Smart City Technologies and Architectures
A Literature Review

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Abstract: The main goal of smart cities is to improve the traditional services that are provided to the citizens and also create new and more challenging ones. This vision aims not only to citizens' prosperity, but also to economic progress and sustainability of the city. It is feasible to achieve this goal through the use of technologies and architectures which purpose is to integrate the various elements of the city and help them interact in an effective manner. In this paper, we discuss the key technologies and architectures that have already been proposed in the literature in order to find the appropriate ones to be implemented for the development of smart cities.

1 INTRODUCTION

Several definitions have been published over the years about the term "Smart City (SC)". One of the most widely accepted is that by IBM (2010) that assumes SC as "*the use of information and communication technology to sense, analyze and integrate the key information of core systems in running cities*". According to Caragliu et al. (2011) "*a city is smart when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance*". SC is also considered to have a strong relationship with digital city. A. Cocchia (2014) referred that digital city is a subcategory of SC, because both of them include Information and Communication Technologies (ICT). The main difference is that SC intends to improve citizens' standard of living through the development of the economy, the social and political progress, the provision of new services and the protection of the environment. Moreover, K. Su et al. (2011) stated that SC generates from digital city when it is combined with Internet of Things (IoT).

The need for SC arises due to urbanization of modern cities and the necessity to solve various daily problems that affect citizens' lives. The technological progress gives us the opportunity not only to manage these problems but also create services and facilities in order to improve people's quality of living. The main sectors that a SC aims to improve are smart economy, smart people, smart governance, smart mobility, smart environment and smart living (Giffinger et al, 2007). In order to manage these sectors and design useful applications, SC exploits all the available resources, monitors conditions and collects information through sensors and critical infrastructure. Then, it analyzes and processes them through the use of ICT so as to offer citizens the expectable satisfaction.

The purpose of this paper is to discuss the basic platforms and architectures that have been proposed over the years and specify the ones that are more useful in building SC. Section 2 presents some of the selected technologies that should be integrated in a SC as we find them in the literature. Section 3 includes the discussion about the usability and implementation of the presented technologies. The last section 4 shows the concluding results and suggestions for future work and research.

2 BACKGROUND

Below we quote several architectures and their including technologies. Although the literature contains many surveys and suggestions about the architectures that participate in the design and

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operation of a SC, there is not yet a standard one that integrates all the functionalities. Furthermore, the greatest number of these architectures is based on a theoretical approach and non in a practical one with real implementation. In this section, we present some of the proposed architectures giving emphasis in the most common technologies that we meet a lot in the literature. We have recognized six perspectives of architectures - the perspective of *Architectural Layers, Service Oriented Architecture, Event Driven Architecture, Internet of Things, Combined Architectures* and finally the new perspective of *Internet of Everything.* In the rest of our paper, we cite the works of different researchers, categorizing them chronologically and respectively to the perspective they belong. Finally, we summarize these works in a table for better understanding.

2.1 Architectural Layers (AL)

AL provide a framework for developing services and applications in SC through their fragmentation into pieces (layers) that can be easily modified and adjusted instead of transforming the whole system. Each layer is physically and logically dissociated from the others. This characteristic is the one that makes the perspective unique and explains its choice and great acceptance by a large number of researchers. In this subsection, we mention some of the most outstanding works that choose to implement this architecture in order to create useful facilities for SC.

Initially, T. Ishida (2000) was one of the first researchers to present a comparative study between the digital cities of America Online, Amsterdam, Helsinki and Kyoto. He recognized three layers in digital cities architecture. The first layer is the *information layer* which includes all the data from real time sensors and files from the Internet that are combined together through geographical information systems (GIS). The second layer is the *interface layer* which creates a virtual environment of the cities through 3D spaces and 2D maps. The last layer is the *interaction layer* where people can communicate with each other through the use of agent systems.

L. Anthopoulos and I.A. Tsoukalas (2006) developed the digital city of Trikala in Greece. Their chosen architecture consisted of five layers. The first and last layers are *user layers* where we can find all the stakeholders of a SC including the designers of the services and end users respectively. The second layer is the *infrastructure layer* which contains the technologies, platforms and networks in order to create and offer the services. The third layer is the *information layer* which consists of all the necessary data about SC operation, such as geospatial data and other records. The fourth layer is the *service layer* which contains all the provided applications of the city and allowed the interaction among citizens and organizations.

Expect from the definition that we mentioned it previously, IBM has also stated the structure of SC. According to IBM, the structure is divided in three layers, perception, network and application layer. *Perception layer* recognizes the device and gathers data via sensors, GPS, RFID and other technologies. *Network layer* processes those data through components related to the intelligence and communication capabilities of the network. Eventually, *application layer* examines and evaluates the total amount of data through advanced technologies, such as cloud computing and fuzzy techniques.

