Exploring Architectural and Organizational Features in Smart Cities

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***Abstract*— Smart cities is a "booming" international phenomenon and they suggest both a novel economic and research domain, which is concerned from various perspectives, i.e. smart growth and urban planning; living labs; information and communications technologies (ICT) state-of-the-art topics etc. Although smart cities follow different forms they offer various types of services to the local communities. Recent studies illustrate that smart cities tend to evolve to green or eco-cities, where technology is capitalized for urban sustainable growth. However, it is not clear what different architecture types are followed and how these architectures are formed. This paper investigates and compares the alternative architectures that are followed by existing smart city cases, as a means to understand how different architectures offer e-services in urban areas.**

***Keywords*— smart city, ubiquitous city, smart services, e-services, urban technologies, smart city architectures**

I. Introduction

Smart city is a term that is still confusing regarding its meaning, although various attempts have been made to clarify it [1, 2], since it describes urban spaces from various perspectives: in Smart-Cities project [3] this term is used to define intelligence's certain characteristics and capacity in medium-sized European cities; IBM Institute for Business Value [4] introduced a model that can be used to optimize cities' seven core systems and improve their sustainable prosperity; Alcatel-Lucent Market and Consumer Insight team [5] recognizes smart city a challenging market area; [6] and [7] focused on the implementation of the information and communications technologies (ICT) for information and transaction flows across the city as a means to contribute on social challenges; [8] and [9] consider smart cities Living Labs; [10] views smart city as information flow that overrides space of places and name it informational city; South Koreans [11] implement cities from scratch with pervasive technology; while recently, emphasis is given on smart solutions for energy efficient and ecological living [12, 13]; finally [14] perform a classification and identify various adjectives to "city" (web or online, knowledge-based, digital, smart, wireless or mobile, broadband, ubiquitous and green or eco) that are used to describe alternative ICT infrastructure and services, which aim to support local life or deal with urban challenges.

All the above approaches seem to converge to a definition about the smart city, regarding *ICT-based infrastructure and services that enhance city's intelligence, quality of life and other attributes (i.e., environment, entrepreneurship, education, culture, transportation etc.)*. More than 150 cities can be documented around the world as smart cities, while many more can be classified according to their ICT or intelligent sophistication. However, it remains unclear what different architectures are followed in the documented smart city cases and offer alternative e-services to the inhabitants.

The aim of this paper is to investigate and compare the alternative architectures that are followed by various smart city cases. This comparison will attempt to answer the following critical question: "*What different smart city architectures exist and how they are formed*?" This question is very important for decision makers in smart city domain, since alternative architectures combined with organizational differences can affect e-service efficiency and smart city performance.

In order to answer the above question, different types of data are combined: literature findings regarding smart city cases will be explored and alternative architectures will be compared, accompanied by the offered e-services; architectural and organizational findings from an on-going survey on smart city managers from different cases will be presented and adjusted to the previous alternative architectural approaches.

The remaining of this paper is structured as follows: the following section II performs a literature review and comparison on smart city architectures. Then, section III contains findings from experts in smart city domain about the architectural and organizational facts of various cases. Finally, section IV contains conclusions and future thoughts.

II. Background

Accepting the previously given definition, the smart city can be understood as a "system", which consists of various elements –beyond the ICT ones- and it is important for its synthesis and architecture to be realized in as a generic manner as possible. System's architecture defines its structure, relationships, views, assumptions and rationale [15]. The identification of these core elements in a smart city is crucial for researchers to understand how different entities in an urban space offer alternative e-services. Different architecture types exist that describe different systems. For the purposes of this paper, various smart city cases are analysed and their architectures are explored (Table 1).

Giffinger et al. [3] defined a smart city model that contains the following six characteristic, which interrelate and comprise the entire urban intelligence:

- Smart economy
- Smart people
- Smart governance
- Smart mobility
- Smart environment
- Smart living

Each characteristic is described by 31 factors and each factor is measured by 1-4 indexes. This approach is rather abstract, it defines a smart city measurement system, but it does not concern architecture.

