RESEARCH ARTICLE

Social network services for innovative smart cities: the RADICAL platform approach

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Abstract: In this paper we present the RADICAL platform, a software stack that enables the combination of social network (SN) services and Internet of Things (IoT) in the context of innovative smart cities. RADICAL makes possible the development and deployment of interoperable pervasive multi-sensory and socially-aware services; facilitates smart governance and flexible replication of services across cities and regions through a Virtual Machine generation mechanism in a sophisticated cloud environment. A large scale piloting of the platform integrates, deploys and tests various services in the areas of Cycling Safety, Participatory Urbanism, Augmented Reality and others while a large group of citizens from different countries are actively involved in the co-creation, validation and evaluation of the RADICAL approach on the basis of an innovative Living Labs approach.

Keywords: smart cities, cloud environment, internet of things, social networks, Living Labs

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1. Introduction

Modern cities are increasingly turning towards ICT technology for confronting pressures associated with demographic changes, urbanisation, climate change[1] and globalisation. Therefore, most cities have undertaken significant investments during the last decade in ICT infrastructure including computers, broadband connectivity and recently, sensing infrastructures. These infrastructures have empowered a number of innovative services in areas such as participatory sensing, urban logistics and ambient assisted living. Such services have been extensively deployed in several cities, thereby demonstrating the potential benefits of ICT infrastructures for businesses and the citizens themselves.

During the last few years, we have also witnessed an explosion of sensor deployments and social networking services along with the emergence of social networking[2] and Internet of Things (IoT) technologies[3,4]. Social and sensor networks can be combined in order to offer a variety of added-value services for smart cities, as has already been demonstrated by various early IoT applications (such as WikiCity[5], CitySense[6], GoogleLatitude[7]), as well as applications combining social and sensor networks[8–10].

Recently, the benefits of social networking and IoT deployments for smart cities have also been demonstrated in the context of a range of EC co-funded projects[11,12]. Despite the proliferation of social networking infrastructures and sensor networking infrastructures and deployments, there is still no easy way to develop, customise, deploy and operate such services in smart cities. Smart cities today have various needs for becoming smarter. They need to optimally exploit their already existing infrastructures (IoT devices such as sensors throughout the urban landscape) for providing new innovative services to the citizens. The ultimate goal is to increase the participation levels of end users/citizens in the daily activities of the city and increase their well-being.

There are various initiatives on the European and global scale on how cities can become smart cities. Among others, the most established initiatives include EUROCITIES[13], OASC[14] and the development efforts made in the context of EIT's digital action line "Urban Life and Mobility"[15]. Furthermore, the coordination actions project FP7 CA FIREBALL[16] is providing a substantial analysis on how European cities are currently developing strategies in order to become smart cities and the lessons we can draw for the future. In the research efforts, we can find interesting publications and results in journals such as the ISJ special issue on smart cities[17].

Motivated by the modern challenges in smart cities, the RADICAL (Rapid Deployment for Intelligent Cities and Living) approach[18] opens new horizons in the operation of intelligent services in smart cities, notably services that could be flexibly and successfully customised and replicated across multiple cities. Its main goal is to provide the means for cities and ICT companies to rapidly develop, deploy, replicate, and evaluate a diverse set of sustainable ICT services that leverage established IoT and SN infrastructures. Eight distinct pilot services were built upon the RADICAL platform architecture dealing with: (i) Cycling Safety Improvement, (ii) Products Carbon Footprint Management, (iii) Object-driven Data Journalism, (iv) Participatory Urbanism, (v) Augmented Reality, (vi) Eco-consciousness, (vii) Sound map of a city, and (viii) City-R-Us—a crowdsourcing app for collecting movement information using citizens smartphones.

RADICAL provides an easy way to develop and customise smart city services bridging both IoT and SN domains. This is due to the fact that it provides special tools to do so, namely the Application Development toolkit, which makes the creation, adaptation and configuration of services a user friendly, clear and easy to manage procedure. The primary targeted users of the RADICAL platform are city authorities who can become the early adopters. Their needs are summarised on how to optimally leverage existing ICT infrastructures (e.g., smart city infrastructures with sensors, etc.) with social networks in order to engage the citizens, interact with them and offer them innovative services.

Replication across multiple cities covers the following need—to have a RADICAL platform with maximum usability and adaptability to other city's contexts. This is particularly beneficial for multiple stakeholders: (i) ICT companies for providing analytics, consultancy or other added value services to city authorities, (ii) citizens for being aware about what is happening around them, (iii) policy makers for taking decisions either in a local government level or at national level. Policy makers (city officials), through the sustainability and replicability of added value services, are able to understand which services fit with their organisational, infrastructural, geographical and socioeconomic characteristics. Accordingly, smart cities could benefit from a technical infrastructure enabling the rapid and effective customisation of the identified services in their environments.

Thus, RADICAL can provide a series of benefits and value proposition for a series of end-users: (i) for city officials by enabling them to have a better control and knowledge on their infrastructures, while engaging citizens in communication and participation with authorities and being able to offer them innovative services on top of IoT and SN; (ii) for city developers as they can build innovative services for the smart cities (deploying IoT their infrastructures and making use of social networks), and (iii) for citizens who can receive smart and innovative services through the joint collaboration of SMEs (providers of services) and the city authorities.

The specific objectives of the current paper are focused on:

(i) Showcasing the RADICAL platform approach on how to aggregate and combine IoT and SN data for the benefit of the city authorities and citizens of smart cities,

(ii) Presenting and analysing the validated results of the pilots implemented through a Living Labs approach,

(iii) Demonstrating the RADICAL approach on cross-city data correlation.

The rest of the paper is structured as follows: Section 2 gives an overview of related and similar works that can be found in the international literature and in projects funded by the European Commission; Section 3 presents the RADICAL architecture and approach;

Section 4 provides the pilot scenarios and the city experiments' configuration and results, along with the citizens' feedback, while in Section 5 we provide the future work to be planned in the context of RADICAL and the conclusions we have come into.

2. Related and Similar Works

There are various efforts today that are focused in providing innovative services in the context of future smart cities. We present some of them along with a comparative analysis against the approach of RADICAL below.

The European Platform for Intelligent Cities[19] is an EU-funded project that aims to wed state-of-the-art cloud computing technologies with mature e-Government service applications to create the first truly scalable and flexible pan-European platform for innovative, user-driven public service delivery. The EPIC project aimed to provide a way for Cities to deliver and share 'smarter services' in a flexible and cost effective way which would not involve large-scale reorganisation of their ICT infrastructure. A cloud-centric vision on Smart Cities is also provided by Gubbi *et al*.[20] where the current trends in IoT research propelled by applications is presented. The authors also discuss the need for convergence in several interdisciplinary technologies and a case study of data analytics on the Aneka/Azure cloud platform is given.

A proof-of-concept of Smart City IoT deployment was provided in the city of Padova, Italy, in the context of Padova Smart City project[21]. In this case, a full range of IoT solutions and services were interconnected with the data network of the city municipality and data collected were further analysed and presented as a relevant example of application of the IoT paradigm to smart cities.