K. Su et al. (2011) focused in the building of SC and recognized three stages. The first stage is the manufacture of *public infrastructure*. The second stage is the manufacture of *public platform*, which includes network infrastructure, cloud computing platform and sensor networks. The third stage is the manufacture of *application systems*, which includes some basic applications like the construction of wireless city, smart home, smart public services and social management, smart transportation, smart medical treatment, smart urban management, green city and smart tourism.

J. Carretero (2012) developed an architecture named ADAPCITY. It is about a self-adaptive system for SC which offers heterogeneous devices the ability to react effectively in environmental changes and adapt their behavior according to the new conditions. Moreover, the system is able to recover immediately and update its operations, even create new ones. The proposed architecture is divided in four layers. The *physical layer* includes the state and behavior of devices and objects. The *grid layer* includes the process, storage and communication among the data come from physical layer. The *management layer* uses statistics, data mining and prediction techniques to manage the processed data from grid layer. Finally, the *control layer* includes the provided services taking into account users desires and optimization measurements.

Finally, I. Vilajosana et al. (2013) presented a generic architecture after observing many existing platforms and combining their common features.

The *capillary network layer* in the bottom of the platform includes sensors and actuators for data collection, data warehouses for storage of historical, real-time and metadata, as well as database nodes and security infrastructures for data management and control offering. The *service layer* has the responsibility to receive the incoming data from capillary network layer and then to process, combine and secure them. It manages different types of data, such as big, open and streaming data and also analytics services. The last layer is the *application layer* where the data are analyzed and converted into useful information, which is eventually provided to people through predefined interfaces.

2.2 Service Oriented Architecture (SOA)

SOA is an approach that aims in collection, communication and interaction between services and in their provision to the users taking into account their needs and requests. The communication between different services in a computer system is implemented through data exchange among them and the ability of each service to act as a whole activity on behalf of another service. Every interaction is considered to be unconstrained since services are unrelated, loosely coupled and self-sufficient. However, according to D. Sprott and L. Wilkes from Microsoft (2004), SOA is more than this. In fact, it is a pattern that includes all the necessary practices and frameworks to offer people the right services that fit to their preferences through the interface.

One of the most underlying works was that of L. Anthopoulos and P. Fitsilis (2010) who tried to create a common architecture for SC called Enterprise Architecture. Their approach is based on SOA and contains information of urban development and service delivery in urban environments. Logical and physical architecture has been combined with the enterprise architecture in order to strengthen the evolution of SC. As authors admitted, the case of Trikala failed to meet some of the challenges that SC have to face (such as information sharing and storage, connection and access through broadband networks, simulation of daily life and so on) with the primary architecture, so they developed this one in an attempt to overcome the existing problems.

2.3 Event Driven Architecture (EDA)

EDA is a framework that deals with the creation, identification, utilization and response to events. These events are usually uncommon, extraordinary and related to uncertain changes and asynchronous conditions. The result of the actions that EDA executes, provokes the generation of event notifications (and not of an event), which are actually an effect of change occurrence. A change can be detected by sensors and the outcoming events can be processed by the system. EDA is loosely coupled about the unknown results of a change by the event itself but it is tightly coupled to the semantics of an event. When the semantic heterogeneity of events is high, it is very difficult to implement that architecture in a SC (H. Souleiman et al., 2012). EDA can be also combined with SOA since an event can make a service operative.

Moving in that direction, L. Filipponi et al. (2010) developed SOFIA project in an attempt to monitor the public city places in order to enhance security and detect emergency cases and abnormal situations. This project is based on EDA that permits sensors (and especially wireless sensors networks) to observe unusual events. The main components of the architecture are Semantic Information Brokers (SIB) and Knowledge Processors (KP). All the data about smart places are stored in SIB. In the sequel, KPs receive these data from SIB, have access to them, generate and use notifications for the events described by them. The joint action between SIB and KP, leads to the production of Interoperability Open Platform (IOP), which gives applications the opportunity to gain entry to data and share them.

2.4 Internet of Things (IoT)

IoT is a paradigm that combines a large amount of heterogeneous devices, which are connected to the Internet and can identify themselves through IP addresses and protocols. All devices are embedded with sensors and actuators and are usually wireless connected to the network. IoT enables the connectivity and communication between sensors and deploys the incoming information in order to provide various applications to the people. Radio-frequency identification (RFID) is considered to be a prerequisite of IoT since it is believed that all things of our daily life could be identifiable with the use of radio tags. Cloud computing, which is actually a different term for Internet, has the duty of sharing computational resources and offering services to devices via the Internet without having in fact hardware equipment to manage applications. These technologies are commonly used together and managed to become an inspiration source for many researchers whose works are related to SC.

