A Conceptual Enterprise Architecture Framework for Smart Cities

A Survey Based Approach

George Kakarontzas[1], Leonidas Anthopoulos[2], Despoina Chatzakou[3] and Athena Vakali[3]
[1]Department of Computer Science and Engineering, TEI of Thessaly, Larissa, Greece
[2]Department of Business Administration, TEI of Thessaly, Larissa, Greece
[3]Department of Informatics, Aristotle University of Thessaloniki, Thessaloniki, Greece

Keywords: Digital Cities, Smart Cities, Survey Study, Software Architecture, Reference Architecture, Software Quality.

Abstract: Enterprise architecture for smart cities is the focus of the research project "EADIC - (Developing an Enterprise Architecture for Digital Cities)" which is the context of the reported results in this work. We report in detail the results of a survey we contacted. Using these results we identify important quality and functional requirements for smart cities. Important quality properties include interoperability, usability, security, availability, recoverability and maintainability. We also observe business-related issues such as an apparent uncertainty on who is selling services, the lack of business plan in most cases and uncertainty in commercialization of services. At the software architecture domain we present a conceptual architectural framework based on architectural patterns which address the identified quality requirements. The conceptual framework can be used as a starting point for actual smart cities' projects.

1 INTRODUCTION

The European Smart Cities project defines a smart city as a city "*well performing in 6 characteristics, built on the 'smart' combination of endowments and activities of self-decisive, independent and aware citizens*" (European smart cities project, 2007). These 6 characteristics are: smart economy, mobility, environment, people, living and governance. Such diversity creates a challenging landscape for smart cities' enterprise architecture (Anthopoulos and Fitsilis, 2013). However without carefully crafted software architectures and the corresponding business processes supporting them, it is not possible to handle the complexity of a smart city project. In this work we present a survey for smart/digital cities. The purpose of the survey was twofold: (1) discover important quality properties for smart cities and propose a conceptual architectural framework for smart cities with these properties. This framework can be used as a starting point for actual smart city architectures. (2) understand the current state in business aspects in relation to the IT support infrastructure for smart cities' projects.

The rest of this paper is organized as follows: in Section 2 we present the survey's details including its construction and participants as well as the questionnaire and the obtained results. Then in Section 3 we use survey's results to derive functional and quality requirements. Based on these requirements we proceed in Section 4 in deriving appropriate architectural patterns for use in smart cities and we propose a conceptual application architecture framework for smart cities, which is based on these patterns. Finally in Section 5 we discuss related work and in Section 6 we present briefly some future research directions and conclusions.

2 SURVEY DETAILS

The construction of the survey targeted the most important aspects of enterprise architecture, namely organizational structure, business processes, information systems and infrastructure (Lankhorst, 2009). Consequently our survey comprises five general groups of questions: "architectural relative questions", "data sources", "smart city management-organization and funding", "smart city management-

Kakarontzas G., Anthopoulos L., Chatzakou D. and Vakali A..
A Conceptual Enterprise Architecture Framework for Smart Cities - A Survey Based Approach.
DOI: 10.5220/0005021400470054
In *Proceedings of the 11th International Conference on e-Business* (ICE-B-2014), pages 47-54
ISBN: 978-989-758-043-7

critical issues/milestones", and "smart city management-project mission and objectives".

The experts who participated in the survey are engineers of real smart cities throughout the world. In total there are 18 engineers from the following smart cities: Digital City of Trikala (Greece), Den Haag (The Netherlands), Amsterdam (The Netherlands), Brisbane (Australia), Waterfront Toronto (Canada), Turin (Italy), Thermi (Greece), Thessaloniki (Greece), Heraklion (Greece), Zurich (Switzerland), Geneva MAN (Switzerland), smart city of Melbourne (Australia), green city of Queensland (Australia), green city of Roland Victoria (Australia), smart city of Brisbane (Australia). Regarding the educational background of the surveyed experts, 11 have a PhD, 5 have a Master degree and 2 a Bachelor degree. The survey took place in June/July of 2013.