The SMARTiP project[22] is aimed at enhancing the ability of the cities to grow and sustain a 'smart city' ecosystem which can support new, emerging opportunities for a dynamic co-production process resulting in a more inclusive, higher quality and efficient public services which can then be made replicable and scalable for cross-border deployment on a larger scale. Citadel on the Move[23] aims to make it easier for citizens and application developers alike from across Europe to use Open Data to create the type of innovative mobile applications that they want and need. Citadel on the Move aims to fulfill this need by: (i) creating formats that make it easier for local government to release data in usable, interoperable formats, and (ii) providing templates that make it easier for citizens to create mobile applications that can be potentially shared across Europe, creating services that can be used on any device, anytime, anywhere.

The objective of PERIPHÈRIA[24] is to deploy convergent Future Internet (FI) platforms and services for the promotion of sustainable lifestyles in and across emergent networks of 'smart" peripheral cities in Europe, dynamic realities with a specific vocation for green creativity. Its Open Service Convergence Platform, an "Internet by and for the People", extends and enhances the Save Energy project's Social Information Architecture, integrating key new components—sensor networks, real time 3D and mobile location-based services—with the FI paradigms of Internet of Things (IoT), Internet of Services (IoS) and Internet of People (IoP). PERIPHÈRIA develops the Living Lab premise of shifting technology R&D out of the laboratory and into the real world in a systemic blend of technological with social innovation.

Open Cities[25] was a project co-funded by the European Commission that aimed to validate how to approach open and user driven innovation methodologies to the public sector in a scenario of FI services for smart cities by leveraging existing tools, trials and platforms in crowdsourcing, open data, Fiber to the Home (FTTH) and Open Sensor Networks in seven major European cities—Helsinki, Berlin, Amsterdam, Paris, Rome, Barcelona and Bologna. The project provided different types of contributions such as new understandings on how to approach open innovation from the public sector, functioning platforms for open data and open networks, and actual FI services provided by developers using these platforms.

Even though the sustainability of the above results was ensured by the presence of all relevant actors—city authorities, research institutions, companies and more importantly, real users using the services and creating the necessary demand for FI services in Smart Cities—its services are not as easy to replicate as RADICAL's. Besides, services developed in the context of Open Cities project do not exploit the potential of the sentiments analysis expressed through Social Networks which is one of the key strengths of RADICAL.

Other recent ongoing efforts include projects such as GrowSmarter[26] and Triangulum[27]. The former brings together cities and industry to integrate and demonstrate 12 smart city solutions in energy, infrastructure and transport while the latter is one of the three European smart cities and communities lighthouse projects, set to demonstrate, disseminate and replicate solutions and frameworks for Europe's future smart cites. It will serve as a testbed for innovative projects, focusing on sustainable mobility, energy, ICT, and business opportunities. The project will demonstrate real smart city solutions with working business and social value models and will facilitate and replicate them across three more follower cities.

Overall, the RADICAL platform approach is set apart from all these efforts by trying to merge in an innovative way based on its unique value proposition, the benefits and functional capabilities of IoT and social networking services. The wide set of application services that are deployed and piloted are collecting all the necessary features for a thorough validation of the RADICAL concept and the benefit it can bring for citizens of the smart cities in the future. Table 1 gives a comparative analysis between RADICAL and the most recent efforts in the area of smart cities.

3. The RADICAL Approach

The RADICAL platform integrates components and tools from SocIoS[28] and SmartSantander[29] projects, in order to develop innovative smart city services leveraging information stemming from social networks (SN) and IoT devices.

Most existing smart city solutions focus on the IoT data aggregation, in order to provide intelligent services to the citizens. RADICAL platform on the other hand, uses SmartSantander IoT infrustructure as a basis, enriched by the social networking services and analytics of SocIoS, along with added value Governance and application-development components that will be analysed in the following sections to provide a complete and sophisticated smart city solution. Thus, the RADICAL platform is able to collect, analyse, combine, process, visualise and provide uniform access to three main types of data—Social Network content (from SocIoS), Internet of Things data collected from sensors and devices (from SmartSantander) and smartphone data specific to pilot scenarios collected by city services themselves.

The architecture of RADICAL is depicted in Figure 1[30] along with a legend of colors explaining the use of each module group. As can be seen, there are three distinct architectural layers from the top to the bottom:

- The **Service Application Layer**: This is external from the RADICAL platform and presents an open list of the City Services (installed in local municipalities) providing a Front-end to the IoT/SN data aggregated in the RADICAL platform. Some services (depending on their functionality) allow citizens to view analysed platform data
- The **Platform Layer**, including Application Management and Platform tools and modules, connecting and exposing its data through Application Programming Interfaces (API)
- The **Data Sources Layer**, including IoT devices, smartphone City Applications and various Social Networks, feeding the RADICAL platform with the three types of data mentioned above. For Social Networks, RADICAL can also post data (e.g., tweets) thus connections are bidirectional

Data coming from the lower layer, with the exception of Social Network-related ones, are saved in the RADICAL platform Repository by the relevant **Data Storage** modules. The **IoT Data** Modules on the left were adapted from existing SmartSantander platform components and include components parsing and pushing IoT device measurements into the Repository (**Service Aggregator** and **Storer —** one direction data flow), as well as components managing the IoT devices registered (Register Manager, IoT Manager).

One the other hand, Social Network Data Retrieval Modules access data in real time from the underlying Social Networks via the **SN Core Services** and **Adaptors**, originated from the SocIoS platform. For each

Table 1. RADICAL analytical comparison with recent similar works

Name	Triangulum	Open Cities	GrowSmarter	RADICAL
Exploitation of SN Capabilities	No	Yes	No	Yes
Cloud Hosting	Yes	No	Yes	Yes
Provides APIs	Yes	Yes	Not explicitly mentioned	Yes
Living Labs methodology	Yes	Yes (Urban Labs)	Yes	Yes
What are differences/complementarities with RADICAL	3 Lighthouse cities and 3 followers. Focus on replication. Applications in energy saving, urban planning and others.	Test bench for innovative Apps and services. Free support for 6 months for technical tests and obtaining real and formalised feed- backs from 60 users.	3 Lighthouse Cities. Low energy district, waste heat recovery, smart waste collection.	6 cities/ regions