To begin with H. Schaffers et al. (2011) who considered SC as open access environments that are designed according to users' preferences. In order to create innovative services, the use of Future Internet technologies seems to be important as enabling the development of applications based on IoT. Furthermore, Living Labs methodologies played a useful role in that direction since they shows the way of organizing and coordinating innovative services and projects. A similar approach was followed by I.P. Chochliouros et al. (2013), who explained the concept of Living Labs and the benefits of their implementation in SC facilities, and also highlighted their contribution in the evolution of Future Internet platforms.

A. Attwood et al. (2011) developed the framework of SC Critical Infrastructure (SCCI) which aimed to protect critical infrastructures from failure or help the system to continue its function if a failure was unavoidable to happen. In order to detect the state of critical infrastructure, to help system recover, extract the conditions and make a change, the use of sensor actuator networks (SAN) is necessary, according to the researchers. SAN connects itself to the IoT so as to collect the data that are useful for the SC and integrate city components that should use an information aggregation utility. The amount of the collected data is usually so big, that the system should process them itself without human intervention. Semantic Web undertakes the role to take these data, give them meaning and specify the relationships between them, which are widely known as linked data. Cloud computing in its turn, used the service model of Infrastructure as a Service (IaaS) to access the data and process them in real-time. Based on these requirements and technologies, researchers developed the basic elements of SCCI, which are Smart Cities Systems Annotation and Aggregation Service, Critical Response Reasoning Instance, Critical Response Visualization and Control and finally Sensor Actuator Network Overlay State Management.

P. Ballon et al. (2011) created a European Platform for Intelligent Cities (EPIC) with the intention to be implemented in all European Cities. Their goal was to evaluate the use of cloud platform, Living Labs and e-Government in a pan-European level and examine the satisfaction of requirements and challenges that a SC has to face. The EPIC integrates the technologies of cloud computing, IoT and semantic Web. Specifically, EPIC used IBM's Test and Development Cloud so as to facilitate public sector to accept the change and the innovation of the cloud. IoT can enable geospatial positioning and 3D display through the use of sensor and RFID. Finally, the semantic layer of the EPIC includes the Command and Control Lexical Grammar (CCLG) technology to solve the problem of the multiple spoken languages in European countries.

E. Asimakopoulou and N. Bessis (2011) focused their research on disaster management using crowd sourcing techniques to create smart buildings. Through crowd sourcing technology, citizens participate in the detection of emergency events and hazards using APIs in their mobile phones. The role of citizens is enhanced by sensors and critical infrastructures in cars and buildings that explore their environment too. Other technologies that were proposed by the researchers were grid computing to integrate heterogeneous resources, cloud computing to enable access in these resources and pervasive computing to collect and handle data from devices.

R. Wang et al. (2012) presented how to use World Wind geographic software developed by NASA to 3D reconstruct a city. It is about an open source platform which allows visualization, simulation and interaction in all sectors of living in a SC. The two main components of this technology are data collection and visual display. The data are collected through IoT, network analysis and web map services. Their visual display is feasible through KMZ files for 3D models which are grounded on KML patterns.

Q. Ye et al. (2012) discussed the architecture of a Smart Sport information system giving emphasis to the including technologies, such as body sensor networks, IoT, cloud computing and data mining. In more detail, the body sensors have the duty to collect data concerned with the health and daily routine of an athlete. Cloud computing is used as the middleware to allow transfer and management of the data. Data mining and other techniques, such as mathematical models and artificial intelligence, are used to process and analyze the data so as to get the necessary information. Last but not least, with the contribution of the IoT and the development of software and hardware, that information is converted into useful applications.

J. Jin et al. (2012) analyzed four network architectures based on the IoT that could be implemented in a SC. The first architecture is the Autonomous Network Architecture, where users can access the network with or without Internet connection. The second is the Ubiquitous Network Architecture, where users access the Internet to find the expected information since radio technologies, wireless sensors and vehicular ad hoc networks are integrated to the Internet. The third is the

Application Layer Overlay Network Architecture, which is capable of reducing the amount of collected data through the IoT by selecting the more useful ones. The last is the Service Oriented Network Architecture, where researchers presented the example of the IDRA platform, which was developed by E.D. Poorter et al. (2011).

N. Mitton et al. (2012) examined the combination of cloud with sensors and actuators empowering by the IoT. This approach is named "Sensing and Actuation as a Service (SAaaS) following the names of the other types of cloud computing services. In their system, a SC is divided in sites. Each site is considered to be an autonomous system which contains sensors for information gathering and clients as information consumers. The collected information is stored in the Database Manager of the site from where it can be published to users after their request or can be distributed to the other sites if there is a need. The operation of this system is feasible via implementing the proposed schema and modules architecture, which consists of three elements, Hypervisor, Autonomic Enforcer and Volunteer Cloud Manager. The Hypervisor is used to abstract sensors from single devices or even from networks. The Adapter facilitates the communication between the devices. The Autonomic Enforcer is the mediator between the above modules and the SAaaS Cloud, exploiting their resources and converting them into applications using IoT capabilities. The Volunteer Cloud Manager concentrates these resources and applications in the cloud and develops strategies after monitoring the connectivity among the devices.

