Defining Smart City Architecture for Sustainability

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Abstract. Smart city has been evolved since late 1990s to a rapidly emerged domain, where the academia, the industry and the government have mutual interest in transforming cities to innovation-based sustainable spaces. However, this evolution has come to a critical point of argument, where existing efforts are being developed mainly with public spending, which serve industrial purposes. As such, governments focus on smart city standardization in an attempt to clarify the smart city domain. Such standardization concerns smart city architecture too, which has to serve all potential innovations. This paper aims to define a common smart city architecture, which serves government purposes for innovation and sustainability, while it utilizes experiences from prestigious cases and corresponding theoretical context.

Keywords. Smart city, architecture, standardization, governments.

1. Introduction

Various scholars have attempted to define smart city from different lens [1; 2; 3; 4; 5; 6; 7] and now the smart city domain is close to a common definition, which concern innovation –not necessarily based on the information and communications technologies (ICT)-, which aim to enhance urban performance in terms of people, governance, mobility, economy, environment and living. The smart city domain has emerged tremendously since its initial appearance in the late 1990s and engages al-most all the business sectors. The smart city niche market is estimated to reach the amount of $3 trillion by 2025 and exceed the size of all traditional business sectors. This estimation was grounded earlier by Simon Giles [8] from Accenture, who sees the source of this money on embedded operational efficiency, as well as on new entrepreneurship. Moreover, [9] predicts that the amount of €38.9 billion will be spent on smart cities in 2016 alone. However, today, the smart city market race is led by public investments [10; 11], which show that enterprises are still reluctant to invest directly on smart cities and they seek to secure their entrance with standardization and business models.

Standardization is welcome by governments too, which fund smart city initiatives. As such, almost all international organizations are under the process of developing corresponding standards: International Standards Organization (ISO) [12], British Standards Institute [13], International Telecommunications Union (ITU) [14] and the US National Institute of Standards and Technology (NIST) [15] are only some of the organizations that develop smart city standards, which contain specifications for urban performance of for various solutions that can be incorporated in smart cities (i.e., energy, water, waste, telecommunications, buildings etc.). However, no standardization has been developed so far, which sees smart city as a whole system, although various scholars and developers have suggested alternatives.

Architecture refers to the abstract representation of a system or structure [16]. As such, smart city architecture defines the organization and interrelation of all potential sub-systems and elements, which deliver all expected smart city services to its audience. The aim of this paper is to deal with the above observation and aims to answer the following research question: RQ1 – *what is the structure of a smart city architecture that could define a corresponding standard?*

The answer to the above question is crucial for both governments and the private sector, which will have a common and agreed "picture" on a smart city and will know how to deliver individual solutions within the urban space. Moreover, governments will hold a precise material to deal with recent arguments, which criticize the use of smart city concept and potential and claim that the smart city is the outcome of vendors' marketing campaigns [17]; others say that smart cities reflect little more than usual urban innovations [18]; while Brown [19] criticizes the whole concept of smart city by questioning their effectiveness.

The remainder of this paper is structured as follows: background section 2 classifies smart city projects. Section 3 presents existing approaches to smart city architectures, according to literature findings and some good practices and concludes on a common architecture. Finally, section 4 contains conclusions and some future thoughts.

2. Background

Smart city has risen from the urbanism phenomenon, according which the proportion of the international population that will live in cities will exceed 70% in 2050. The previously given smart city definition considers smart city [14, 6, 20] to be an urban space with innovative –not necessarily based on ICT- features, which are grouped in the following dimensions:

- *People*: in terms of discovering and meeting today and future requirements;
- *Living*: enhancing quality of life and social coherency, as well as efficiency regarding energy, food, water etc.
- *Environment*: protection, waste and emissions control and resilience against climate change;
- *Governance*: in terms of ensuring urban utility and service availability;
- *Economy*: in terms of sustainable growth and city competitiveness;
- *Mobility*: addressing transportation and traffic management issues.