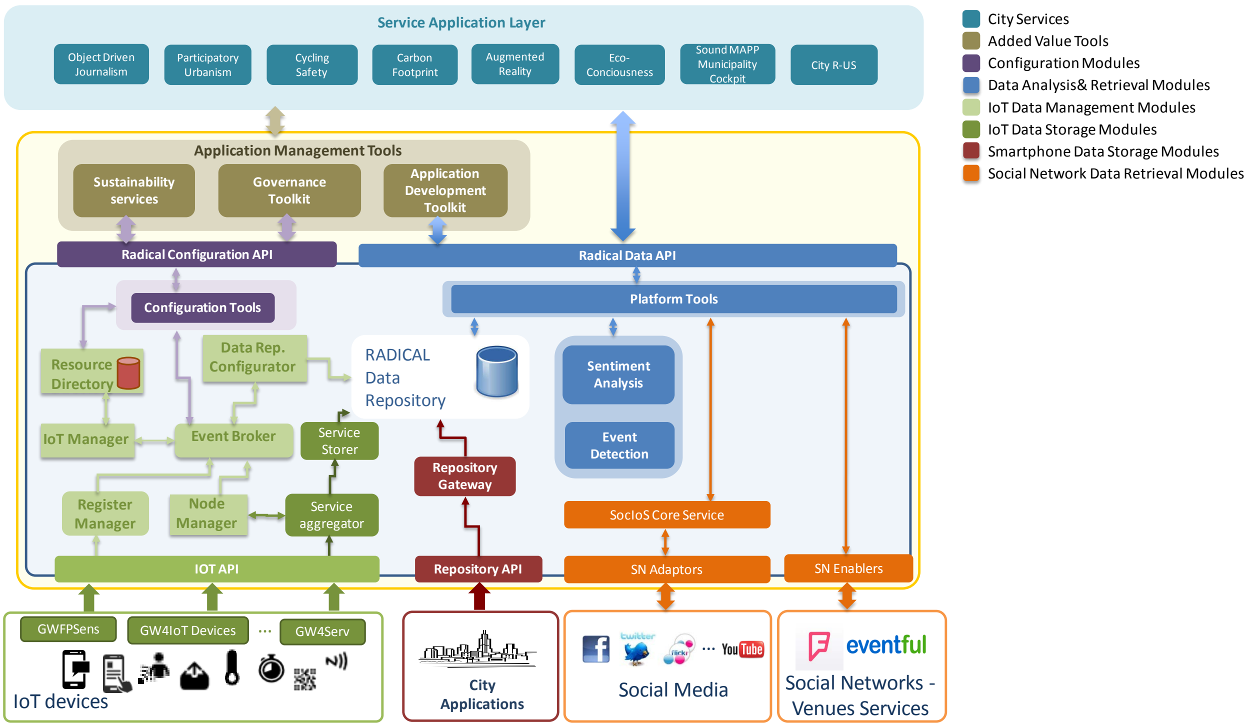

Figure 1. RADICAL architecture.

supported SN a respective adaptor is provided, encapsulating its data structures and functionality. Apart from SocIoS-parsed data, **Social Enablers** are also used to retrieve venue-related information data for more plain Social Networks like Foursquare, where SN Adaptors' implementation does not make sense.

Platform and **Configuration tools** as well as **Data Analytics** services (Sentiment Analysis, Event Detection) provide more sophisticated use and combination of RADICAL data, as needed for City Services Front-end presentation (Service Application Layer). Any data transfer between the RADICAL platform and City Services or IoT infrastructures is made possible through the respective **APIs** (Configuration API, Data API, IoT API, Repository API) that will be presented below.

Lastly, on top of the core platform, RADICAL delivers a set of tools (**Application Management Tools**) allowing City Service administrators and developers to configure the RADICAL platform or combine its various functionalities. Most notably, the **Application Development Toolkit** added value service is the one combining different types of data originated from various cities and will be further analysed in Section 3.3.

3.1 RADICAL APIs, Authentication and Data Security

The main functionality of the RADICAL platform is exposed through the **Data API** which allows smart city services to access the different sources of information (social networks, IoT infrastructures, city applications), perform analysis and combine data by using the appropriate platform tools. In addition to that, the platform exposes a second API, the RADICAL **Configuration API**, which allows smart city service administrators to configure the RADICAL platform through the **Data Repository Configurator** and manage the IoT devices listed in the **Resource Directory**. Data flows for both APIs are bidirectional, as API consumers can pull (retrieve SN/IoT data, extract platform configuration) or push data (make a new SN post, set configuration parameters).

Finally, aiming at data forwarding to the RADICAL platform, the RADICAL **IoT API** provides the interface for registering devices and feeding relevant IoT measurements and reported events as observations, while the **Repository API** allows City applications to push their data observations to the RADICAL platform and store them into the RADICAL data repository.

Regarding the aforementioned APIs, a major concern raised was to ensure the integrity and confidentiality of all data sent or retrieved through them, in order to protect citizens' privacy when using smart city services. Thus, a sophisticated authentication system was built for restricting usage of those APIs, following the same logic as Social Networks' APIs' authentication — city service administrators are provided with specific credentials, which must be passed to an authentication method that returns an "API key", in the form of a 32-character hash. API keys are updated periodically (as dictated by the corresponding configuration parameter) and are required for any API call that requests or sends city data.

Moreover, to install and use a smart city app connected to RADICAL; end-users are asked to provide their consent and are informed about all anonymised data that their smartphones provide to RADICAL, such as GPS location or events reporting. Reassuring end-users that their data is being processed anonymously and confidentially is crucial, as much concern is now publicly raised on privacy and security around online networks and smartphone-related applications that citizens use in their everyday life[31,32].

3.2 Social Network Adaptors and Data Analytics Services

The main Social Networking related functionality in RADICAL is provided by the SocIoS services, i.e., a set of tools and mechanisms for leveraging the potential of Social Networking Sites. The SocIoS framework is a software stack that operates on top of Social Networking Sites' APIs. It provides an abstraction layer for aggregating data and functionality from a multitude of underlying social media platforms as well as a set of analytical tools for leveraging that functionality.

The SocIoS tools that are integrated into the RADICAL platform are the SocIoS API[33], an abstraction layer providing uniform access to the data and functionality of the most popular Social Networks, and two analysis services, i.e., the Event Detection Service and the Sentiment Analysis Service.

The SocIoS API exposes operations that encapsulate the functionality of the underlying SN APIs. It is based on its own generic object model, encapsulating the entities and relationships residing in the underlying SN.

For each supported SN API, an adaptor has been implemented transforming SN data to the SocIoS object model, allowing the API consumers to access data from the respective underlying SN in a uniform way. The design overview of the SocIoS API and the supported Social Networks is depicted in Figure 2[30].

The Event Detection Service aims to enable RADICAL end users to detect and monitor real-world events that are defined by citizens' activity. The service analyses the comments, tweets and other text messages generated by the citizens and classifies them to categories that are most likely to relate to events. It also generates a set of keywords that define each event so as to assist the end user in understanding the event context.

The goal of the Sentiment Analysis Service is to extract sentiment expressive patterns from user-generated content in social networks or any other types of text posts. The service comes to the aid of RADICAL's city services' administrators, helping them to categorise sentimentally charged texts, e.g., analyse citizens' posts, to separate the subjective from objective opinions or count the overall positive and negative feedback concerning a specific topic.