The questionnaire comprises 34 questions, including 3 questions with demographic characteristics. As mentioned already, the questionnaire is divided into five general categories. In most questions multiple answers were possible so the percentages do not always sum up to 100%. Also notice that for brevity in most cases we only present the most popular answers where the rest of the answers do not influence the conclusions. Therefore not all possible questions and responses are mentioned in the various tables.

The first group of questions, entitled "Architectural relative questions", contains two questions: "Provided services" and "Installed infrastructure". In the first the most popular services are the environmental and communication services with 67% and 56% respectively. In the second question, the most popular infrastructures are wired or wireless backbone infrastructures with 67% and 61% respectively (Table 1).

Table 1: Architectural Relative Questions.

Provided Services	**Total**	**Percentage**
Environmental services	12	67%
Communication services	10	56%
E-Government Services	9	50%
Installed Infrastructure	**Total**	**Percentage**
Wired backbone	12	67%
Wireless backbone	11	61%
Rented backbone	0	0%

The "Data Sources" category of questions (Table 2) tries to understand how data collection is conducted and to identify the level of data security. The first question is related to the "Data collection and storage" where it appears that 72% of the smart cities address this issue with direct data collection, while the 33% with indirect methodologies. Regarding the data storage 44% use local data infrastructure and 22% external data infrastructure (e.g. cloud storage). Additionally, there are three questions related to the level of access in the available data from the city administrative staff, the city's stakeholder's staff and the city's end users. In these questions 'project dependent' access means that different access mechanisms may be used per project, whereas role-based authentication means that access is provided based on the users' role.

Concerning data ownership in general usually the municipality and the project organization with 50% and 39% respectively are responsible for the manipulation of the data. In many cases data is owned jointly by more than one organization. Finally, an impressive element (not shown in Table 2) is that the 78% of smart cities do not make use of encryption. The remaining 22% supported that usually the data encryption is based on the used software and the data in question.

Table 2: Data Sources.

Data Collection and Storage	**Total**	**Percentage**
Direct data collection	13	72%
Local data storage	8	44%
Indirect data collection	6	33%
External data storage (cloud)	4	22%
Access level of city's staff	**Total**	**Percentage**
Role-Based Access	7	39%
Project-Dependent	4	22%
Access level of city's stakeholders	**Total**	**Percentage**
Project-Dependent	12	60%
Access level of end users	**Total**	**Percentage**
Individual Data Access	6	33%
Project-Dependent	5	28%
Data Ownership	**Total**	**Percentage**
Municipality	9	50%
Project Organization	7	39%
Various stakeholders	5	28%

Regarding the "smart city management - organization and funding" set of questions the aim was the identification of some critical financial, administrative and promotional issues, as the followed procedure is important for the viability of the smart cities (Table 3).

The goal of the first question in this category was the recognition of the key persons that are involved in the performance of the services. Service performance measurement here means which party is responsible for monitoring and improving the various services. According to the results in all cities the municipality was involved, as well as the local transportation services with 50% and various others. Of course in most of the cities more than one organization are involved in the performance of services.

Table 3: Smart city management - organization & funding.

Who are involved in service performance measurement?	Total	Percentage
Municipality	18	100%
Local Transportation	9	50%
Local SMEs	7	39%
Who funds the project?	**Total**	**Percentage**
Both Private & Public Sectors	10	56%
Public Sector	8	44%
Where do funds come from?	**Total**	**Percentage**
Government	9	50%
Individual funding	9	50%
EU	7	39%
Service Provider	5	28%
Who is responsible for service promotion (marketing)?	**Total**	**Percentage**
Public Organization	12	67%
Municipality	12	67%
Private Company	10	56%
Who sells the services?	**Total**	**Percentage**
Uncertain	8	44%
Services are free of charge	3	17%
Private Companies	3	17%
Who collects incomes?	**Total**	**Percentage**
Municipality	4	22%
Free-of-charge	4	22%
Various stakeholders	4	22%
Who manages the services?	**Total**	**Percentage**
Municipality	13	72%
Project organization	12	67%

The next four questions are related to funding. They reveal that usually either the public sector with 44% or the public and private sector together with 56% are responsible for the project's funding. Usually funds come from the government and/or individual funding with 50% in both cases and the European Union with 39% for the EU cities involved in this survey. Regarding services' marketing, it is being jointly performed by public organizations with the municipality and private companies in most cases. Regarding commercialization of services 44% were uncertain about the mechanism followed, while for 17% of the participants services are either free of charge or sold by private companies.