IBM [4] recognizes cities as a system with 7 subsystems, to each of which various urban core elements are aligned, instrumented and interconnected:

- City services: public services, local administration
- Citizens: health, education, safety, Government services
- Business: environment, burdens
- Transport: cars, road, transportation, airports, harbors
- Communication: broadband, wireless, phones, computers
- Water: sanitation, freshwater supplies, seawater
- Energy: oil, gas, renewable, nuclear

This architecture is abstract too and identifies some intelligent domains in a city; it is closer to a Service-Oriented-Architecture (SOA) [15] since it analyses the city on discrete elements and functionalities, which offer alternative types of services and ensure smart city's functionality. SOA was found by [7] too, who explored the information architectures of two cities in Netherlands. They considered information architecture a blueprint of relationships within a system, which has to do with using information and managing the relationship between individual systems.

Alcatel-Lucent performed a detailed analysis of 52 smart city cases [5] and identified seven e-service groups and a chain of three elements for their provision (technologies-suppliers-customers):

- City administration (Government services)
- Education
- Healthcare
- Public safety (responses against crises)
- Real estate (energy efficient and of high performance buildings)
- Transportation (traffic and parking management and public transportation)
- Utilities (resource capitalization, environmental services)

Their analysis concluded on a multitier architecture of 4-stages, which from bottom-to-top concern:

- Network Infrastructure

- Content and communications
- Building intelligence (utilities that enhance local intelligence, i.e., wireless sensors)
- E-services to citizens

The multi-tier architecture for smart cities has been initially presented by Ishida [16], who described the cases of Amsterdam, Helsinki and Kyoto, with three-layer architecture (information, interface and interaction layers) and later in [17]. This architectural approach was followed by other scholars too during the examination of the following cases:

- Dubai City (UAE) [18] (3 layers: infrastructure, data, application)
- Trikala (Greece) [19] (6 layers: data, infrastructure, interconnection, business, service and user)
- Barcelona (Spain) [20] (4 layers: code, nodes, infrastructure and environment)
- Blacksburg Electronic Village [21] (3 layers: infrastructure, content, community)
- Amsterdam (Netherlands) [6, 22]
- Singapore [23, 24] (4 layers: ICT infrastructure, Cognitive infrastructure, Services, Customers)

Multi-tier architecture is preferred by other vendors too, such as Hitachi [25], which defines 5 layers to analyse the smart city environment:

- National infrastructure (i.e., energy, communications and transportation networks)
- Urban infrastructure (the above networks in the city)
- Service infrastructure (i.e., healthcare and education facilities)
- Urban management infrastructure (ICT platforms for service provision)
- Lifestyle (ICT orientation to peoples' life, job, study and travel)

Furthermore, smart city has been recently considered to be accompanied by the Internet-Of-Things (IoT) [9, 26]. In such an approach, n-tier is the most appropriate architecture to be followed too, since *content* (provided by city users and stakeholders) is transformed by the *IoT infrastructure and services* to *benefits* (to the same consumers) (Figure 1).

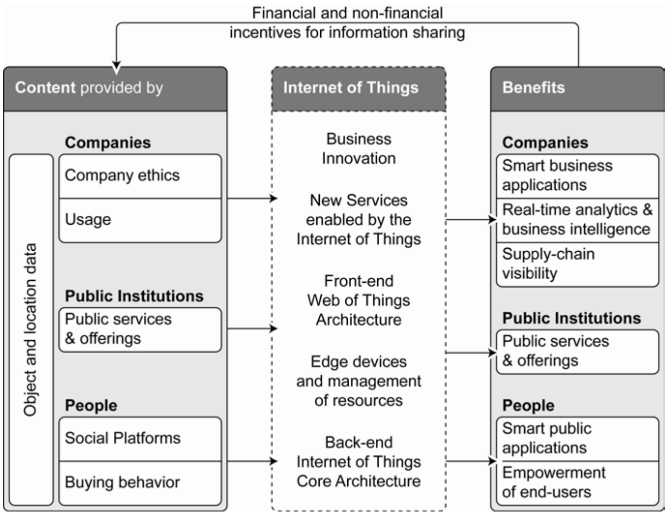

Figure 1. A Holistic Internet of Things Scenario Including Companies, Public Institutions and People [25]

A final architectural approach concerns event orientation (Event Driven Architecture (EDA)) [27], where in smart city various events occur, which are triggered either by real world events or by internal transactions. This approach has been followed under a European research project; it looks more likely to be applied to ubiquitous smart city cases, but it is not clearly observed in an existing case.