3.3 Application Development: Integrate and Analyse SN and IoT Data from Various Cities

One of the main added values that RADICAL platform provides to Smart Cities is the ability to form sophisticated Applications integrating social and IoT data from different cities and perform data analytics tasks

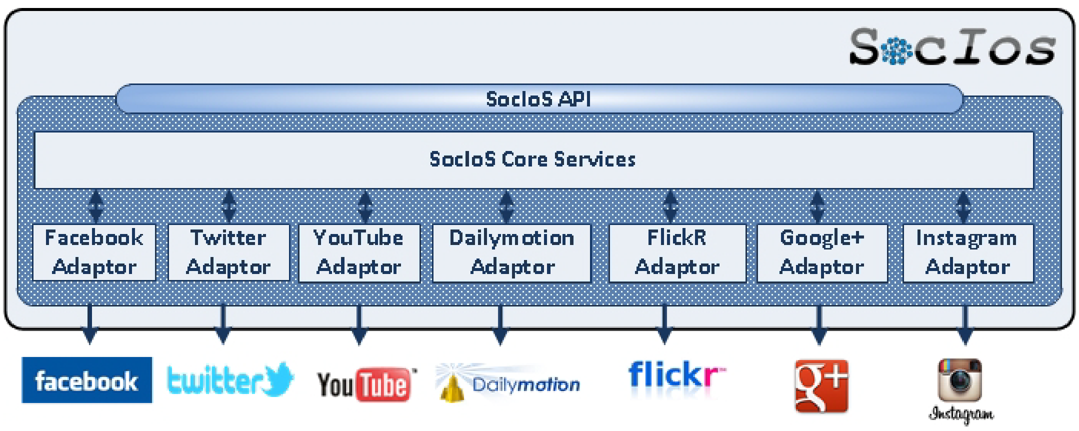

Figure 2. SocIoS API.

on the aggregated data. The building of such Applications is achieved through the RADICAL Application Development Toolkit.

The Application Development Toolkit based on the WebHookIt open-source tool[34], is located in the Application Management layer (Figure 1) and combines various data through web services offered by the platform. It can be used both as a mash-up tool, enabling the concurrent APIs' and services' consumption and output aggregation, as well as a service composition tool, constructing sequential service workflows.

For this purpose, as can be observed in the architecture figure, it consumes the RADICAL Data API, to get access to the RADICAL Repository data and the integrated Social Networks. The tool functionality is exposed to the City Service developers via a usable graphical interface (GUI), where they can create complex RADICAL Applications, using simple drag and drop actions. Through RADICAL Applications, the city service administrators can multi-query for SN and IoT from various cities and get an analysis of the combined results.

The Application Development Toolkit also includes a scheduling functionality for periodic Application executions; an Exception Handler for a meaningful management of the runtime errors, and a Service Discovery component which is using a Yahoo! Query Language module for services retrieval from a Web Application Description Language (WADL) document.

After the list of services is retrieved, the tool end-user can use or combine services into a workflow Application, by dragging and dropping them into the wiring and mapping input and output.

Figure 3 presents an example wiring workflow, mining a Social Network (Twitter) for posts with specific keywords (concerning the Fort d'Issy POI) and applying data analytics (Topic Detection) to the results to get a parsed JSON output. For this purpose the respective RADICAL Data API web methods are called (findTextMediaItems, getTopicsFromTextItems) with the relevant parameters (sns="Twitter", keywords="issy, fort") and the result is parsed by an XML parsing component (xml2js) to be presented as a list of topics in the output panel below.

Note that the resulting wiring workflow can form the basis of a web-based Application. To this end, a City Service developer can create a web panel as part of the city administration portal, presenting the output results of an Application in a user friendly manner. In the example shown above, through this panel the city administrators can be informed of what is reported in the city through IoT devices or Social Networks in the form of a list of events.

3.4 Correlating Cross-city Data for a RADICAL City Service

In Smart Cities, a major need of city officials in order to administer City Services is a tool for controlling

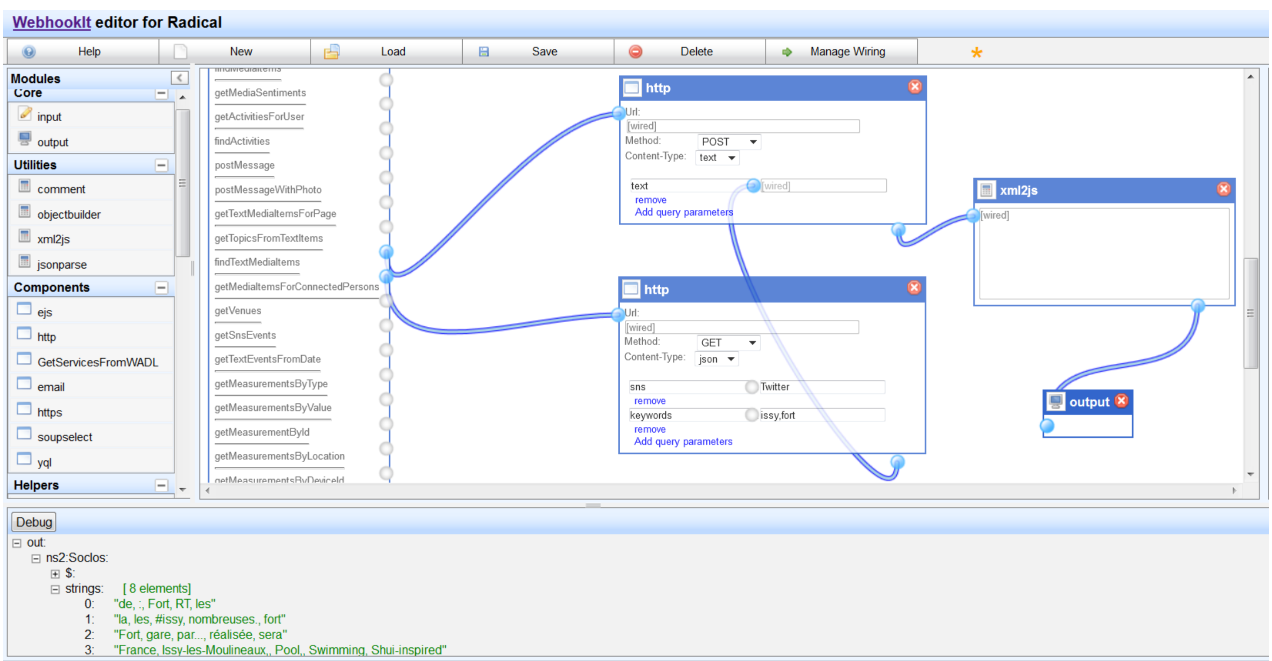

Figure 3. Wiring application services in WebhookIt editor GUI.

large amount of data related to any facet of those services. This tool must present aggregated usage, as well as qualitative characteristics of citizens' activity for every Smart City Service.

Towards this direction, a Smart Cities Dashboard was introduced by RADICAL, implemented as a web interface that presents information about IoT data sent by any device registered in the platform, such as smartphones sending citizens' geo-location and activity, weather stations with climate measurements or even bicycles carrying RFID tags. By the use of this web application, City Service administrators can view aggregated statistics from one or various cities for the same City Service during a specific time frame. Diagrams and charts with all devices' measurements as well as registrations are provided per day for each service, for every city that this service running. This way, the overall usage and user acceptance of a specific City Service can be estimated and also compared with another RADICAL city running a service of the same nature (e.g., Augmented Reality for POIs).

Thus, depending on the City Service chosen, city officials are able to retrieve reliable statistics about citizens' behavior on work weeks, weekends, bank holidays or areas popular among citizens. A typical example of this can be seen in Figure 4 for the Augmented Reality pilot scenario (described in Section 4) comparing Santander and Cantabria Smartphone and POIs' reports Registrations.