A similar study was undertaken by S. Distefano et al. (2013). The researchers kept the basic elements of the above framework and went further by distinguishing two phases in the architecture. The first phase was SAaaS provisioning system and infrastructure setup and the second phase was the SAaaS application setup.

G. Suciu et al. (2013) proposed the framework SlapOS, which combined cloud and IoT architectures, as a mean for designing SC. According to the researchers, the necessary features of building a SC are sensor networks and open source cloud platforms. Their framework integrates these technologies and has also the ability to transfer and offer IoT applications through the use of cloud middleware.

M. Roscia et al. (2013) presented a model for SC that was called Intelligent Distributed Autonomous SC (IDASC). IDASC involves multi-agent systems and IoT to enable observation, audit and performance of the system. It also integrates ZEUS framework to ensure functionality and communication between the agents.

C. Samaras et al. (2013) developed SEN2SOC platform to be implemented in the SmartSantander City of Spain. Their aim was to enhance the interaction between sensor and social networks through the use of Natural Language Generation (NLG) system in order to improve citizens and visitors experience in living in a SC. The architecture of SEN2SOC platform is component-based and includes *mobile and web applications* (IoT) to facilitate users login, support their navigation in city routes and promote feedback, *sensor and social data monitoring* to collect data from sensor and social media networks and detect anomalies in the environment, *statistical analysis* to process the income data and export the results from this action, and *interface* to allow communication between the components. The NLG system, which is embedded in the platform, has the ability to receive information from sensors and convert it into messages that can be easily understood by humans.

G-J. Horng (2014) designed a system for smart parking in order to facilitate citizens in finding parking spaces easily and quickly and help in reducing fuel congestion and air pollution. The architecture is based on an Adaptive Recommendation Mechanism, which includes various technologies in order to allow system's implementation. In more detail, it uses wireless sensor networks so as to search the existence of vehicles near a parking space. Then, an Internal Recommendation Mechanism of the specific place informs the Parking Congestion Cloud Center (PCCC) which with its turn transmits these data to the Cloud Server. Finally, the user receives the desirable information through his/hers mobile device, which in the same time acts as a sensor for the Cloud Server.

2.5 Combined Architectures

Except from the perspectives that we analyzed above and the presentation of the most underlying works that have been already published in the literature, there is also the perspective of combined architectures, which manages to integrate characteristics and technologies of the abovementioned ones. It is a common phenomenon for researchers to mix technologies and platforms in order to create an architecture that can probably be implemented in a SC. In this section, we cite some of these works distinguishing them in categories.

2.5.1 IoT – AL

Z. Khan and S.L. Kiani (2012) presented a cloud-based architecture for improving services and applications offered to citizens of SC. According to the researchers, citizens act as providers of data through the use of their mobile phones, and also as consumers of the developing services after processing the collected information. The proposed architecture which is based on a cloud environment is divided in seven layers (five horizontal and two vertical) and contains the context-awareness element. The first layer is the *platform integration layer* which contains the cloud technology and facilitates the access to all kinds of information. The *data acquisition and analysis layer* enables data collection and includes the context-awareness element to separate useful data from non-useful ones and synthesizes them together. The *thematic layer* categorizes data in sections according to their context. The *service composition layer* specifies the origin of data and contains the context-awareness element to state the workflows among corresponding services. The *application service layer* enables modeling and visualization of data to create applications that meet end users requirements. The *management and integration layer* manages the flow of data so as to ensure that only useful and related data are shifted from one layer to another. Finally, the *security layer* certifies the authentication of data and their use from authorized users.

Y. Wang and Y. Zhou (2012) presented an abstract study about the use of cloud computing with Near Field Communication (NFC) technology in SC. NFC is a card embedded in mobile devices, which is based on Internet and RFID technology. Its role is to promote user confirmation, data transmission, distant payments and public information. The researchers distinguished three basic layers in the cloud architecture of NFC application, which were *user information storage layer*, *device information layer* and *process layer.* Process layer included six other layers, from which researchers chose to discuss in more detail the resource scheduling layer.

R. Szabó et al. (2013) built a framework using Extensible Messaging and Presence Protocol (XMPP) to collect data from citizens' mobile devices. Their intention was to enhance participatory sensing while creating and operating SC applications. This knowledge is considered to be real-time big data that are processed by the IoT. The first scale of the framework's architecture is based on the publish - subscribe feature of the XMPP, which give users the opportunity to take part in information gathering (publish) and enjoy the updating applications after this action (subscribe). The second scale of the architecture is the analytics component, which is distributed in layers in order to anticipate citizens' mobility. According to the researchers, these layers are *streaming, persistence, serialization, caching, mobile data processing and users defined functions layers* and include platforms and technologies that can facilitate data processing and system's recovery after a failure.