Other approaches discuss resilience in terms of resistance against natural disasters, pandemics, terrorist attacks, accidents etc. [21], which are considered by the above environment and governance dimensions; innovation in terms of urban innovation [22], which is mainly disruptive, although the smart city becomes steadily a social innovation [23]. The above characteristics illustrate the complex nexus, where the identified six dimensions co-exist and interrelate. Smart Cities can be classified according to the smart infrastructure type and corresponding development stage [24] to the following categories:

- *Hard infrastructure based:* this category refers to city innovations, which target the efficiency and technological advancement of the city's hard infrastructure systems (i.e. transport, water, waste, energy).

- *Soft infrastructure based:* city innovations, which address the efficiency and technological advancement of the city's soft infrastructure and the people of the city (i.e. social and human capital; knowledge, inclusion, participation, so-cial equity, etc.).

With regard to the city development's stage they're classified in the following groups:

- *New cities* (Greenfield or 'cities from scratch' or 'planned cities'): they concern smart city projects where the entire city is being developed from ground zero, even urban planning addresses the above smart city dimensions and innovative solutions are embedded in the city. Various cases of this type are under development around the world, such as Songdo (South Korea), Tianjin (China), Masdar (United Arab Emirates) etc.

- *Existing cities:* they concern smart city projects where the innovative solutions are installed in existing infrastructure. Representatives of this category concern all the cities, which develop various types of innovative solutions (i.e., Barcelona, Amsterdam, Vienna, Copenhagen etc.).

- *Smart plants:* they concern from-scratch projects, which are developed inside existing cities (i.e., new neighborhoods, new blocks or harbors etc.). Indicative cases of this category concern the Kentucky Harbor, Kista (Stockholm) etc.

The above categories analyze the smart city in the following components:

- Soft infrastructure: people, knowledge, communities

- Hard infrastructure: buildings, networks (transportation, telecommunications), utilities (water, energy, waste)

- ICT-based innovative solutions: both hardware and software solutions, which address the above hard and soft infrastructure.

- Other innovative solutions (beyond the ICT): technological innovation that addresses smart city dimensions (i.e., open spaces, recycling system, smart materials, organizational innovations in government etc.)

- Natural environment: it concerns the physical landscape and the corresponding characteristics, where the city is installed (i.e., ground, forests, rivers, lakes, mountains, flora etc.)

3. Existing smart city architecture approaches

An analysis was performed with literature review, with findings from the following sources: international standards organizations for smart city documents; and SCOPUS, with searches only in journals that publish smart city articles [25], with the combination of terms “smart city” and “architecture”. Article crawl was performed within the period of 1997 (appearance of smart city concepts in literature) to early 2015. More than 200 articles were returned from this crawl, where screening was used to leave out irrelevant publications (like “city architecture”).

The most important articles that discuss smart city architecture where from [11, 26, 27, 28]. Anthopoulos and Fitsilis [11] explored various smart cities around the world and concluded that the architecture that is preferred by well-managed managed cases is the multi-tier (Table 1), which is applied in new, existing and smart planting cases, while it addresses both soft and hard infrastructure, while it considers natural environment and the evolving Internet-of-Things (IoT) in terms of sensor installation.

Module definition for a smart city is an extremely complex process and it has to consider both the type and the architecture. According to the above analysis, soft urban infrastructure (people, data and applications) is flexible and can easily extend and interconnect. Difficulties rise from requirements, which deal with hard infrastructure and environment. Various attempts illustrate modular smart city approaches [26, 27, 28]. A modular architecture approach to smart city has been inspired from Al-Hader et al. [27] and can be utilized to the following:

1. Networking Infrastructure and Communications Protocol: this module addresses the necessary infrastructure to deploy smart services and enhance living inside the city. Cities from scratch are based on innovations (both ICT-based and non ICT-based), which are embedded on city’s hard infrastructure. For instance, in New Songdo (Seoul) a waste disposal, recycling and tele-heating factory is installed and interconnected with buildings inside the city (Clever rubbish). In the same case, fiber-optic networks connect all local buildings with a central operating center, while smart buildings are accessible by their inhabitants via specific applications. In existing cities on the other hand, corresponding SSC cases integrate innovation with existing hard infrastructure with the IoT and basically with sensors that exchange data with specific applications. Moreover, protocol defines the codification for information inter-change in SSC.