Another example involves services related to weather monitoring that provide precise insight into climate or gas emissions such as carbon footprint. Figure 5 presents graph comparisons of daily values sent to the carbon footprint monitoring City Service from relevant sensors, between 2 pilot cities (Genoa and Cantabria).

In addition to sensor measurements, RADICAL Pilot Services' scenarios also report events, e.g., when citizens report incidences taking place in an area. In this case, a correlation of activity and event types is provided by the Dashboard, as shown in Figure 6, presenting device registrations and events reported in the context of the Participatory Urbanism City Service in the cities of Santander and Issy Les Moulineaux.

4. RADICAL Experiments: Configuration, Pilot Scenarios and Evaluation Results

4.1 Evaluation Method

RADICAL evaluation aims at demonstrating the platform's technical soundness, in terms of the fine-grained implementation and operation of the platform tools, and the ease of the virtualised smart solution replication for a city, as well as the illustration of its added value for the various types of end-users (citizens, city officials, etc.). More specifically, the purpose

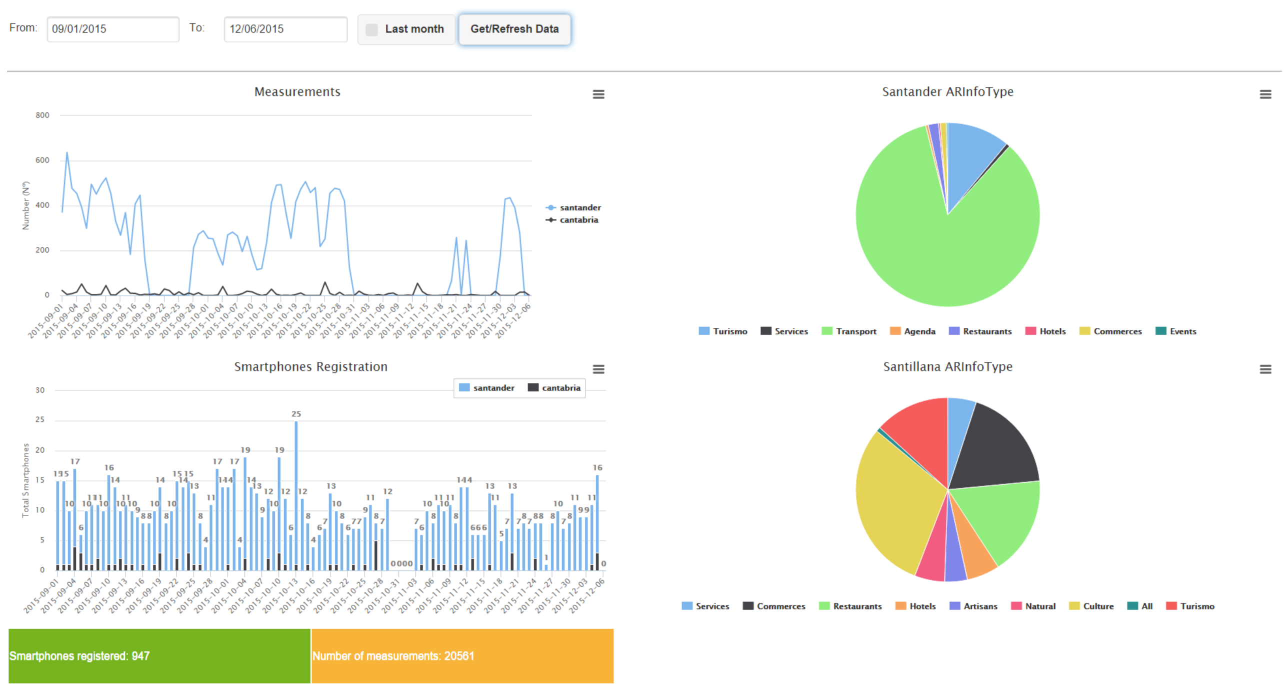

Figure 4. RADICAL Cities Dashboard presents aggregated citizens' activity.

Figure 5. RADICAL Cities Dashboard compares climate-related sensor measurements between cities.

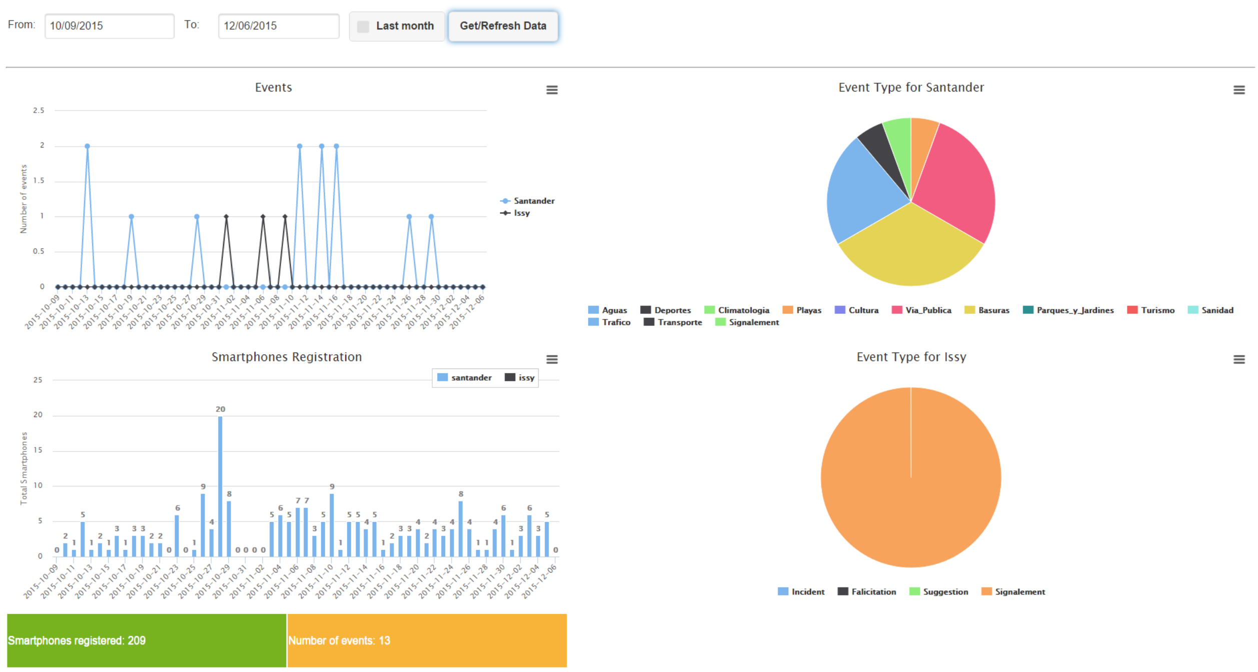

Figure 6. RADICAL Cities Dashboard compares events in the Participatory Urbanism service of different cities.

of evaluation performed in the context of RADICAL was three-fold:

- **Technical Coherence**: A set of stress tests was employed to validate the platform operation under heavy data load
- **Smart Exploitation Potential**: City administrators with the help of technical experts evaluated RADICAL in terms of usability, sustainability and replicability
- **User Acceptance**: A major concern was to evaluate citizens' satisfaction and added value for a Smart City derived from the RADICAL operation

Regarding the latter, assuring the engagement and validation of citizens' participation in pilot cities, we decided to follow an innovative Living Labs approach to observe RADICAL's impact on dedicated citizens' groups in the long term. This involved representative samples of the population, in order to study the penetration and sustainability of the services within each individual city.