Q. Zhang et al. (2013) examined the use of IoT in the food industry of a SC. Especially, they focused in the creation of an IoT system, which can observe, control and analyze the food supply chain so as to offer citizens protection of consuming contaminated or polluted products. The logic architecture of IoT is divided in four layers, *data collection and management layer, intelligent processing layer, graphic representation layer and self-correction layer*, each of which includes specific algorithms and metrics techniques. The collection of data from sensor networks is feasible through the Self-adaptive Dynamic Partition Sampling (SDPS) strategy in an attempt to eliminate the portion of sample of products that need to be examined so as to enhance the effectiveness of the procedure and the accuracy of the control. Furthermore, the researchers implemented a tracing algorithm to discover the origin of the pollution and a backtracing algorithm to withdraw polluted products that could not be traced in the supply sequence.

L. Sánchez et al. (2013) presented the architecture of SmartSantander city in Spain. Their aim was to find the necessary technologies and platforms based on the IoT to develop a common context for all SC. Their proposed architecture consists of three layers which are IoT *device layer, gateway layer and server layer*. The IoT device layer has the duty to estimate the number of the connected devices to the network and facilitates their heterogeneous nature through the use of mobile phones, RFID and other technologies. The gateway layer allows the communication and connectivity between the devices and the network. The server layer enables the access of users in the system by offering high level scalability and availability to the servers. Except from the layers, the architecture is also divided in four subsystems, each of which provides information about its embedded functionalities and is accessible by specific groups of people. Briefly, these subsystems are Authentication, Authorization and Accounting, Testbed Management, Experimental Support and Application Support subsystem.

2.5.2 IoT - SOA

F. Andreini et al. (2011) proposed an architecture infused by the notion of SOA, which combined IoT and geo-localization in order to promote access in SC services. Researchers emphasized in the term of scalability which could be achieved by using the Distributed Hash Table (DHT) protocol.

M. Hu and C. Li (2012) proposed the use of 3S and IoT for the creation and design of a SC. The 3S technology is associated with geospatial information (RS, GPS, GIS) for accurate positioning, with 3D visualization for city construction, with sensor networks for incessant observation, and with DPGrid and GPU (Graphics Processing Unit) technologies for real time processing of data. IoT is thought to be associated with RFID, barcodes and 2D codes technologies for allowing computational systems identify things of daily life, with sensor web for space monitoring, with SOA for managing geospatial data, and with grid and cloud computing for allowing access to services through the use of Internet and wireless networks.

2.5.3 IoT - SOA - AL

Z. Xiong et al. (2014) introduced a novel architecture of Data Vitalization (DV) in order to indicate a more effective way of managing the heterogeneous incoming data from sensors. DV architecture, which is divided in cells (master, data and special cells), mainly uses the technologies of SOA and cloud computing. An application of DV is the Smart Service Platform (SSP), which architecture distinguishes into four layers-*data gathering and storage layer*, *supporting layer for DV service*, *application layer for DV* and *application Layer for development*. Data gathering and storage layer collects and stores data in particular cells, while supporting layer for DV service processes these data. These two layers constitute of the data cell, which is applied by a virtual machine and their framework is the infrastructure as a service (IaaS) cloud computing services type. The other two application layers for DV and development concern both end users and developers, since they offer users the desirable applications, users can react as sensors and collect data from their devices and also developers can exploit APIs and create new services. The implemented technologies are virtual machine manager in the third layer and platform as a service (PaaS) cloud computing services type in the latter.

2.5.4 IoT - EDA

Based on the EDA of the SOFIA project, J. Wan et al. (2012) discussed the implementation of Machine to Machine (M2M) communications in order to improve SC's applications. M2M technology has the ability to facilitate the connection between people, computers and mobile devices, and also sensors and actuators. According to the researchers, in order to maximize the efficiency of the SC system, M2M communications need to be combined with Internet, sensors, networks and cloud computing, and further with KPs and SIBs.

2.5.5 IoT- SOA -AL - EDA

R. Wenge et al. (2014) proposed an architecture for SC from the perspective of data management. Their architecture is divided in six layers – *data acquisition layer*, *data transmitting layer*, *data storage and vitalization layer*, *support service layer*, *domain service layer* and *event-driven application layer*. The data acquisition layer gathers the data coming from sensor networks and other sources, like RFID technology and system on a chip (SoC). The data transmitting layer integrates the technologies of wireless networks and ultra wide band in order to facilitate users with Internet access. The data storage and vitalization layer focuses on clarification, correlation, sustainment, development and storage of data using the Internet of data technology (IoD) that is similar to the IoT and also cloud computing. The support service layer emphasizes in data management and provision to the users through SOA architecture, cloud platforms, visualization and simulation technologies. The domain service layer concerns every single sector of the SC and tries to integrate them together in order to enhance citizens' experience. Ultimately, the event-driven application layer stresses on citizens requirements and tries to offer them applications that satisfy their needs.