In respect to the income collection the respondents stated that the municipality is responsible for this procedure, that it is free-of-charge or that various stakeholders are involved in the procedure with 22% at each case.

In relation to the management of services, in 72% of the cases the municipality has this responsibility and in 67% of the cases the project organization (or in some cases both).

The next group of questions "Smart city management - critical issues/milestones", in Table 4, tries to identify the quality of the provided services based on the evaluations and the reviews that are conducted during the operation of the smart city. Initially, the respondents were questioned about the key person or organization (public or private) that had the initiative for the smart city. The municipality was responsible in 44% of the cases and in 28% of the cases a research team had this role.

Table 4: Smart city mgmt. - critical issues/milestones.

Who had the central initiative?	Total	Percentage
Municipality	8	44%
Research Team	5	28%
Who is responsible for the service monitoring?	**Total**	**Percentage**
Municipality	12	67%
Various stakeholders	5	28%
Project partners	4	22%
Do you perform evaluation & reviews and if yes how often?	**Total**	**Percentage**
Regular evaluations	**11**	**61%**
How often are the services/infrastructure undergo maintenance?	**Total**	**Percentage**
Uncertain	9	50%
Continually (more than once/year)	3	17%
Rarely (less than once/year)	3	17%
Annually	2	11%
Depends on project specifications	1	5%

Regarding the key actors in the service monitoring, answers include the municipality (67%), followed by "various stakeholders" (28%) and project partners (22%). It is quite promising that 61% of smart cities perform regular evaluations and reviews. Finally, the smart city managers' were asked to state the frequency with which the service or infrastructure maintenance is carried out. 50% of the respondents stated that they are not sure about the frequency of this procedure, while the remaining

50% stated that this procedure takes place continually, rarely, annually or depending on the project's specifications.

The final set of questions, namely "smart city management - project mission and objectives", attempts to specify the reasons that led to the development of the smart city and if the whole project was developed according to some specified standards, such as following business or project plans.

Table 5: Smart city mgmt. - project mission & objectives.

Potential business goals	**Total**	**Percentage**
Innovative spirit	6	33%
Resource savings	6	33%
Increase extroversion	4	22%
Internal organization structure	**Total**	**Percentage**
N/A	11	61%
SOE (State-Owned Enterprise)	5	28%
Individual organization	3	17%
Internal organization framework	**Total**	**Percentage**
Rules	10	56%
Guides	9	50%
What where your initially provided set of services?	**Total**	**Percentage**
Varies	8	44%
Intelligent Transportation	4	22%
Online dialogues	4	22%
Have you added services and which?	**Total**	**Percentage**
Too numerous to mention individually	3	17%
Have you canceled services and which?	**Total**	**Percentage**
Intelligent Transportation	1	6%

The existence of a well-constructed master/business plan determines to a significant degree the city's viability. Only 56% of the respondents stated that a master or business plan was followed, which is a quite small percentage for such an important procedure, whereas 44% did not follow a business plan. In the question "What are the potential business goals" the predominant responses (with 33% each one) were: innovative spirit, resource savings and various other goals (for instance increase city's extroversion etc.).

The Internal Organization Structure in most cases (61%) is not available. When available the internal organization framework is based on rules and guides.

A final set of questions was concerned with the initially provided set of services and the evolution (addition and cancellation) of the provided services.

3 FUNCTIONAL AND QUALITY REQUIREMENTS FOR SMART CITIES

In order to come up with the suitable architecture patterns for the smart city architecture we will first use the questionnaire results to understand the most important functional and quality requirements for smart cities. Then we will use these requirements to suggest an architectural approach for smart cities based on architectural patterns. Quality requirements can be defined using the ISO-25010 quality model (ISO/IEC, 2011), which provides the different quality categories that we need to consider.