The employed Living Labs approach[35] is going beyond most conventional Living Labs that commonly take into account representative samples in testing and experimentation of novel ICT services. RADICAL extended existing LL methodologies by involving the end-users not only in the requirements of the capture and design phases but also in the testing validation, evaluation and feedback phase. While such an approach has been taken in other solutions, it is the breadth of the user communities and the involvement of our multi-disciplinary expert communities (technology SMEs, public bodies, citizens with different interests) supporting the process, which maximises the impact of RADICAL[36].

Unlike previous efforts, RADICAL's approach is broader as it involves expert users from all relevant disciplines and citizens' contribution in all phases, to multiple, concurrently developed modules (from application services for cyclists to one Platform supporting the services). Thus Living Labs' participants contribute in multiple aspects of RADICAL's developments and not only to the Labs that they have participated in.

4.2 Pilots Setup and Scenarios

For the establishment of Living Labs in different areas, RADICAL was piloted in six cities (Aarhus, Athens, Genoa, Issy les Moulineaux, Santander and Cantabria region), with the support of respective municipalities. To logically separate city repositories and data control access, it was decided to follow a "one platform instance per city" deployment approach.

For this purpose, the BonFIRE[37] cloud infrastructure was employed, providing one Ubuntu Linux Virtual Machine (VM) for each city where the corresponding RADICAL Platform instance and Data Repository (MySQL Database) were installed. A "Template" VM with generic data was also kept for backup (Figure 7). The advantages of this approach are apparent in case a new city decides to adopt RADICAL—the "template" instance can be easily replicated for every new entry with a minimum effort of parameterising and defining the domain name of the new instance.

RADICAL pilot scenarios were selected with a view to maximise its impact and meeting the challenges of future smart cities. Specifically, the following criteria have driven the selection:

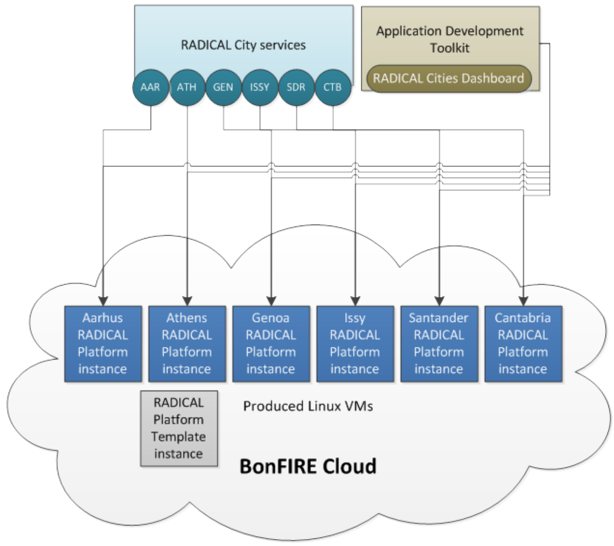

Figure 7. RADICAL deployment diagram.

- **Societal Challenges**: RADICAL scenarios are representative cases of ICT services addressing the emerging societal challenges in the urban environment (demographic trends, climate change).
- **Involvement of Multiple Stakeholders**: RADICAL introduces a holistic approach to the development, deployment and operation of ICT services in urban environments. Thus, RADICAL scenarios involve all the envisaged stakeholders.
- **Innovation**: The services combine knowledge from SN and IoT to provide real-time information and intelligence to citizens. Such services have not been deployed at large in the scope of modern cities.

City Services present a fair degree of heterogeneity and diversity in terms of their socio-economic and legal characteristics. This is intentional and serves the purpose of studying different deployment cases and associated governance schemes. An overview of these services is presented below, along with the benefits for citizens and relevant stakeholders:

(1) Cycling Safety: Cyclists, acting as human sensors, report the situation in city streets through their smartphone apps (Figure 9). Benefit for the citizens: Cyclists benefit by sharing routes, road conditions (including traffic and infrastructure issues) and events in real time. **Benefit for city officials:** Real time reporting of potential problems in city infrastructure, recording of preferred cyclist routes for the implementation of measures to accommodate them.

(2) Augmented Reality in Points of Interest: Tourists use their smartphone apps (Figures 8 and 9) to receive information about points of interest in a city. Coordinates, sceneries, or QR codes are used for the identification of location in different cities. **Benefit for the citizens**: Visitors get or share useful information about the place they are visiting in their SN accounts. **Benefit for city officials**: Points of interest in a city can be promoted. **Benefit for local businesses**: Visitors can be diverged to specific areas thus strengthening the local market.

(3) Citizen journalism/Participatory Urbanism: Citizens report events of interest by posting images, texts and metadata through RADICAL's smartphone apps (Figure 8) in a city-dedicated page or in SNs. Others can then consume the information perhaps in a curated/structured way or alternatively crawl into Social Networks and detect events of interest in the city. **Benefit for the citizens**: Citizens get involved in public issues by reporting through their phones. **Benefit for city officials**: Events of interest to the city administration are reported in real time.

(4) Monitoring the carbon footprint of products, people and services: A range of sensors monitors the CO_2 emissions in specific places in a city. **Benefit for city officials**: Increasing awareness about the processes that generate CO_2 emissions and assist in the creation of a zero-emissions city policy. **Benefit for local businesses**: Taking measures for the reduction of their service's or product's carbon footprint, leading to a reduction of relevant taxes and promoting CO_2-free processes.

(5) Propagation of eco-consciousness: Leveraging on the viral effect in the propagation of information in social networks as well as the recycling policy of a city through monitoring and reporting relevant actions from eco-conscious citizens' smartphones. **Benefit for city officials**: Eco-conscious activities are monitored and city officials spend relevant resources in a more direct manner.

(6) Social-Oriented Urban Noise Decibel Measurement Application: This scenario aims at creating a socially-enabled and aware service which allows citizens to better monitor and report environmental noise in the streets. Noise sensors are employed for that purpose and citizens are able to report and comment noise-related issues through SNs under specific hashtags. **Benefit for city officials**: Having a clear sentiment-based map overview of how the noise is affecting the city.

(7) City Reporting application for the use of Urban Services: This service gathers sensory data along with SN check-ins in city venues to construct a traffic map throughout the city, leveraging the process load of any centralised decision making processes. **Benefit for city officials**: Local governments can listen to the mobility needs of citizens, combine it with traffic sensor data and advanced analytics to deliver smart transportation solutions and better infrastructures.