2.6 Internet of Everything (IoE)

IoE is a future perspective which is being designed to extend, overcome and substitute the IoT. Cisco defines the IoE for SC as the technology that connects people, process, data and things in order to improve the livability of cities and communities. IoE provides not only computing devices but every object (everything) with the capability of high connectivity and intelligence so as to operate various facilities. IoT based its function in the great number of the connected objects. Nevertheless, IoE operates via the deployment of networks that have the ability to transport all the collected and created information by these objects and also facilitates the connection of many more objects even if every object. In other words, IoE flags a new and innovative era when smart objects are connected together and everyone

Table 1: Smart City Architectures and Technologies.

Researchers	Research Area	Architectures	Technologies
T. Ishida (2000)	Digital cities of America, Amsterdam, Helsinki & Kyoto	AL	Sensors, Internet files, GIS, 3D/2D spaces and maps, agent systems
L. Anthopoulos and I.A. Tsoukalas (2006)	Digital city of Trikala	AL	Networks, geospatial data
IBM (2010)	SC structure	AL	Sensors, GPS, RFID, networks, cloud computing, fuzzy techniques
K. Su et al. (2011)	SC manufacture	AL	Network infrastructure, cloud, sensors
J. Carretero (2012)	ADAPCITY	AL	Data mining, statistics, prediction & optimization measurements
I. Vilajosana et al. (2013)	Generic architecture for SC	AL	Sensors, actuators, data warehouses, security infrastructures, interface
L. Anthopoulos and P. Fitsilis (2010)	A common architecture – Enterprise Architecture	SOA	Logical and physical architecture, service delivery
L.Filiponi et al(2010)	SOFIA Project	EDA	Sensors networks, SIBs, KPs, IOP
H. Schaffers et al. (2011)	SC and the Future Internet	IoT	IoT, Living Labs
I.P. Chochliouros et al. (2013)	Living Labs in SC	IoT	IoT, Living Labs
A. Attwood et al. (2011)	SC Critical Infrastructures	IoT	IoT , Sensor actuator networks, Semantic Web, IaaS
P. Ballon et al. (2011)	European Platform for Intelligent Cities	IoT	Test &Development Cloud, Living Labs, Semantic Web, RFID, sensors, CCLG
E.Asimakopoulou and N.Bessis (2011)	Disaster Management and smart buildings	IoT	Crowd sourcing, sensors, grid, cloud and pervasive computing
R.Wang et al. (2012)	World Wind for 3D reconstruction of SC	IoT	IoT, networks, web maps, KMZ files
Q. Ye et al. (2012)	Smart Sports	IoT	Body sensor network, cloud, data mining
J. Jin et al. (2012)	SC Network Architectures	IoT	IoT
N. Mitton et al.(2012)	Cloud and sensors in SC	IoT	IoT, SAaS
S. Distefano et al. (2013)	SAaaS in SC	IoT	IoT, SAaS
G. Suciu et al. (2013)	SlapOS	IoT	IoT, open source cloud platform, sensors
M. Roscia et al. (2013)	Intelligent Distributed Autonomous SC	IoT	IoT, multi-agent system, ZEUS framework
C. Samaras et al. (2013)	SEN2SOC platform	IoT	IoT, Natural Language Generation, sensor and social networks
G.J. Horng (2014)	Smart Parking	IoT	IoT, adaptive recommendation mechanism, wireless sensors, cloud
Z. Khan and S.L. Kiani (2012)	Cloud for citizens services in SC	IoT – AL	IoT, cloud, context-awareness component
Y. Wang and Y. Zhou (2012)	Cloud based on NFC in SC	IoT – AL	IoT, cloud computing, NFC card, RFID
R. Szabó et al. (2013)	Participatory sensing	IoT – AL	IoT, XMPP, analytics component
Q. Zhang et al. (2013)	Smart Food Supply Chain	IoT – AL	IoT, sensor networs, SDPS, tracing and backtracing algorithms
L.Sánchez et al(2013)	SmartSantander	IoT – AL	IoT
F.Andreini et al(2011)	Geo-localized services in SC	IoT – SOA	IoT, wireless sensors, SOA, DHT
M.Hu and C. Li (2012)	SC design	IoT – SOA	3S, GPS, 3D, sensors, DPGrid, GPU, RFID, 2D code, cloud, grid computing
Z. Xiong et al. (2014)	Data vitalization in SC	IoT – SOA – AL	IoT, SOA, sensor networks, IaaS, PaaS
J. Wan et al. (2012)	M2M communications in SC	IoT – EDA	IoT, sensors, actuators, cloud, KPs, SIBs
R. Wenge et al. (2014)	SC architecture from data management perspective	IoT – SOA – EDA – AL	IoT, sensors, RFID, SoC, wireless networks, ultra wide band, IoD, cloud, visualization & simulation technologies