TABLE 1. SMART CITY ARCHITECTURE AND ORGANIZATION APPOACHES

Case	Literature findings	
	Architecture	**Organization**
European Smart Cities	Urban Intelligence Measurement System	Project (various European Cities)
[4]	SOA	N/A
[7] Two cities in Netherlands	SOA	SOE run by the municipality
52 cases [5]	n-tier architecture *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 [16]	n-tier architecture *information, interface, interraction*	State-Owned-Enterprise (SOE) run by the Municipality
Dubai [18]	n-tier architecture *Infrastructure, data, application*	Public Organization (Government)
Trikala [19]	n-tier architecture: *data, infrastructure, interconnection, business, service and user*	State-Owned-Enterprise (SOE) run by the Municipality
Barcelona [20]	n-tier architecture: *code, nodes, infrastructure and environment*	SOE run by the Municipality in cooperation with the local university
Blacksburg Electronic Village [21]	n-tier architecture: infrastructure, content, community	PPP between Bell Atlantic Telecoms, Virginia Tech, Municipality
Amsterdam [6, 16, 22]	n-tier architecture	PPP between Municipality and Liander grid Operator
Singapore [23,24]	n-tier architecture: ICT infrastructure, Cognitive infrastructure, Services, Customers	Public Organization
[9, 26]	n-tier architecture: content, IoT, benefits	N/A
[27]	Event Driven Architecture (EDA)	N/A

III. Domain Study

The above literature review returns useful findings regarding the architecture approaches in smart cities: information architecture is recognized as the means to analyse the business relations between the urban entities; SOA and n-tier are applied in the examined cases, while n-tier is preferred although the selected layers vary among the cases. This finding questions the criteria that lie behind layer prioritization, which could be either technological, political or else.

da Silva et al. [28] for instance, explored various smart city cases from a point of view, where each city's element is considered a data provider or consumer and they identified a set of requirements for a holistic smart city architecture: interoperability; sustainability; real-time monitoring; historical data; mobility; availability; privacy; distributed sensing and processing; service composition and integrated urban management; social aspects; and flexibility/extensibility. However, these requirements confirm layer determination from only a technological perspective.

To this end, authors needed to confirm the alternative perspectives and the criteria that lie behind architecture selection and layer determination for multi-tier approaches. In this order, they defined three hypotheses:

- H1: smart city's technological approach [14] influences architecture selection and/or layer definition;
- H2: smart city organization plays significant role in architecture selection and/or layer determination
- H3: the adopted business models define the appropriate architecture and/or layers.

In order to verify these hypotheses and to connect the pieces between technological approach, organization and business models, authors selected the following research method:

- **Step 1:** literature findings were utilized (Table 1) and smart city approach, organization and architecture were compared.
- **Step 2:** they defined a questionnaire that aimed to collect information from smart city experts about H2 and H3. Various experts are participating in a survey, which is still under execution.
- **Step 3:** they performed interviews with smart city experts of prestigious cases.

A. *Literature review results*

Literature review findings depict that architecture selection is independent to the technological approach, **meaning that H1 does not stand directly**. Various types of smart city technological approaches follow n-tier architectures (i.e., virtual city: Kyoto; digital city: Trikala; knowledge base: Blacksbourg; u-city: New Songdo etc.). Moreover, similar technological approaches (i.e., digital cities of Trikala and Barcelona) follow n-tier architectures of different layers. However, it remains unanswered the technological approach impact to layer definition.

