From Digital to Ubiquitous Cities: Defining a Common Architecture for Urban Development

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Abstract - Digital cities have been evolved from web applications and knowledge bases to smart urban environments. This evolution has mainly been based on broadband metro-networks and complex information systems, and it suggests the form of the future city that is called wireless/smart/digital or ubiquitous city. Although common practices are being developed all over the world, different priorities are defined and different architectures are followed. In this paper we summarize on the applied architectures of multiple city case studies, we use the experiences of the digital city of Trikala, Greece, and we conclude to a common Enterprise Architecture for digital city cases. This common architecture identifies the blue prints for urban information based development. Moreover, this paper presents a common architecture for service delivery in urban spaces.

Keywords-component; formatting; style; styling; insert (key words)

I. INTRODUCTION

All digital cities face common challenges: the improvement of habitants’ everyday life; the development of knowledge based communities; the simplification of both public and private service delivery in town areas etc. Digital cities initially became online with the America-On-Line cities [1], which offered public information in common forms. Later the Kyoto’s case [2], [3] simulated a city in a virtual form, and it was available to a citizen or a visitor. The above online forms soon evolved to knowledge bases and applications that faced local needs such as the Copenhagen base [4]. Wireless networks and fiber optics gave cities the opportunities to install complex information systems accessible by households and enterprises. Some cities utilized this opportunity and developed networks exchanging information and interconnecting their civilians. These infrastructures are now combined with pervasive computing able to deliver services from anywhere to everyone, suggesting the ubiquitous city (or u-city). New Sondgo [5] and Osaka [6] are the first u-city cases, where Information and Communication Technologies (ICT) are applied during urban development rather just being applied in the city, suggesting that future urban planning will possibly set ICT as an axe of precedence.

The variety of cases gave multiple definitions to the digital city, which can be aggregated to the following: digital environments collecting official and unofficial information from local communities [1] and delivering it to the public via web portals are called information cities [7], [8]; networks of organizations, social groups and enterprises located in a city area are called digital cities. The evolution to municipal ICT environments -based on metropolitan networks such as metro-Wi-Fi- composed a recent digital city definition [9]: city-area infrastructures and applications aiming to cover local needs and support local community’s everyday life. This definition evolved to the ubiquitous city or U-city [5], [10], [11]: a city or region with ubiquitous information technology.

All these different cases provided useful information concerning the successes and the failures of metropolitan ICT projects. Different architectures were designed to face common challenges. In this paper we summarize on an extensive number of digital city cases, which proves the wide range of digital city models. We present their missions, their architectures and their progress, in order to conclude on common standards and on a common architecture. The common standards are used to extend the “Collaborative Enterprise Architecture” [12] to the “Digital City Enterprise Architecture”, which consists of the blue prints for future developments. This common architecture follows Service-Oriented-Architecture (SOA), and it combines the experiences of current initiatives and the challenges of the u-city.

II. THE HISTORY OF THE DIGITAL CITIES

Multiple terminologies and definitions have been used to describe metropolitan ICT cases: virtual and smart cities, broadband metropolis, knowledge bases, wireless and mobile, digital and ubiquitous are only some of them. For the purposes of this paper we will use digital city as a common term.

Since early 90s different digital cities were implemented all over the world (Table I). The first case was the America-On-Line cities [1], where web environments simulated a city via grouping services according to civilian logic. The digital city of Kyoto (Japan) [2], [3] and the digital city of Amsterdam [13] were 3D web applications, which simulated the city and its local life (streets, enterprises, malls etc.). These web approaches were evolved to virtual reality (VR) environments [14] operating beyond the physical borders of a city.

A unique case that utilized ICT for social purposes was the Copenhagen Base [4]. It was a public database containing useful information concerning local community and resources. Moreover, the Craigmillar City of Scotland [4] used the ICT as
collaborating tools to structure groups of citizens and to offer social services to the local community.