from everywhere and at anytime can have access to them. Cisco clarifies the exact procedure that IoE follows. More specifically, IoE exploits the Internet infrastructure and connection networks, manages in an effective way the incoming information from devices, creates applications that can satisfy citizens' requirements in both public and private sectors and makes networks less complex through the use of APIs. Cisco plans aim to the opening of a global innovation centre for IoE in Barcelona by the mid-2016 like the ones that already exists in Brazil and South Korea and those that under construction in Germany and Canada. The purpose of those centers is to operate as the examples of introducing a common pattern when designing new applications for SC that are in the initial stages of creating urban facilities. For the time being there are not published use cases for that perspective.

3 DISCUSSION

Above we enumerate many architectures and technologies that have been proposed in the literature in order to find implementation in the whole SC system or in a SC sector. In this section, we will discuss them and try to determine these platforms that are more useful when designing a SC.

The AL perspective was one of the first to be applied by researchers if we consider the comparative study of T. Ishida between the digital cities of America Online, Amsterdam, Helsinki and Kyoto in 2000. The implementation of this perspective gave researchers the opportunity to modify features in different layers without having to change the whole system. As we recognized from the previous analysis, each researcher made a different proposal of a set of layers since there was not any specification agreed on the layer formation. Even today there is still not a standard pattern to follow when choosing to implement this architecture. It is remarkable that L. Anthopoulos and I.A. Tsoukalas who developed the digital city of Trikala in 2006, admitted that they failed to meet city's challenges with the existing architecture. The integration of more sophisticated technologies, such as sensors, actuators, GPS, cloud and so on managed to enhance layers' functionality. IBM opened the way with the definition of SC structure and its including technologies. The contribution of J. Carretero (2012) was also important since he added the characteristic of self-adaptation while creating the ADAPCITY system. Furthermore, I. Vilajosana et al. (2013) proposed a generic layer architecture presenting the key platforms and technologies to support SC applications. This architecture offers lots of benefits in designing a system since it can make it more flexible to changes and each change can affect only one layer and not the others. Furthermore, the separation of the SC system into layers facilitates the implementation of reusable components, while the component distribution helps the system to be more scalable and reliable. No serious technology restrictions have been noticed while implementing this architecture. The effectiveness of this perspective will be improved, if it is combined with more advanced technologies or even another perspective. This attempt is really valuable when building a SC since the system can better respond to all challenges and requirements.

The SOA perspective takes into account citizens' needs and preferences and tries to provide them with high quality services. These services can communicate and interact with each other while being independent and loosely coupled. L. Anthopoulos and P. Fitsilis (2010) used this architecture in order to improve the city system of Trikala and in an attempt to create a common architecture for SC. The implementation of this perspective fits very well with the purpose of a SC which is to offer citizens the right services that satisfy their needs. Service orientation seems to be one of the most useful architectures since its functionality offers a great number of advantages such as flexibility, service re-use, ability to create both new functions and combinations of functions. However, there are still issues to be solved concerning the complexity, performance and cost of the designing system. SOA functionality can be enhanced if it is combined with IoT.

The EDA perspective has the ability to identify an uncommon situation and respond to unusual events. This feature is very expedient in cases of crowd sourcing and monitoring public spaces in SC. L. Filipponi et al. (2010) developed SOFIA project in order to ensure citizens security. A subway station use case, facilitated by SOFIA infrastructure, was implemented to prove the effectiveness of the architecture in detecting abnormal events. However, the basic disadvantage of this perspective is that it can not respond properly when the events are characterized with great heterogeneity (H. Souleiman et al., 2012). One solution could be the combination with SOA since an event can trigger the operation of a service. Another solution could be a combination with IoT since the existence of sensor networks can enhance the efficiency of EDA.