Moreover, literature returned five types of smart city organization: *public organization*, where the State or the municipality has the entire project's responsibility; *public-private-partnerships*, where the State assigns parts of the project to private companies; State-owned-enterprise where a new organization is grounded to supervise the project, with the participation of the State and the private sector; private companies that implement the project; and project, where coalitions were formed to implement the smart city. Findings illustrate that smart city organization does not affect architecture selection, since all organization forms are observed in n-tier architecture for instance. This result **refutes H2** while the role of organization in layer definition cannot be directly answered.

Regarding the third hypothesis, a business model presents the underlying business rational [7] of a smart city and at least eight (8) are followed. Although business models are not supposed to be observed in public organization cases (i.e., Masdar, Gdansk etc.), even in these forms smart city plays the role of investments' attraction in urban spaces. Various types of business models can be observed in the examined cases, which show that architecture selection is not influenced by the underlying business and **H3 does not directly stand**. However, it is unclear whether layer selection is affected by the business model.

B. *Questionnaire's composition*

Literature review was sufficient to document that smart city architecture's selection is independent to the technological approach, organization and business models. However, architecture's structure could be affected by all these variants and remained unanswered. In this order, a survey is being conducted with experts in smart city domain, with the use of a structured questionnaire. The aim of the survey is to collect architecture structures; infrastructure and facilities; information management processes; and project organization in examined cases.

The questionnaire [29] is analysed in the following 4 parts:

- *Architecture* relative questions
- *Data* relative questions (sources and structure)
- Questions regarding *project and organization management*
- Details regarding the *components' selection*

The survey has been running since July 2013 until the end of 2013, while it is still in progress since various experts have been invited and participated in different time slots. Participants have commented over various questions and the questionnaire has been revised twice.

C. *Interviews with experts*

Authors have also conducted interviews with the above mentioned structured questionnaire, with the experts from the following smart cities: Tampere (Finland); Trikala (Greece); Geneva and Zurich (Switzerland); and Brisbane, Melbourne, Queensland and Roland Victoria (Australia). Interviews have returned extremely useful findings regarding the mission, organization and management of the examined cases (Table 2). Moreover, interviews prove that when a common telecommunications network exists, n-tier architecture is preferred, where infrastructure layer is formed to contain this network facility. Finally, according to the experts, layers are formed on the basis of the offered e-services and the involved partners and not on the adopted business model(s).

TABLE 2. FINDINGS FROM INTERVIEWS BY SMART CITY EXPERTS

Case	Findings		
	Architecture	**Organization**	**Business model**
Tampere	SOA (various partners offer different types of services)	Public organization (Municipal agency)	Open network to expert free-lancers
Trikala	n-tier (layer selection was based on the rationale of an information system)	SOE (Municipality and Local Chamber)	N/A
Geneva	n-tier (fibre-optic network lies under the smart city and concerns the key-component)	SOE (Municipality, SIG State energy company, SWISS Telecoms)	Open access network (rent to operator)
Zurich	n-tier (fibre-optic network lies under the smart city and concerns the key-component)	SOE (Municipality, EWZ State energy company, SWISS Telecoms)	Open access network (rent to operator)
Australian cases	n-tier (virtual communities)	Public projects (the State with the collaboration of the University)	N/A

IV. CONCLUSIONS

This paper attempted to identify the architectures that are being followed in smart cities and reasons that lie behind their selection and formulation. In this order, authors explored literature and they found out that SOA and multi-tier are the architectures that smart cities follow, while n-tier but with no specific layers is the mostly preferred one. They also discovered five organization types in the explored cases, while they concluded that architecture's selection is independent to the smart city approach, organization and business models.

Furthermore, in order to identify the variants that affect architecture's structure, a survey is being performed and interviews with smart city experts have been conducted. Existing results depict the crucial role of the network infrastructure in the n-tier's layer formulation, while e-services and service stakeholders influence layer determination. It is expected that survey's completion will bring more "secure" findings on the basis of more cases' contribution.

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