The “Smart City” [15] refers to a city where the ICT strengthen the freedom of speech and the accessibility to public information and to public services. The Smart City approach was initially applied in the case of Brisbane (Australia) and supported the social participation and the close of the digital divide. The Smart City notion has been evolved to an urban space for business opportunities. This approach has created a network of cities (www.smartcity.ae), which offers infrastructures supporting knowledge society and business growth. Today, this network consists of the cities of Malta, Dubai and Kochi (India), where the ICT is used for the development of landscapes with opportunities to business growth and knowledge exchange. The Smart City is fully applicable in Dubai, where it is analyzed into the “media city” (www.dubaimediacity.com) and the “internet city” (www.dubaienternetcity.com) where broadband and media infrastructures offer cost effective platforms to the enterprises.

The cases of Hull (UK, www.hullcc.gov.uk) and of Beijing (China) [7] used fiber optic backbones installed in the city, which were called “Metropolitan Area Networks (MAN)”. MAN offered broadband access to public information and services from local agencies, aiming in simplifying everyday life. However, Beijing digital city was implemented for the purposes of the Olympic Games of 2008, and initially offered relating information and services. MAN was used in the case of the “Digital Metropolis” of Antwerp [4], the first digital city in Belgium. The Antwerp city was interconnected with the City of Amsterdam, in order to share information and services. Geneva [4] on the other hand, used its MAN to interconnect the foreign enterprises that were located in the area. It then offered the MAN for public use, and constructed a digital market for all local businesses.

“Broadband metropolis” was introduced in Seoul [16] and contains dense fiber optic networks interconnecting public agencies, citizens and enterprises in the city. Last mile connection to a MAN backbone is established with fiber channels (Fiber-to-the-Home, FTTH). Broadband metropolis comprises an area of healthy competition among telecommunication vendors, while it is attractive for further private investments.

“Mobile cities” such as the New York [17], installed wireless broadband networks in the city, which offered free-of-charge access and various services. These cities are also called “Wireless Cities”, while their wireless broadband networks are called “metro-Wi-Fi” or “Muni-Wi-Fi”. Many wireless cities have been developed all over the world, such as the ones of www.wirelesscities.org and www.muniwireless.com, but most of them re-consider their business models [18].

The Eurocities (http://www.eurocities.org) is a European network of cities, which focus on the development of an inclusive, prosperous and sustainable ICT environment operating in the city. The participating cities exchange their experiences and they cooperate in the development of an open market and in the treatment of corruption in municipal agencies. The final product of the Eurocities initiative is the development of prototype digital city, covering local needs in Europe.

The World Foundation of Smart Communities (http://www.smartcommunities.org) is a nonprofit educational organization studying the development of Smart Communities; meaning cities with broadband networks interconnecting their local resources with resources from other geographic areas. Their aim is the improvement of living and working.

The Communities of the Future (http://www.communitiesoffuture.org) is a nonprofit organization defining the digital city as a Knowledge Democracy. This approach concerns the development of societies, where the novel privileges (privilege to access public information and services), risks (privacy and security) and challenges (social participation) based on the ICT, are analyzed and participation is encouraged. The Knowledge Democracy approach was applied in Blacksbourg (Australia) implementing the Blacksbourg Electronic Village (http://www.bev.net).

The knowledge based cities [19] is a digital city approach, where the ICT support local democracy and local economy. This approach was applied in Portugal and uses broadband networks developed by telecommunication vendors connecting cities and local economies. Virtual organizations are structured in this network of cities, such as virtual organization for the municipalities, for the enterprises, for the citizens with common interests etc. The interconnected cities structure a regional virtual environment, where cities support each other’s progress via the ICT.

The digital geography [20] extends city physical boundaries and structures teams of interconnected citizens who share knowledge of common interest. The digital geography uses the Internet and the mobile networks to compose digital communities, and it emphasizes on the development of Digital States in the same country.

Trikala (central Greece) [9] extended the above cases and older ones [21] suggesting an ICT-based environment whose priorities concern a) the availability of digital means that support local needs and transactions, b) the transformation of the local community to a local information society, and c) the information collection to support sustainable development of the local community.

Broadband cost minimization and the simplification of IS installation and maintenance resulted in further digital city cases. Moreover, the “cloud services” and the “ubiquitous computing” solutions result to the Ubiquitous City (or U-city). The U-city architecture is being implemented in South Korea (e.g. New Songdo) and Japan (e.g. Osaka) and delivers information anytime, anywhere to anybody, via interconnected information systems and ubiquitous ICT solutions over the city.
TABLE I.  