The IoT perspective is the most common

approach used nowadays considering the number of published works in that domain. Internet is also related to sensor networks and cloud computing, technologies that are considered to be necessary when collecting, managing and storing information for developing SC's applications. However, some researchers made modifications in the features of these technologies to fulfill the requirements of their systems. For instance, both N. Mitton et al. (2012) and S. Distefano et al. (2013) used the approach of Sensing and Actuation as a Service (SAaaS). The first researcher presented the case study of a SC and the latter the use cases of smart traffic control and smart surveillance systems respectively. Other researchers added extra technologies to the abovementioned ones for improving the functionality of their systems. More specifically, P. Ballon et al. (2011) incorporated the technology of Command and Control Lexical Grammar in the EPIC framework which is already implemented in the SC of Brussels, Issy-les-Molineaux, Manchester and Tirgu Mures in Romania still studying its impact and implementation results. Furthermore, C. Samaras et al. (2013) added the technology of Natural Language Generation in SEN2SOC platform and illustrated two significant scenarios including citizens and city authorities. Another group of researchers used these technologies for developing applications for one SC sector and not for the whole SC system. For example, Q. Ye et al. (2012) dealt with smart sport applications presenting the cases of smart stadiums, smart shoes, smart athletes and smart fitness. G-J. Horng (2014) designed an adaptive mechanism for smart parking, the effectiveness of which was proved via a simulation test. R. Wang et al. (2012) dealt with 3D city reconstruction through the use of World Wind software showing three implementation scenarios of Lujiazui city, weather data and subway lines. The general idea that came out of this analysis is that this perspective is really valuable since it can gather data from citizens' devices and external sensors, transfer and process them via the Internet, create applications that fit to citizens needs and finally store these applications in the cloud to eliminate the waste of resources. This architecture is suitable for SC development considering all of the above-mentioned features and can be implemented alone or combined with another perspective. However, attention is required in terms of privacy and security of citizens' information and personal data since all of them are stored in the internet and are vulnerable in hacking and stealing. It is worthwhile to mention that scientific community tries to extend IoT and enhance its functionality with new features, creating the new Internet of Everything.

The combined architectures perspective is possibly the most appropriate for building SC since the integration, communication and connectivity between various technologies can help in the creation and easy management of more advanced applications. After a careful study we realized that Internet technologies are the key components to all architectures. Researchers combined them with AL, SOA and EDA. Combining IoT with AL was the primary choice of R. Szabó et al. (2013) who dealt with participatory sensing presenting three use case applications, concerning crowd sourcing based on public transport, soccer events and university campus all of which are still under development. Also, Q. Zhang et al. (2013) dealt with the use of IoT in food industry and highlighted two cases, one general and one including big data, proving the efficiency of SDPS strategy, tracing and backtracking algorithms. However, F. Andreini et al. (2011) preferred to combine IoT with SOA and presented a use case for proving the effectiveness of their proposed architecture. An extraordinary attempt was done by Z. Xiong et al. (2014) who combined IoT with SOA and AL to create a Data Vitalization architecture so as to find a way of better managing the incoming data from sensors presenting the social hotspots sense use case. Finally, equally significant was the work of J. Wan et al.(2012) who extended the EDA of SOFIA project by adding the M2M communications technology combined with IoT and sensor networks showing a case study for vehicular networks.

As a matter of fact, the combination of the perspectives can help the SC system to gain the max of its effectiveness by offering citizens the desirable applications, avoiding failures or recovering immediately in case of one and detecting for abnormal events enhancing citizens' security.

4 CONCLUSIONS AND FUTURE WORK

In this paper we presented and discussed many architectures and technologies that have been proposed in the literature in order to design and build a SC system or a SC component. We cited and analyzed various works that belonged to different perspectives, such as AL, SOA, EDA, IoT and combined architectures. We also mentioned the embedded technologies of these perspectives.

Finally, we summarized these works in a table and evaluated each perspective separately.

Based on the above analysis, we deduce that the perspective of AL was preferred by many researchers even though the chosen layers varied among their works. In most cases, researchers combined them with Internet technologies in order to enhance the functionality of each layer. SOA was also selected to be applied in SC since it distinguishes the city in different components which offer all kinds of services to the citizens. Considering the number of published works in the literature, we can easily determine that AL were mostly preferred for implementation than SOA. In the sequel, EDA implementation was only observed to one European project. On the contrary, IoT is the new trend in SC development and many recommendations about its implementation have been published until today. Its association with sensor networks and cloud computing amplifies its acceptance and choice by researchers. In recent years there is the tendency to combine IoT with the other perspectives to improve the functionality of the SC system. The most common combination is IoT with AL in which researchers used to add extra technologies to enhance system's capabilities. The combination of IoT with SOA was chosen to facilitate geolocalization matters and offer citizens the right services according to their requirements. Finally, the combination of IoT with EDA was selected for improving the functionality of the SOFIA European project by adding Internet technologies to the proposed architecture. There were also remarkable attempts that tried to combine together three or even all the abovementioned perspectives to empower SC with the advantages that each of them can offer to the citizens.

In the future, IoE intends to launch a new era in SC development. Its purpose is to extend the capabilities of IoT and create a common pattern in designing applications for SC that are in the initial stages of building their infrastructure and developing their services. Even if it is not implemented yet, it is expected to offer lots of capabilities to the citizens in order to improve their experience in the SC. As a matter of fact, IoE seems to be a promising architecture since it aims to totally change the economy, society and our way of living.

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