Smart Cities and the Future Internet: Innovation ecosystems of embedded spatial intelligence

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Intelligent or smart cities rely on collaboration networks among human communities, innovation ecosystems, and digital infrastructure, applications and e-services, which enable the urban challenges of competitiveness, sustainability and inclusion to be addressed more efficiently. This urban paradigm is characterized by continuous transformation, fuelled by evolutions in innovation ecosystems, broadband networks and web technologies. This paper explores changes which are currently being introduced by future Internet research and outlines how cities and regions are affected by emerging Internet technologies, smart environments, and the resulting changes to innovation ecosystems. The paper is based on a corpus of foresight exercises, roadmaps to future Internet technologies and FIRE experimental facilities, OECD and governmental reports on the future of the Internet economy and surveys on hype cycles for smart city technologies. The first section is a short introduction to intelligent city concepts and looks at the turn towards future Internet technologies. Sections two and three are about the drivers of embedded spatial intelligence of cities guided by the rise of sensor networks and solutions embedded into the physical space of cities. The next four sections discuss the technological context of the future Internet and the expected impact of the Internet-of-Things, sensors, tags and RFID, semantic web, and cloud computing on smart cities. The final section is concerned with the new innovation ecosystems emerging from embedded spatial intelligence where citizen empowerment meets with smart environments.

Keywords: Embedded spatial intelligence; future Internet; innovation governance; intelligent cities; smart cities.

1. Introduction

New Internet technologies, the Internet-of-Things (IoT), networks of sensors and smart devices, embedded systems, the semantic web, the Internet of users and people, cloud computing, in two words the 'Future Internet', marks a technological turn that introduces a new type of spatial intelligence of cities, namely an embedded spatial intelligence. This form of intelligence is advancing the information and knowledge capabilities of communities which were created by web 2.0 applications, social media, and crowdsourcing platforms, and opens a new cycle of innovation and e-services in cities.

The concept of spatial intelligence of cities refers to the ability of a community to use its intellectual capital, innovation institutions, physical space and smart infrastructure to create intelligent environments that more efficiently address the challenges of competitiveness, sustainability, and inclusion [1], [2]. This concept allows the terms of 'intelligent city' and 'smart city' to be unified into a common field of research focusing on the underlying cognitive processes and combined deployment of ICTs, institutional settings for innovation, and physical infrastructure, which taken altogether increase the problem-solving capability of communities and cities.

Collective intelligence and social media have been major drivers of the spatial intelligence of cities. They offered the appropriate technology layer for organizing the involvement of citizens and end-users in the creation and use of information with crowdsourcing platforms, mush-ups, web-collaboration, and other means of online participation. Now, the turn towards new Internet technologies, smart environments and embedded systems offers a new type of spatial intelligence of cities; an embedded spatial intelligence, based on sensors, augmented reality, real-time information and gigabit data generated by the functioning of cities. Embedded spatial intelligence has a direct impact on location-based services that cities offer to citizens and on the optimization of urban networks. It bring us closer to the way in which William Mitchell has described the intelligence of cities as the effective combination of digital telecommunication networks, ubiquitously embedded intelligence, and software for knowledge and cognitive competence [3]. Future Internet technologies with instrumentation and interconnection of mobile devices and sensors can collect and analyze urban data in real time, improve the ability to forecast and manage urban flows, and thus push city intelligence forward. In this context, new research questions have arisen concerning (a) the technology drivers of embedded spatial intelligence, (b) the new e-services that can be created in cities, and (c) the governance of innovation ecosystems within smart environments embedded in the urban space.

The paper discusses these questions while outlining the impact of future Internet technologies on smart cities. It is based on a combination of literature about future Internet research, cases studies on smart city projects and experimental facilities in smart cities, foresight exercises about the rise of future Internet technologies and smart city technologies, and trends about the future of cities. The reference corpus that we have taken into account includes a variety of sources and documents:

- EU FP7 research on future Internet technologies, future media Internet, future media networks, and Future Internet experimental facilities; research on smart cities in the context of the Competitiveness and Innovation Programme and the Strategic Energy Technology Plan.
- OECD reports and governmental papers on the future of the Internet economy outlining strategic policy directions.
- Large corporate research programmes and platforms in the field of intelligent and smart cities and white papers by large consulting groups on smart city solutions.
- Gartner's Hype Cycles on emerging technologies and smart city technologies, which illustrate societal expectations and innovation cycles of technologies.
- Foresight exercises about the future of cities presented by academic institutions, the Institute for the Future and related academic literature.

This corpus helps us describe how smart / intelligent cities are changing with the rise of new Internet technologies and how the internal mechanisms of information, innovation and knowledge-creation within smart cities are affected by embedded systems, cloud-based solutions, and smart-object centered services.