<table>
<thead>
<tr>
<th>Case/City</th>
<th>Digital City</th>
<th>Short Description</th>
</tr>
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<tbody>
<tr>
<td>America On Line (AOL)</td>
<td>Digital City of AOL Cities</td>
<td>Virtual groups exchanging knowledge over the Internet.</td>
</tr>
<tr>
<td>Kyoto</td>
<td>Digital City of Kyoto</td>
<td>web and VR based simulation</td>
</tr>
<tr>
<td>Amsterdam</td>
<td>Digital City of Amsterdam</td>
<td>- web and VR based simulation. - MAN and interconnection with Antwerp</td>
</tr>
<tr>
<td>Copenhagen</td>
<td>Copenhagen Base</td>
<td>Public database covering local needs.</td>
</tr>
<tr>
<td>Craigmillar</td>
<td>Digital City of Craigmillar</td>
<td>Groups of citizens sharing knowledge and social services</td>
</tr>
<tr>
<td>Brisbane</td>
<td>Smart City of Brisbane</td>
<td>- Decision making services. - Virtual groups</td>
</tr>
<tr>
<td>Malta, Dubai, Kochi</td>
<td>Smart City</td>
<td>- Attractive areas for business growth</td>
</tr>
<tr>
<td>Hull</td>
<td>Digital City of Hull</td>
<td>- MAN and portals offering local information and services.</td>
</tr>
<tr>
<td>Beijing</td>
<td>Digital City of Beijing</td>
<td>- MAN and metro-WiFi - Services oriented to the Olympic Games.</td>
</tr>
<tr>
<td>Antwerp</td>
<td>Digital City of Antwerp</td>
<td>- MAN and interconnection with Amsterdam - eDemocracy services</td>
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<tr>
<td>Geneva</td>
<td>Geneva-MAN</td>
<td>- MAN - Interconnected market</td>
</tr>
<tr>
<td>Seoul</td>
<td>Broadband Metropolis</td>
<td>- Dense Fiber optic network across the city.</td>
</tr>
<tr>
<td>New York</td>
<td>Mobile City of New York</td>
<td>Wireless broadband network covering the city area.</td>
</tr>
<tr>
<td>European city network</td>
<td>Eurocities</td>
<td>Research on: - Social Participation - Local community evolution - Sustainable development</td>
</tr>
<tr>
<td>Smart Communities</td>
<td>Interconnected cities</td>
<td>Cities interconnected with broadband networks.</td>
</tr>
<tr>
<td>Blacksburg</td>
<td>Knowledge Democracy</td>
<td>Knowledge based environment</td>
</tr>
<tr>
<td>Portugal cities</td>
<td>Knowledge Based Cities</td>
<td>- interconnected cities - Groups sharing knowledge</td>
</tr>
<tr>
<td>Digital Geographies</td>
<td>Digital City of Trikala</td>
<td>- various IS - Multi-tier architecture - Global e-Government - trusted third party for local transactions</td>
</tr>
<tr>
<td>Trikala</td>
<td>U-city of New Sondgo</td>
<td>Ubiquitous computing in the city</td>
</tr>
<tr>
<td>New Sondgo</td>
<td>U-city of Osaka</td>
<td>Ubiquitous information systems in city area</td>
</tr>
<tr>
<td>Osaka</td>
<td></td>
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</tbody>
</table>

III. COMMON ENTERPRISE ARCHITECTURE

The variety of the examined cases shows that cities around the world face common challenges (Table II) and they utilize technology in multiple ways. The improvement of citizen everyday life in the city for instance can mean the simplification of citizen transportation, the access to city resources (libraries and public buildings, malls, networks etc.) or the opportunities for the employment and local growth. It can also mean the existence of online portals offering accurate and updating data concerning the city life, and the availability of location based services across the city. By this point of view, the mission statements cannot define the scope of a digital city case. Additionally, political leadership and mayors cannot determine how the ICT can deal with local needs and with their political vision concerning the digital city. Moreover, the implementation of various digital cities has given many outcomes concerning the significance of these projects: a lot of argument concerning whether initiatives -such as the Wireless Cities- [18] triggered by municipalities and city councils can sustain and really deal with some challenges, such as local capital growth and the close of the digital divide.

