from different types of the questionnaires. In addition, CITI-SENSE CO central web portal also provides various existing Social Media Platforms (e.g., CO Facebook page, Twitter account, LinkedIn group, YouTube channel, etc.) for users to gather and share information. Furthermore, CO central web portal provides links to other Similar Citizens' Observatories Projects around the globe; it additionally provides useful information about air quality in general for data/information sharing, awareness raising, and interaction with other projects' stakeholders.

The second level of CITI-SENSE CO central web portal is part of the gateway concept, where each of the three CO thematic areas will have pages dedicated to them, with links, images, live data and reports. The third level of CITI-SENSE CO central web portal is the actual location-based case study sub-web portals that are created within each of the CO locations. The CITI-SENSE CO central web portal can therefore be seen as the gateway for exchange and access to all project products and services, while each of the CO web portals will provide access to their specific CO products and services. This enables multiple points of access for the project outcomes either via the CO central portal or directly to the specific location-based CO sub-web portals.

Figure 8. Citizens' Observatories central web portal – three levels of structural hierarchy.



7. DISCUSSION AND CONCLUSIONS

CITI-SENSE posed the question, 'How can citizens use low-cost micro sensors to their personal benefit, and that of society as a whole?' Over four years we addressed this simple question by implementing twenty-four case studies in nine countries, while gathering millions of sensor measurements.

At the conclusion of the project in 2016, we considered that the primary priorities, that of deploying sensors and sensor platforms (both static and portable devices) and dealing with data accuracy and other sensor-related issues, was an overall success.

Personal perception data, or Volunteered Geographic Information (VGI) enabled us to utilize the general public as citizen sensors. This, combined with low-cost micro sensors, created a fusion of data that "despite significant uncertainties at the individual sensor level, indicates that we are able to exploit the "swarm knowledge" of the entire sensor network and to extract realistic signals, resulting in the possibility of high-resolution spatio-temporal mapping of urban air quality" (Schneider et al., 2017).

All data was published via the SEDS database. Post project, we anticipate that future researchers will take advantage of the accessibility, data processing, data fusion and visualization features developed during the CITI-SENSE lifecycle, to further explore the potential of the citizen sensor and low-cost micro sensor.

Another important activity was the further development of location-based CO web portals and the CITI-SENSE CO central web portal. These portals enable citizens to both access data/information as well as to continue to provide their own personal observations. As such, the data-gathering component of the project continues. The portals provide information useful and appropriate to different end users, as well as scientific usage. Research will focus on how to manage, assimilate and present the varying degree of accuracy and reliability inherent in data drawn from the traditional standard air monitors, existing monitoring programmes, air quality models, GNSS (Global Navigation Satellite System), low-cost sensors, and VGI. Related to this also is the need to investigate issues of data sensitivity and privacy.

As a resource, the CITI-SENSE project results may be unique and we hope that they continue to be of use in future research projects.

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