2. Drivers for embedded spatial intelligence of cities

The paradigm of intelligent cities appeared at the turn of the 21st century as a fundamental component of the global knowledge economy and model for organizing people-driven innovation ecosystems and city-based global innovation hubs. By injecting information technologies and innovation capabilities into the ecosystems of cities, they become more open, innovative, efficient, and manageable. City infrastructure and utilities benefit from the deployment of broadband networks because of lowered operating costs, real-time alert and response, and better prediction capability. The entire urban system of products, services,

and infrastructure becomes more sensitive to changing demand and needs, by adopting more intelligent ways of operation and via rapid adaptation to changing external conditions.
Since 2009, within this paradigm of urban development and planning, smart environments, embedded devices, and real-world user interfaces have attracted significant attention following a wider uptake of embedded technologies and future Internet solutions. Emerging information and communication technologies, high speed broadband networks, cloud computing and mobile smart devices have become enablers of sustainable urban development and new e-services in areas such as transport, environment, business, and government. Large companies in the ICT sector, such as IBM, Cisco, Microsoft, and Accenture are involved to a considerable degree in and are contributing to shaping the smart city agenda. EU research in the context of the FP7 and CIP is also stimulating a wider uptake of innovative ICT-based services for smart cities, linking smart city solutions with user-driven innovation and future Internet infrastructure. Quite new fields of research and experimentation have opened up, redefining the way innovation ecosystems and smart environments are combined to address urban challenges.

A major milestone in this turn towards an embedded intelligence of cities has been the IBM initiative '*Smarter Planet - Smarter Cities'* (SP-SC) launched in 2009 [4]. Proposed as central strategy for a sustainable future, this initiative was intended to stimulate economic growth and quality of life in cities and metropolitan areas with the activation of new technology systems and infrastructure. The SP-SC initiative sees the city as an agglomeration of ecosystems (a system of systems) and as a platform, which - more than states, provinces or even nations - can make 21st century life more productive, efficient and vibrant. The model for making cities more efficient and sustainable was described as a combination of connectivity, instrumentation, and intelligence.

- Connectivity offers communication capability among a sea of networked things, buildings, cars, roadways, pipelines, appliances, infrastructure, and people.
- Instrumentation offers real-time information from all city sub-systems captured by meters and embedded devices.
- Intelligence comes from algorithms, analytics and visualization that turn data into informed decisions and actions.

In 2009 CISCO also launched the global '*Intelligent Urbanization'* initiative from the city of Bangalore, India, and signed a MoU with the local government authority to develop a roadmap for an intelligent and sustainable Bangalore. '*Intelligent Urbanization'* was designed to help cities around the world, by using broadband networks as a utility for integrated city management, better quality of life for citizens, and economic development. Bringing together a broad portfolio of products, services, partners and solutions across CISCO, the initiative was initially focused on intelligent, sustainable solutions for public safety and security, transportation, buildings, energy, healthcare and education. As an example of how technology can be used to improve security operations, CISCO described its own internal Security Operations Centre with real-time security monitoring and alert, video surveillance tools, acoustic sensors, card-readers with biometric recognition, automatic alerts and security activation systems. Later, the company moved to the '*Smart Connected Communities*' initiative to help communities transform themselves and realize sustainable economic growth, resource management and enhanced quality of life. The broadband network was seen as a 'fourth utility' and as a platform to connect everything. Areas of implementation were transportation, utilities, real estate, safety and security, and government. Recently, CISCO endorsed the IDC concept of '*Intelligent X'* as a technology ecosystem which integrates smart devices (involving M2M and telemetry capabilities), high-speed ubiquitous communications networks, and intelligent software and services that can process, consolidate and analyze data in order to support industry-specific business processes. At the core of '*Intelligent X'* solutions lie three key enablers: (a) increased computational power available through high-performance chipsets and hardware and high-performance networks, (b) improved maturity in business intelligence and analytics, and (c) the introduction of new delivery models based on cloud computing [5].

ACCENTURE, a global management consulting and technology services provider, presented a similar smart city concept focusing on city infrastructure and utilities. The company argued that rapid urbanization and rising population place enormous pressures on ageing city infrastructure for gas and electricity, water supply, waste management, and transportation. In parallel, the mobility of populations and businesses, as the world is now more open, requires that cities remain globally attractive. Cities increasingly compete in four different arenas: (a) for businesses that generate wealth, (b) for public and private investments, (c) for residents - mainly well-educated, entrepreneurial people, and (d) for visitors. Intelligent infrastructure is the technological response to these challenges: "The intelligent infrastructure is both analogue and digital. That is, in addition to the physical infrastructure - roads, buildings, rail, power and utility grids - an information and communications technology infrastructure serves as the basis for most of the monitoring and optimization capabilities of an Intelligent City, and for the interaction between citizens and service providers" [6]. For ACCENTURE, the most important enabler for Intelligent Cities is an open, interoperable and scalable platform that provides intelligent infrastructure-as-a-service for optimal resource management. Among the fundamental characteristics of this platform are the existence of an environment for partnering and cooperation, fully automated service via a central hub, efficient data exchange, flexibility for service and product combination, modular architecture, scalability, Internet-based service; in effect all the core features of cloud computing. The proposed platform makes the delivery of services feasible in seven key domains of cities: transportation, health and safety, waste management, education and culture, public administration, office and residential uses, and nature resource management. As technologies and solutions evolve, new components can be replaced and integrated on demand.