A digital city project is complex and concerns a global range of the activities in a city. It can be considered as a major novel service or as a different virtual city operating in parallel to the physical one. The definition of a common Enterprise Architecture (EA) for a digital city can support the success of project and the achievement of its political vision.

TABLE II.  

<table>
<thead>
<tr>
<th>Challenges</th>
<th>Case</th>
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<tbody>
<tr>
<td>Knowledge sharing and exchange</td>
<td>- America On Line Cities - Digital City Craigmillar - Smart City of Brisbane - Knowledge based cities - Digital Geographies - Knowledge Democracy</td>
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<tr>
<td>City life simulation</td>
<td>Kyoto and Amsterdam</td>
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<tr>
<td>Common local information storage</td>
<td>Copenhagen base</td>
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<tr>
<td>Areas attractive to business</td>
<td>- Smart Cities - Geneva - Trikala</td>
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<tr>
<td>Local growth due to broadband access</td>
<td>- Mobile/Wireless cities - Seoul</td>
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<tr>
<td>e-Democracy and participation, e-Government services</td>
<td>- Smart City of Brisbane - Hull - Antwerp - Beijing - Trikala</td>
</tr>
<tr>
<td>Interconnected cities</td>
<td>- Eurocities - Knowledge based cities</td>
</tr>
<tr>
<td>Ubiquitous information systems</td>
<td>- New Sondgo - Osaka</td>
</tr>
<tr>
<td>Improvement of citizen everyday life</td>
<td>-Beijing -Trikala - New Sondgo - Osaka</td>
</tr>
<tr>
<td>Close of digital divide</td>
<td>- Mobile/wireless cities</td>
</tr>
</tbody>
</table>
According to [22] “Enterprise Architecture (EA) is a strategic information asset base, which defines the mission, the information necessary to perform the mission and the technologies necessary to perform the mission, and the transitional processes for implementing new technologies in response to the changing mission needs.”. EA is accompanied with a specific framework [23] containing the proper procedures, that each public Agency has to follow in order to implement the EA. In [12] the notion of the Collaborative Enterprise Architecture (CEA) was introduced as “an information plan, where the strategic e-Government mission and the information needed for mission’s performance are defined with the contribution of representatives of all the target groups and they meet end-users’ needs. The enterprise lifecycle is executed with the collaboration of the working group, the involved social parties and experts invited from the private and from the academic sectors. The evaluation of the architecture’s progress is based on end-user satisfaction and acceptance.”

CEA was inspired by the US Federal Enterprise Architecture (FEA) [23], it was applied and tested in the Digital City of Trikala case and it consists of the following architecture layers:

a) The organization architecture, dealing with organization’s physiognomy and vision, and national EA. In a digital city case the organization is the leader organization (e.g. the municipality, the city council, a new organization managing the project etc.).

b) The collaborating architecture that refers to the cooperating schema of the involved participants.

c) The technical architecture, which contains the technical standards.

d) The data architecture describing physical storages, data structure, semantics, copyright and securing options.

e) The accessibility architecture that describes the efficiency of the architecture.

Trikala cannot be considered a successful case [24], since six years after its initiation habitants are not aware nor do they use the digital city services. Additionally, the expensive (more than €5 millions) infrastructure costs a lot for maintenance and management, while the only vendor of the project is still the municipality. Moreover, the project has not supported the close of the digital divide, although public points of access and free-of-charge Muni-Wi-Fi exist.

On the other hand, the international practice shows that the evolution of the digital city is based on: 1) the installation of new urban spaces in the city that contain ubiquitous computing, able mainly to host enterprises who wish to invest in the area.

2) Wireless cities, Muni-Wi-Fi and other Municipal initiatives deliver a ubiquitous environment in existing urban spaces; however their business models have to be redesigned in order to sustain. The redesigning of the business model is beyond the purposes of this paper.