2. *Applications*: this module concerns all the smart applications, which are available inside the smart city. A well method for analyzing this module could be the classification of applications in the four smart city dimensions, including a separate group of mobility (i.e., intelligent transportation applications).

3. *Business*: it addresses business groups, which are available in the city.

4. *Management*: this module contains all rules and procedures for managing a smart city: processes, people, resource, land and information are the primary elements and could be controlled centrally or individually with the appropriate set of standards.

5. *Services*: this module concerns all type of smart city services, offered with the contribution of the ICT from the supplier-side users (smart city stakeholders’ users) and requested by the demand-side users (inhabitants and smart city stakeholders’ users). Smart city stakeholders have been identified by [30] and concern organizations from the urban area (utility providers, NGOs, city service companies etc.); governments (local, state and national); international and multilateral organizations; citizens; the academia; urban planners and standardization bodies. On the other hand, services concern: transportation; e-government; e-business; safety and emergency; smart health; tourism; education; smart building; waste management; smart energy; and smart water.

An indicative n-tier ICT meta-architecture, where physical, utility and ICT environments coexist and interact, while people and businesses are also part of the eco-system and interact with the smart city via e-services is illustrated on (Figure 1). These 5 layers were chosen as the result from the above analysis, as well as an attempt to address all United Nations Habitat (UN Habitat) key-performance indicators [14]. Service groups were also selected to meet these indicators accordingly.

Another architectural approach concerns the Service Oriented Architecture (SOA) [20], which is proposed for existing cities, where innovation mainly focuses on soft infrastructure, as well as where IoT is utilized [29]. Finally, event-driven architecture (EDA) is also discussed [11], but it has not been applied yet.

Table 1. Preferred architectures in various examined cases [11]

Case	**Findings**	
	Architecture	**Organization**
European Smart Cities	Urban Intelligence Measurement System	Project (various European Cities)
Two cities in Netherlands	SOA	State-Owned-Enterprise (SOE) run by the municipality
52 cities	n-tier architecture (4 layers): *Network, Content, Intelligence, e-services*	Public Organization (i.e., Gdansk (Poland), Masdar (UAE)) Public Private Partnership (PPP) (i.e., Amsterdam (Netherlands)) Private Companies (Malaga (Spain), New Songdo (Korea))
Helsinki, Kyoto	n-tier architecture (3 layers): *information, interface, interaction*	State-Owned-Enterprise (SOE) run by the Municipality
Dubai	n-tier architecture (3 layers): *Infrastructure, data, application*	Public Organization (Government)
Trikala, Greece	n-tier architecture (6 layers): *data, infrastructure, interconnection, business, service and user*	State-Owned-Enterprise (SOE) run by the Municipality
Barcelona	n-tier architecture (4 layers): *code, nodes, infrastructure and environment*	SOE run by the Municipality in cooperation with the local university
Blacksburg Electronic Village	n-tier architecture (3 layers): infrastructure, content, community	PPP between Bell Atlantic Telecoms, Virginia Tech, Municipality
Amsterdam	n-tier architecture	PPP between Municipality and Liander grid Operator
Singapore	n-tier architecture (4 layers): ICT infrastructure, Cognitive infrastructure, Services, Customers	Public Organization

Table 1 shows that architecture is independent to the smart city organization (Public organization, State-Owned-Enterprise (SOE), Project coalition or Private Company), since the multi-tier architecture for instance is observed in various cases that follow alternative organization forms. On the other hand, layer selection in multi-tier architectures is not influenced by the ICT smart city selection (i.e., Trikala is a digital city, Kyoto is an online city etc.).