4.3 Evaluation Results

Citizen participation in the context of RADICAL pilots was evident throughout the cities, with the highest activity observed in more mature smart cities, like Santander and Genoa. Table 2 presents aggregated IoT data statistics by pilot and by city platform instances,

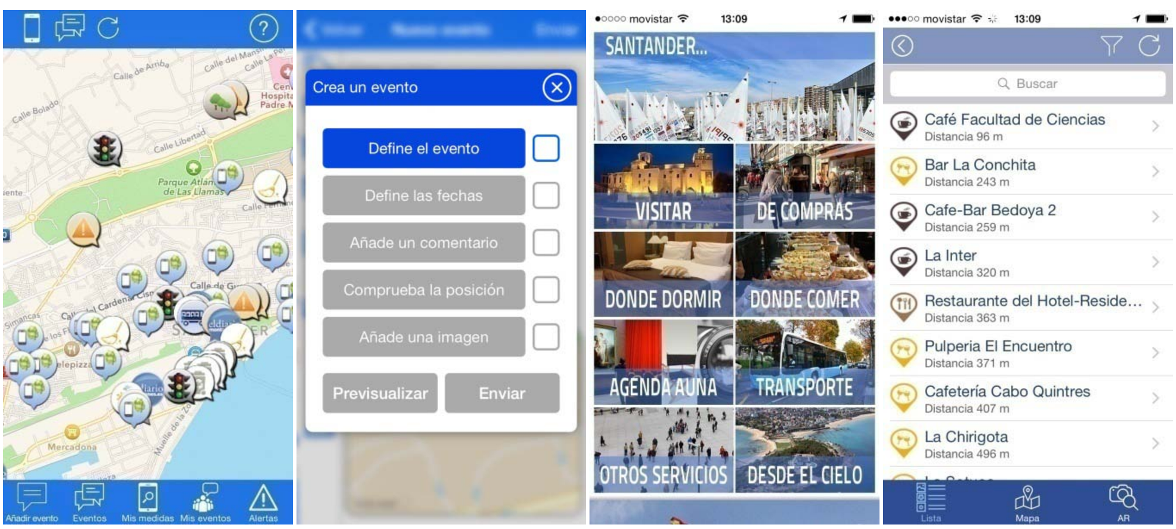

Figure 8. Participatory urbanism and augmented reality RADICAL apps in the city of Santander.

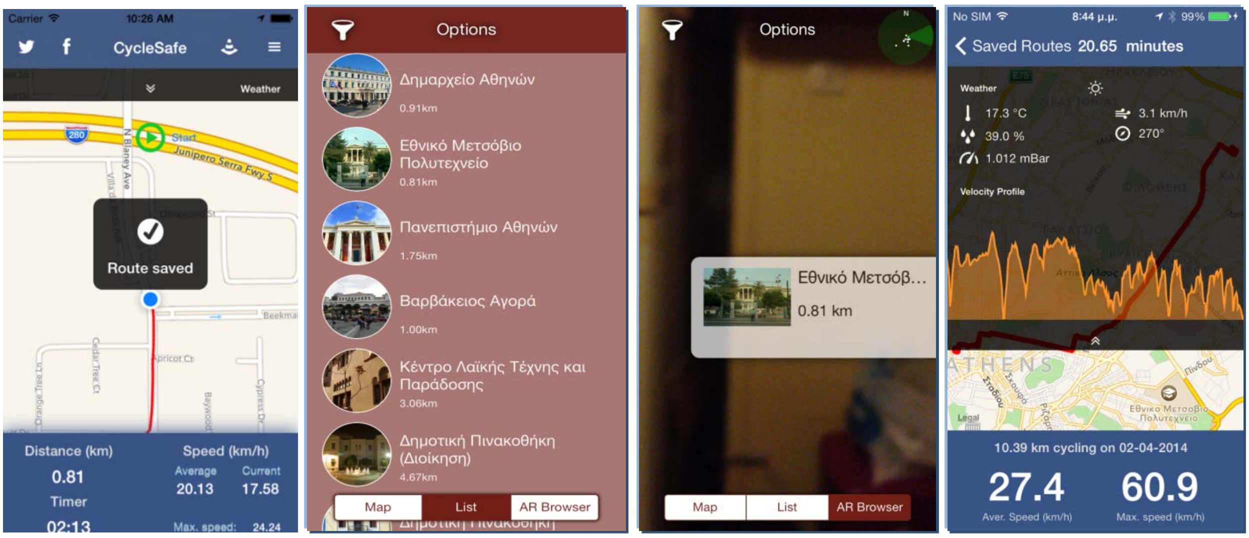

Figure 9. Augmented reality and cycling safety RADICAL apps in the city of Athens.

Table 2. Aggregated RADICAL usage statistics per city and pilot service

City/Services		Cycling safety improvement	Carbon footprint management	Citizen journalism	Participatory urbanism	Augmented reality	Propagation of eco-consciousness	Total
	# of IoT devices			4		2		6
Issy	# of Observations			750		10		760
	# of Measurements			8083		50		8133
	# of IoT devices				470	4270	185	4925
Santander	# of Observations				5011	56818	12	61841
	# of Measurements				16362	341842	72	358276
	# of IoT devices	45				2		47
Athens	# of Observations	139				162		301
	# of Measurements	139				162		301
	# of IoT devices		19				7	26
Genoa	# of Observations		3015				230074	233089
	# of Measurements		7545				1839928	1847473
	# of IoT devices		1			628		629
Cantabria	# of Observations		412258			7999		420257
	# of Measurements		3179598			55993		3235591
	# of IoT devices	3						3
Aarhus	# of Observations	12005						12005
	# of Measurements	12002						12002
	# of IoT devices	48	20	4	470	4902	192	5636
Total	# of Observations	12144	415273	750	5011	64989	230086	728253
	# of Measurements	12141	3187143	8083	16362	398047	1840000	5461776

extracted from the RADICAL Governance Toolkit's added value tool. Those results provided the big picture of citizens' engagement in the RADICAL pilot, showing overall IoT devices (smartphones or installed sensors) and data sent per service for each participating city.

Device-related data as dictated by the RADICAL object model are presented in the form of Observations or Measurements. Observations correspond to general IoT events, for example sensor reports or bicycle “check-in” events, while Measurements cover more specific metrics included in an Observation like Ozone measurements (mpcc) or the average bicycle speed (km/h).

As can be observed, data handled by RADICAL’s repository reach the range of millions. Thus the aim of the technical evaluation performed was to stress the RADICAL platform and tools with parallel calls for retrieving IoT and SN data. More specifically, the following tests were run to validate the platform’s technical stability:

• Parallel calls for retrieving various IoT (devices, events, observations) large datasets (**results scale: ~10.000 results per dataset**)

• Parallel calls for retrieving IoT and SN large datasets (**results scale: ~100 results per dataset, 5 topics identified**)

• Parallel calls for retrieving large sets of measurements in many pages (**results scale: 10.000 results per page**)

• Parallel calls to various cities for retrieving IoT data (**results scale: ~2.000 results from 5 cities’ platforms**)

RADICAL’s APIs successfully replied parallel requests in a matter of less than 3 sec with resource utilisation being balanced. Server crashes did not appear, proving the platform’s soundness in terms of technical integrity.