3) The extension of a digital city is an ongoing process, it is necessary and it demands a strategic vendor as a partner, because the ICT evolution leads to depreciation of digital city infrastructure – more of which cannot easily be re-installed (e.g. metropolitan networks). This point of view has to be considered in ubiquitous city cases too, since pervasive computing infrastructures (e.g. “smart floors” and “smart buildings”) cannot be re-installed easily either.
Democracy projects have to consider “how can social networks interchange with digital city decision making systems?”. h) Finally, the administrative perspective deals with the proper management of the project, with the continuous assessment of the installed platforms and applications that have to cancel or keep on their operation.

The resulted architecture uses both collaborative and sustainable options, which can support the maintenance of a digital city project. The extension of the CEA can be called “Digital City Enterprise Architecture” and it has been applied to some of the common challenges of (Table II) in the case of Trikala Greece.

IV. COMMON DIGITAL CITY ARCHITECTURE

In the previous section we presented the blue prints that a digital city has to follow for the proper implementation and for its sustainability. However, the project can consist of an unlimited number of sub-projects, which deliver multiple applications and services to the urban area. In Trikala case for instance, a number of fifteen sub-projects have almost been implemented, while technology and user needs are keeping on updating.

Both logical and physical architectures of the digital city have to align to the proposed Enterprise Architecture, while they have to secure the effective administration and maintenance of the project deliverables. In [24] an n-tier, modular architecture was proposed for the digital cities, which can achieve in sustainability and continuous evolution of the project. The logical architecture contains the following layers (Table III):

- **Stakeholders layer**, describes the potential user groups of the digital city services: end-users (citizens, businesses, students), groups of end-users (local chamber, teams with common interests), servants who offer public and commercial services via the digital city (civil servants, public agencies, enterprises).

- **Service layer** contains software applications that deliver public information and services to citizens and enterprises (e-Government and e-Commerce portals, social (e.g. tele-care) services, geospatial services etc.). This layer has to interact with the previous layer via a unique interface collecting all available services from digital city, avoiding information replication.

- **Business layer** defines the policies, the operating rules and the Enterprise Architecture of the Digital City. Moreover, this layer defines the “WHOs and HOWs” for each transaction delivered via the Digital City.

- **Infrastructure layer** includes the local broadband networks (MAN and a metro Wi-Fi), an intelligent transport system, phone centre for public calls, and public access points in the city hall and in other public buildings.

The information layer refers to information and data that is produced and stored in the infrastructure layer, together with the necessary repositories for information storage.

The proposed physical architecture is inspired from [9] and by [24], it is presented in (Figure 2) and it covers the requirements of ubiquitous cities: the infrastructure layer for instance contains a metro-Wi-Fi network, together with a MAN in case that it approaches households and enterprises with FTTH technologies, and with an information system offering location based services. The information layer could have mobile or social network storages accessible via cell phones and portable devices, while the service layer could offer location based services to users with portable devices. The business layer vertically transacts with all other layers, applying its rules and blueprints to all unique applications and systems.

![Figure 2. Digital city physical architecture](attachment:image)

The architecture presented above follows Service Oriented Architecture (SOA). According to [25] “SOA is an architectural style and formally separates services, which are the functionality that a system can provide, from service consumers, which are systems that need that functionality. This separation is accomplished by a mechanism called service
contract, coupled with a mechanism for providers to publish contracts and consumers to locate contracts that provide the service that they desire”. Usually SOA is based on a service registry installed by the organization that offers the services, where all available services are stored and presented. In the case of a digital city, probably the organization is the municipality, who connects all other organizations with the digital city infrastructures. The digital city services will be offered either via a central information system [26], either via distributed systems located in various local organizations. SOA simplifies these probabilities, since service location is not necessary, while on the other hand it establishes interoperability amongst multiple legacy systems.

V. CONCLUSIONS

This paper examined the history of digital cities in order to conclude on common challenges and standards that different technologies followed. Important issues that deal with future digital cities concern their sustainability and continuous evolution. The objectives of this paper were to summarize on common enterprise architecture, and on common logical and physical architectures, that could manage existing and future ubiquitous cities and that could achieve in some of their major challenges.

Future research will focus on the transaction of these architectures with social networks, either existing or others installed in city areas. Moreover, we will approach measurement methods to investigate the impact of ubiquitous technologies on habitants’ everyday life.

REFERENCES