All the above information collected from literature and case studies, provide with answer the RQ1 and suggest that the architecture of the smart city must be multi-tier in order to be clear and sustainable, in terms of standardization and communication of these standards. This architecture (Figure 1) meets existing standardization efforts [12;13] and more specifically the UN Habitat key-performance indicators [14], which define a model for urban measurement at an international level. According to the examined cases, this n-tier architecture must utilize hard and soft infrastructure and must contain the minimum following layers (Figure 1) from top to bottom:

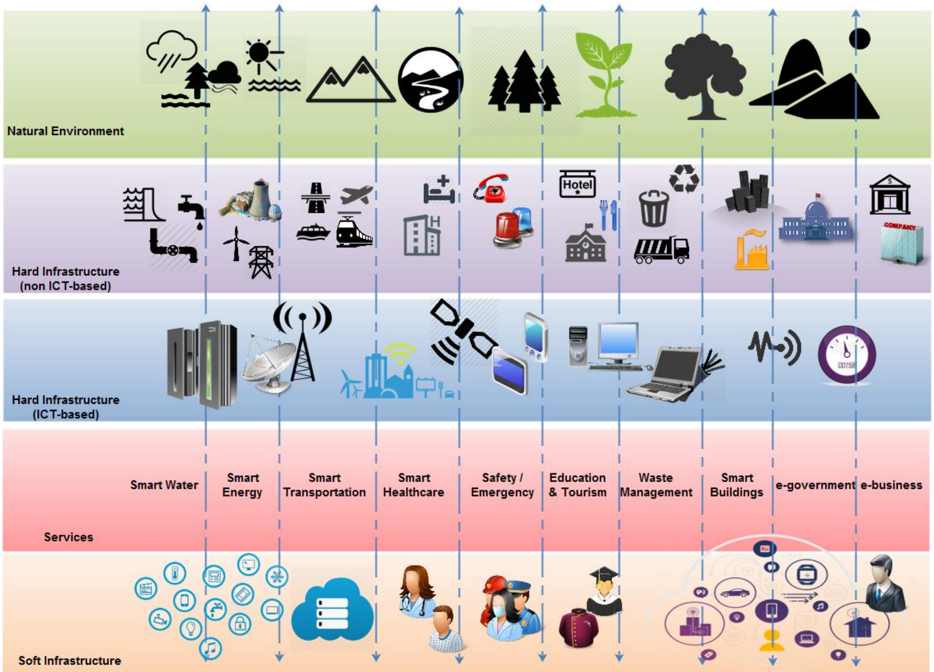

Figure 1. A generic multi-tier ICT architecture for smart city [31]

Layer 1) Natural Environment: it concerns all the environmental features where the city is located (landscape, rivers, lakes, sea, forests etc.).

Layer 2) Hard Infrastructure (Non ICT-based): it contains all the urban features, which have been installed by human activities and are necessary for city operation (buildings, roads, bridges, energy-water-waste utilities etc.)

Layer 3) Hard Infrastructure (ICT-based): it concerns all smart hardware, with which SSC services are offered (i.e., datacenters, supercomputers and servers, networks, IoT, sensors etc.)

Layer 4) Services: all types of smart city services, grouped in the smart city six dimensions and organized according to international urban key-performance indicators.

Layer 5) Soft Infrastructure: individuals and groups of people living in the city, as well as applications, databases, software and data, with which the SSC services are realized.

4. Conclusions and future thoughts

This paper addressed an important problem regarding the lack of standardization, which would consider smart city as a system and grounded a research question (RQ1), regarding the type and the structure of a smart city architecture that could define a corresponding standard.

In order to provide with answer RQ1, this paper used literature findings and combined them with data from well-known smart cities. Findings suggest that a common architecture must be multi-tier, consisting of five layers (natural environment, hard non-ICT infrastructure, hard ICT-infrastructure, services and soft-infrastructure). These layers address all potential smart city solutions, while it leaves space to incorporate services that are delivered across the urban space and grouped according to UN Habitat key-performance indicators. This architecture can be the baseline for smart city standardization, since it adopts internationally defined smart city requirements, it can fit to all city types (existing cities, new cities and city blocks) and it is easy to follow architecture principles like scalability, interoperability, security and vendor independence etc. [31]. However, limitations come from the missing of this architecture testing and corresponding validation. Future thoughts concern the testing of this architecture in alternative cases across the globe or the validation with responses from smart city experts.

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