The many different types of applications and services (Table 1 & Table 5) reveal the need for a generic application architecture, ensuring at the same time the communication between these applications in a seamless manner (if needed). Therefore ensuring ***interoperability*** among these different applications and services is necessary. Providing only a small percentage of security and health related applications (22% each), smart cities seem to have a relatively low need (at the moment) for safety-related hard real-time infrastructures and therefore *performance efficiency* sub-characteristic of *timing behavior* is less important.

Since there is no virtualization (17%), metropolitan backbone (6%) and rented backbone (0% in Table 1) it will be challenging to guarantee specific Quality of Service (QoS) levels. It seems again that *time* ***performance*** is not a predominant concern.

In Table 2 the local storage (44%) combined with the multitude of service performers (Table 3) shows that data may be stored in many different locations. Each application and the host organization is ultimately responsible for safeguarding its own data, but at the same time it should be possible that other applications are allowed to access this data remotely in prescribed ways. Therefore the ***authenticity*** aspect of ***security*** becomes important as well as the ***interoperability*** aspect of the ***compatibility*** characteristic.

Table 2 also shows that data access is complicated since many different parties may access data with many different ways. Again this shows that each application should be made responsible for providing its own ***authentication*** mechanism. Role-based access for ***authorization*** is needed for administrative staff. Also in Table 2, depending on the application and the organization responsible, data is owned by many different parties, something that again creates a need for ***interoperability*** and for the provision of some application dependent data access mechanism. There are a small percentage of cases (22%) that use encryption. So ***confidentiality*** may not be one of the prominent architectural drivers, but nevertheless it should be possible.

Table 3 reveals that there is a multitude of service performers. This fragmentation of responsibility strongly points to the need to create some ***interoperability*** layer between these services since in many cases the performance besides the Municipality is assigned to other parties. It also raises concerns for the ***reliability*** of the provided services as a whole. In general it may be more challenging to guarantee that all provided services are ***available*** all the time since the many different installations for isolated services will have different types of hardware/software infrastructure.

The marketing and commercialization of the services (Table 3) show that most of the smart cities projects at this time are not considered as income sources with only 17% reporting that private companies are responsible for services' commercialization and an apparent fragmentation regarding income collection. Therefore in order to become viable, they must be able to provide these services with relatively low cost. This creates some constraints for the smart city project (e.g. usage of open source software usually drops the cost at the expense of supportability). Also, there is split management between the Municipality and project organizations, which again demonstrates the need to provide ***interoperability***, different access mechanisms (***usability***) and different authorization mechanisms (***security***).

Although there are evaluations and reviews (Table 4), service maintenance is not performed regularly. This shows that there is a need for ***recoverability*** regarding the ***reliability*** quality property. Services should be able to recover rather gracefully and quickly in cases of failures.

The lack of business plan in many cases as well as the existence of a multitude of potential business goals (Table 5), imply that these projects can be considered at the time as an umbrella under which many different applications co-exist and can grow in many different directions in the future. This creates a need for improved ***maintainability*** in order to enable such developments. This need is also apparent when considering the diversity of the initially provided services (Table 5). The multitude of provided services also indicates that ***usability*** may be important, especially when considering the different types of user interfaces that may be required to support all these different types of applications.

Concluding this Section we can say that the most prominent quality drivers that we need to consider are in the order of importance: **1) Interoperability; 2) Usability; 3) Authentication and Authorization; 4) Availability; 5) Recoverability; 6) Maintainability; and 7) Confidentiality (should be possible).**

Free/Libre and Open Source Software (FLOSS) can and should be used, when possible, to drive down costs.

Of course the above mentioned ranking is a generic one. Specific applications may have different needs (e.g. an application may require increased confidentiality).

4 SELECTING ARCHITECTURAL PATTERNS FOR SMART CITIES

In this Section we identify suitable architectural patterns the combination of which provides a conceptual application architecture framework for smart cities considering the identified needs.

To follow a systematic approach, we apply the Pattern-Driven Architectural Partitioning (PDAP) proposed in (Harrison and Avgeriou, 2007) and depicted in Figure 1. PDAP is a stepwise iterative process that uses architectural patterns (Buschmann et al., 1996) with known quality outcomes. Usually in complex architectures, such as those for smart cities, more than one architectural pattern must be applied to satisfy the many and at times conflicting architectural drivers.