The European Commission set up several funding lines for research and experimentation on Smart Cities in the context of Future Internet research, the Competitiveness and Innovation Programme (CIP), and the Strategic Energy Technology Plan (SET-Plan). FP7-ICT projects focused on smart cities were mainly part of *Future Internet Research and Experimental* (FIRE) action line. The most well-known one is the Smart Santander testbed currently composed of around 3,000 IEEE 802.15.4 devices, 200 GPRS modules and 2,000 joint RFID tag/QR code labels deployed both at static locations (streetlights, facades, bus stops) and on-board mobile vehicles (buses, taxis) envisioning the deployment of 20.000 sensors. The architecture supports a secure and open platform of heterogeneous technologies and the facility applies user-driven innovation methods (through competitive open calls) for the design of innovative applications and implements 'use cases' in the city of Santander in northern Spain, such as bus tracking, air quality monitoring, urban waste management, and others. FIREBALL was another FIRE project that established a coordination mechanism among a network of cities across Europe engaging in long-term collaboration for user-driven open innovation to explore the opportunities of Future Internet in smart cities. The coordination process was grounded on exchange, dialogue and learning between Smart Cities, which were considered as key demand-side drivers of Future Internet innovation, and by bringing together European communities of Future Internet research, Living Labs, and Smart Cities.

The Directorate General of Energy, in the context of the SET-Plan and SETIS (the SET Information System) introduced the '*European Initiative on Smart Cities'* to demonstrate the feasibility of implementing advanced energy and climate technologies at a local level. The

Initiative fosters the dissemination of the most efficient models and strategies for a low carbon and low emissions future throughout the Smart Cities Stakeholders Platform. It supports cities and regions in ambitious and pioneering projects and cooperative schemes, such as an 80% reduction in greenhouse gas emissions through green energy by 2050. The SETIS smart cities initiative is based on systemic approaches and organizational innovations related to energy efficiency, low carbon technologies and smart management of supply and demand. Three main domains for applications are energy efficiency in buildings, energy supply networks, and energy in mobility and transport.

The Competitiveness and Innovation *Programme* (CIP) has also included an action line for '*Open innovation for future Internet-enabled services in smart cities*', which combined three co-related perspectives: (a) user-driven open innovation, (b) innovative Internet-based services, and (c) cross-border networks of smart cities. In the first round of experimentation, seven smart city pilot projects were funded by the CIP- ICT-PSP (Epic, Life 2.0, Open Cities, People, Peripheria, Smart IP, and Smart Islands) with the participation of many cities in Europe. These pilot projects focused on accelerating the uptake of smart technologies in cities, creating user-driven innovation ecosystems, improving the capacities of small companies, and strengthening the role of the user / citizen. The emphasis was on fostering innovation in services under realistic conditions, taking-up completed R&D work, extending tested prototypes and combining partial solutions for an innovative outcome. Priority technology areas were those of real-time interaction, open-trusted service platforms, sensors and RFID, multimodal user interface, simulation, location-based technologies and services. Priority domains for application were those of smart education, smart energy, e-participation, e-government, smart retail, well-being and transportation.

Both in large multinational companies and research institutions, the recent turn and interest in smart cities and the future Internet has been driven by two objectives. On the one hand, we have the use of new Internet technologies, such as sensor networks, smart devices, RFID, the semantic web and the Internet-of-Things, cloud computing for offering new e-services to citizens and optimizing the functioning of cities. On the other hand, there is the pursuit of sustainability as cities are looking for a more inclusive and sustainable future, transforming themselves into green cities with less energy consumption and fewer CO_2 emissions. From an interdisciplinary perspective, intelligent / smart cities are implementing the latest advancements in mobile and pervasive computing, wireless networks, middleware and agent technologies as they become embedded into the physical spaces of cities, moving towards a more sustainable and environmentally-friendly form of development. By implementing a wide range of technologies and user-driven innovation, intelligent cities are replacing smart growth and New Urbanism principles for a sustainable future.