Regarding citizens’ and city officials’ platform evaluation, feedback was collected through online surveys, presenting user questionnaires in +Spaces[38] dedicated poll apps in Facebook and Twitter. Living Labs’ participants in pilot cities were asked to evaluate RADICAL’s city-provided application’s usability and operation, and its added value in general.

City Service administrators and developers on the other hand were asked about the functionality and operation of RADICAL as well as the sustainability potential in the context of Smart City.

Overall, 337 participants (235 citizens and 102 city officials) coming from the 6 cities evaluated the various aspects concerning RADICAL. 12 Living Labs were established overall (2 for each city), thus 12 questionnaires were finally deployed to citizens, asking them to evaluate the impact RADICAL had in their everyday lives. The final validation also included 3 questionnaires for city officials (service admins and technicians) in order to evaluate the technical aspects of the platform (functionality, replicability, security and privacy), as well as its business potential (sustainability).

Feedback collected was promising, as presented in some indicative questions in Figures 10 and 11, extracted from +Spaces Data Analysis page. Full questionnaires and detailed numbers for RADICAL Living Labs can be found on the project website[39].

5. Future Work and Conclusion

Future work in the RADICAL platform is aligned to the progress of the RADICAL project and includes the operation of pilots for large groups of people participating in Living Labs. These people will validate the benefits of the core concepts and technical implementations. In particular, the main challenge is to prove that the combination of knowledge gathered and deployed in social networks combined with sensors and Internet of Things elements in smart cities contexts can provide a wide set of services that are beneficial

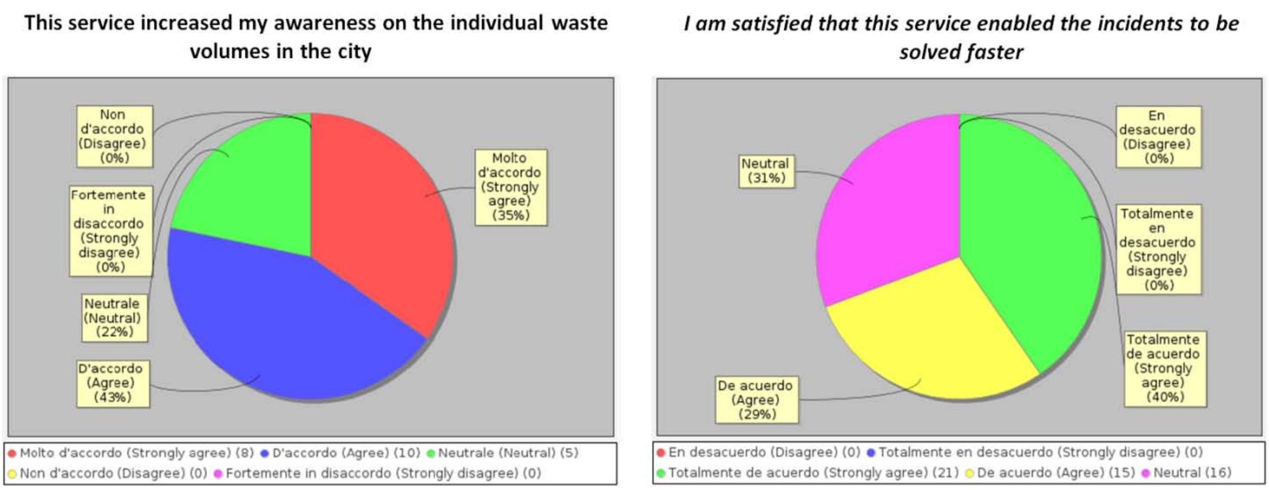

Figure 10. Indicative results of citizens’ polls (Eco-consciousness service in Genoa/Participatory Urbanism service in Santander).

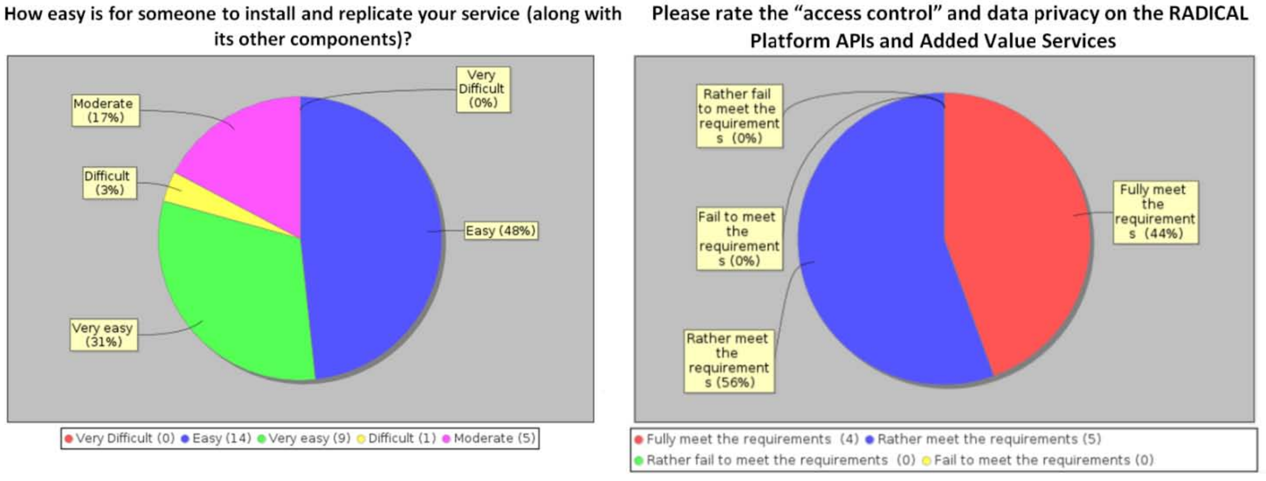

Figure 11. Indicative results of city officials' polls (Ease of RADICAL installation and replicability/Data privacy evaluation).

for the citizens and the urban planning of the public administration and policy makers.

The evaluation from city officials demonstrated that the described approach promotes sustainable integration of social networking and IoT services, enabling third parties (i.e., cities and service developers including SMEs) to successfully engage in the co-design and take-up of similar services. In relation to replicability, the proposed approach seems to be achieving its goals. Evaluation showed that almost 79% of city officials could replicate RADICAL's services with ease.

Finally, we showed that the RADICAL platform is a technically sound solution while the currently hosted services serve their purpose in raising awareness and providing access to government services.

The main task set as future work is the development of best practices that will not only cover technical and technological issues but will mainly emphasise on planning, financing, sustainability, operational and legal aspects. For example, as shown before, privacy and security are regarded as crucial factors in smart city platforms.

Along with these best practices, RADICAL will produce roadmaps associated with sustainable deployment and operation of social networking services in smart cities, illustrating the roles and responsibilities of all stakeholders towards sustainable development and operation. Based on the best practices and roadmaps, RADICAL will also elicit a number of guidelines that will be provided to policy makers in order to shape policies at the regional, national and EU levels, in a way that boosts the development and adoption of social networking and IoT services in urban environments.

Conflict of Interest and Funding

No conflict of interest was reported by all authors.

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