In this work we do not have a complete architecture to consider because specific functional requirements do not exist and the stakeholder concerns, as expressed in the questionnaire's answers, are generic and not particular for a specific application. What we discuss here is best described as a *conceptual application architecture framework* capturing the most prominent architectural drivers for smart cities' applications. This conceptual framework will be modified and transformed as necessary to address all specific functional and non-functional requirements for specific smart city projects. It is expected that in most cases the framework will cover the most significant requirements and will be suitable for most projects without or with small modifications. Notice in Figure 1 that we grayed out the tradeoff analysis which is based on the documentation and evaluation of a specific architecture. We cannot evaluate a conceptual framework because many aspects (e.g. specific technologies used), that have an impact in the evaluation of the architecture, are not finalized.

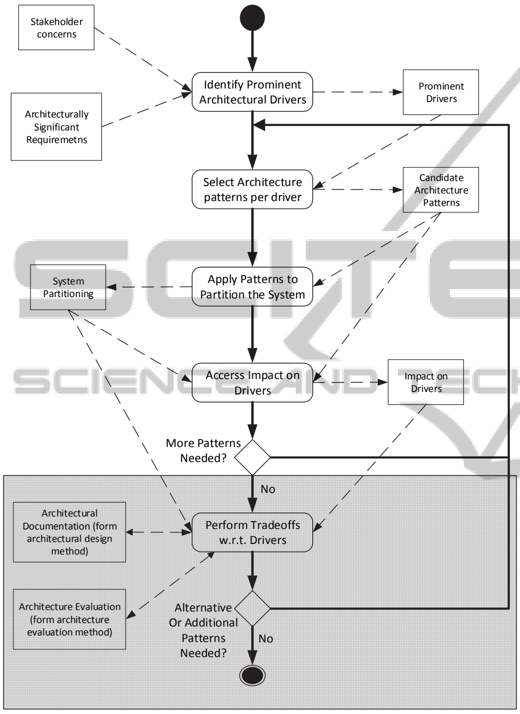

Figure 1: Pattern Driven Architectural Partitioning (Harisson and Avgeriou, 2007).

The first step of PDAP is the identification of prominent drivers, which was discussed in Section 3.

In the next step the architecture patterns for each driver are selected.

1. *Interoperability*: For the interoperability aspect we suggest an ***API Façade*** (Gamma et al., 1995.) for each application. Each application will expose through this façade a set of services. In order to enable the communication between different types of applications, possibly written in different programming languages, the provided façade will be WSDL-based using SOAP/XML for the interfaces. To enable this type of API we will use the ***Layers architectural pattern*** (Buschmann et al., 1996) for each application in which the Business Logic layer is separate and the WSDL interface can be built around this layer. Business layer includes various services public or private etc. depending on the specific smart city that the proposed model will be used.
2. *Usability*: The use of the ***Model-View Controller (MVC) pattern*** (Reenskaug et al., 1996), (Buschmann et al., 1996) is highly recommended in the User Interface layer to enable many different types of presentation approaches for the same data. This is considered necessary since the same information may be presented differently for different user types and for different types of devices.
3. *Authentication, Authorization & Confidentiality*: For these aspects the ***Layered*** architecture pattern is very suitable because it can provide authentication and authorization at designated layers in the software architecture. Additional services such as anonymity of information are application-specific and are left for the instantiation of the conceptual framework in specific smart cities.
4. *Availability and Recoverability*: In order to guarantee some availability in cases of failures and to integrate additional data from many possible databases that store data locally, we propose the use of an ***integrated application*** that communicates loosely with other smart city applications using the ***Messaging*** architecture pattern (Hohpe and Woolf, 2003). The integrated application will run in a reliable application server (e.g. in the Municipality or in a public cloud) and will collect data from all other applications using messaging. Messaging with Message Oriented Middleware (MOM) enables loose communication with many different styles (e.g. publish-subscribe pattern etc.) and many different QoS levels.
5. *Maintainability*: the ***Layered*** architectural style and the MOM-based communication both provide excellent maintainability.

The third step after selecting the appropriate architectural patterns is the application these patterns to partition the system. The result is the conceptual application architecture framework which is depicted in Figure 2.

In Figure 2 we display one application hosted in a host organization and also a second host organization is depicted but without the details which are analogous to the first one. In addition we depict a separate integration server which is executed in the municipality infrastructure or in any other reliable organization that can be considered the main organizer of the smart city project.

In the fourth step of the process we will assess if the proposed partition has the desired impact on the architectural drivers.

Interoperability is achieved by providing a Web Services (WSDL) interface at the Business Logic layer which runs in the application server.

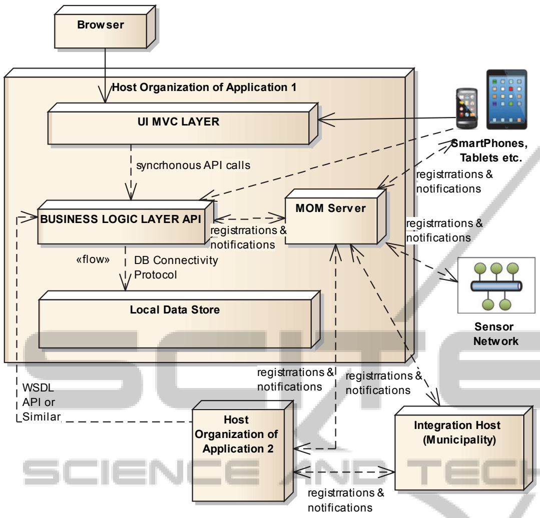

Figure 2: Conceptual Architectural Framework.

Usability is served by providing access to the application from possibly different channels including browsers and mobile devices.

Authentication, authorization and confidentiality (if desired) are all achieved thought the application's and web server's provided mechanisms, while at the same time various levels of security are supported with ease.

Availability and recoverability are enhanced by using the smart city integration host which uses the messaging pattern to gather data from the different applications. The integration platform can be used as a failover platform when an application in a host server becomes unavailable. Furthermore it can provide features such as data collection and archiving, data aggregation, statistical analysis etc.

Maintainability for a single application is achieved from the layered architectural style which excels in this aspect. Maintainability is also served with the use of messaging since it enables the various applications that exist in the smart city to evolve gracefully without compromising their clients as well as the integrated application.

5 RELATED WORK

There are some works in relation to the architecture of smart cities. In (Da Silva et al., 2013) the authors refer to the need for a distributed and integrated architecture and relate this need with numerous nodes where each one has the obligation to produce and provide data to a central location. This architecture leads to the Internet of Things, which is the necessary infrastructure for "smart" cities. The authors conclude that a reference architecture that contains all the functionality aspects of a "smart" city has not been proposed yet, so they proceed to analyze existing architectures from the literature for extracting the minimum necessary requirements that a "smart" city should satisfy. We provide in this article a conceptual architecture framework as a first step towards a more detailed reference architecture. Our proposed framework however concerns only the application layer of the smart city and also provides suggestions for the business aspects.

In (Hernández-Muñoz et al., 2011) the authors mention that smart cities '*at a holistic level are systems of systems*' and that '*a unified ICT platform should be built on top of a unified model so that data and information could be shared among different applications and services at global urban levels*'. Our approach, in which several applications provide information to a federated integrated application at the municipality center, reflects also this multi-systemic reality. The authors also emphasize the need for interoperability. Indeed this reflects our own findings too. In our work, the Ubiquitous Sensor Network (USN) described in (Hernández-Muñoz et al., 2011) could be the sensor network represented in Figure 2. Sensor networks and other infrastructure are considered to belong in the physical layer of the proposed architecture

In (Anthopoulos and Fitsilis, 2014) the authors report, based on the literature, a number of architectures for smart cities, which follow the layered architecture. Here, we follow a similar approach, but we propose that each application is not only layered but also provides a messaging interface (e.g. a Publish-Subscribe messaging). So it is possible to loosely get data that will be presented/integrated/analyzed etc. in other applications, increasing in that way the availability, and providing at the same time improved fault tolerance and maintainability. Cities that follow the layered architectural style are reported in (Al-Hader and Rodzi, 2009), (Anthopoulos and Tsoukalas, 2006), (City Council of Barcelona, 2014) and elsewhere. In our approach we provide a justification in the form of quality attributes served using the layered approach rather than concentrating on specific types of services that may differ from city to city.

6 CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

In this work we presented the results of a survey related to architectural aspects of smart cities. The sample and the investigating process can be considered sufficient for conclusion extraction, due to geographic distribution and sample’s homogeneity, accompanied by the expertise of the participants. A limitation concerns the absence of Asian experiences, which authors aim to cover in their future research. However, it is estimated, due to the variance and size of the involved cases, that there will be small divergence from the existing outcomes, but this speculation has to be confirmed. Using the survey’s results we identified important quality properties for a smart city architecture. Additionally, we used the Pattern Driven Architectural Partitioning (PDAP) method to select appropriate architectural patterns and provide a conceptual application architecture framework. This framework will need to be tested, evaluated and complemented on each specific city case, but it provides a good starting point to take into account when launching such a project.

Concerning the business aspects we suggest the use of a supporting IT organization and also the use of Free/Libre Open Source Software to drop the costs where feasible.

In the future we aim to create partnerships with real smart cities interested in applying the proposed framework and use the findings of real projects to adjust the conceptual application architecture framework proposed in this work.

ACKNOWLEDGEMENTS

This research has been co-financed by the European Union (European Social Fund - ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: ARCHIMEDES III. Investing in knowledge society through the European Social Fund.

REFERENCES

Al-Hader, M., Rodzi A., 2009. The Smart City Infrastructure Development & Monitoring, Theoretical & Empirical Researches in Urban Management, no. 2(11).

Anthopoulos, L., Tsoukalas I. A., 2006. The implementation model of a Digital City. The case study of the first Digital City in Greece: e-Trikala. Journal of e-Government, Vol.2, Issue 2.

Anthopoulos, L., Fitsilis P., 2013. Using Classification and Roadmapping Techniques for smart city viability's realization. Electronic Journal of e-Government, 11(1), pp. 326-336.

Anthopoulos, L., Fitsilis, P., 2014. Exploring Architectural and Organizational Features in Smart Cities. In proc. of the 16th International Conference on Advanced Communications Technology, IEEE.

Buschmann, F., Meunier, R., Rohnert, H., Sommerlad, P., Stal, M., 1996. Pattern-oriented Software Architecture: A System of Patterns. Wiley.

City Council of Barcelona, January 2014. Barcelona Smart City (http://www.majorcities.eu/workshops/2012-helsinki/helsinki2012_barcelona.pdf)

Da Silva, W.M., Alvaro, A., Tomas, G.H.R.P., Afonso, R.A., Dias, K.L., Garcia, V.C., 2013. Smart cities software architectures: a survey. In proc. of the 28th Annual ACM Symposium on Applied Computing, 1722–1722.

European smart cities project, Smart cities Ranking of European medium-sized cities, October 2007 (http://www.smart-cities.eu/download/smart_cities_final_report.pdf)

Gamma, E., Helm, R., Johnson, R., Vlissides, J., 1995. Design Patterns: Elements of Reusable Object-oriented Software. Addison-Wesley.

Harrison, N., Avgeriou, P., 2007. Pattern-Driven Architectural Partitioning: Balancing Functional and Non-functional Requirements. In proc. of the 2nd International Conference on Digital Telecommunications, ICDT ’07, IEEE.

Hernández-Muñoz, J.M., Vercher, J.B., Muñoz, L., Galache, J.A., Presser, M., Gómez, L.A.H. and Pettersson, J., 2011. Smart cities at the forefront of the future internet. (Jan. 2011), 447–462.

Hohpe, G., Woolf, B., 2003. Enterprise integration patterns: designing, building, and deploying messaging solutions. Addison-Wesley.

ISO/IEC, 2011. ISO/IEC 25010: Systems and software engineering - Systems and software Quality Requirements and Evaluation (SQuaRE) — System and software quality models

Lankhorst M., 2009. “Enterprise Architecture at Work: Modelling, Communication and Analysis”, 2nd ed., Springer-Verlag.

Reenskaug, T., Wold, P., Lehne O.A., 1996. Working with objects: the OOram software engineering method. Manning.