3. Future Internet and smart cities

The social, economic and technological perspectives of new Internet technologies and their potential impact on cities and spatial ecosystems were described in two foresight reports prepared by the Institute for the Future. The report entitled '*Future Knowledge Ecosystems'* identified fourteen trends that will broadly set the context for technology-based cities and regions over the next 5 to 20 years [7]. Changes were described in three domains: economy and society, science and technology, and models and location sites of R&D. In each domain weak signals and early indications of upcoming trends were identified as well as the expected impact on technology-led urban spaces. In science and technology, most important trends were (a) the spread of **ubiquitous computing**, which is expected to create massive streams of data, while simultaneously providing new tools for scientific collaboration in the lab, and (b) the shift from artificial intelligence to **hybrid sensemaking** and hybrid identities which combine inputs from social networks and more limited forms of machine intelligence. The second report entitled '*A Planet of Civic Laboratories. The Future of Cities, Information and Inclusion*' was ten-year forecast covering the period up to 2020 that focused on the intersection between urbanization and digitalization and the massive stream of data generated within cities by IoT solutions, which is expected to turn every city into a unique civic laboratory, a place where innovations driven by citizens are born to meet local needs [8]. In both foresight reports, technologies that mattered most for smart cities were those of smart sensors and devices, open data, and cloud computing. The same group of technologies was also pointed out in Gartner's estimations about emerging technologies. Gartner's analysts reviewed more than 1,800 technologies and highlighted a series of technologies relating to smart cities, such as cloud computing, sensor networks, consumer generated media, location-aware applications, and predictive analytics.

4. The Internet-of-things, sensor networks and smart cities

The Internet-of-Things (IoT) is probably the most important component of the current technology shift in smart cities, combining active sensors and RFID for robust and cost-effective identification of many different objects in terms of functionality, technology and application fields in cities. Sensor networks in cities can gather enormous amount of information from connected smart objects and grids over utility networks. Real-time response to this data and prediction of behavior patterns become possible with high capacity processing and computing power. Also, the web is going out from PCs and user interfaces embedded into the physical space of cities

These technologies can overcome the fragmented market of smart city applications and provide generic solutions for cities. Examples of generic architectures include networked RFID tags (passive and active tags, mobile devices), sensor networks (multimodal sensors and actuators, built-in intelligent agents), and connected objects, such as distributed intelligent systems, intelligent objects and biometrics. A new round of applications, such as location aware applications, near field communication, speech recognition, Internet micro payment systems, and mobile application stores, which are close to mainstream market adoption, are expected to offer a wide range of services via embedded systems. Augmented reality is also becoming a hot topic enabled by smart phones, eye glasses, and is creating next generation location-aware information and services projected over the built space of cities.

The IoT is growing exponentially. Thomas Frey mentions an estimation of GSMA that 24 billion devices will be connected by 2020, while Cisco and Ericsson project the number to be 50 billion. In 2009 the number of connected devices exceeded the number of people on earth; the number of connected devices per person reached 1.84 in 2010 and is expected to reach 3.47 by 2015 and 6.58 in 2020 [9]. This new infrastructure of embedded sensors in cities paves the way for spatial intelligence, further advancing the capabilities created by web 2.0, social media and crowdsourcing: a real-time spatial intelligence based on automated information processing, M2M communication, and response available on smart phones and mobile devices. For this type of embedded spatial intelligence, an important issue is the development of Urban IoT platforms over city clusters or districts offering a common framework for ambient sensor networks such as intelligent information infrastructure and universal ubiquitous sensor network architecture [10].

While the future uses of IoT technologies that will bridge the physical and virtual worlds are still largely a matter for speculation, there are estimations that they will bring significant economic benefits. The OECD policy guidance encourages research in this field, investments in business R&D, technological neutrality, open global standards, and harmonization of frequency bands [11]. There are however significant technological barriers to overcome. Sensor communication requires the cooperation of all devices over all communication technologies and different networks, including GSM and WLAN. Hildenbrand estimates that this is not feasible with current networks, devices and communication technologies, as technology cannot convert all devices operating on a certain communication technology or protocol. There is a need for a new technology that virtually overlays all others and allows communication between the different protocols [12].

5. The semantic web and smart cities

Data-driven decisions, techniques for forecasting and predictive analytics are a follow-up to the IoT and data generated by sensor networks. What is needed, however, is semantic M2M communication as gigabit data generated by the functioning of cities can be processed and analyzed only by machines. Use of ontologies and other semantic technologies open up a new domain for smart city applications as they can combine information from multiple sources and inform users when information matches their interests.

Semantic meaning provided by ontologies, like the Good-Relations annotator tool for creating rich RDF meta-data, can describe products and services more accurately. The introduction of HTML5 was also an important step. The cloud will offer additional opportunities for linked data as any object can be related to other objects contained in the cloud. The semantic web is expected to break down barriers, merging data from different sources and presenting data in ways one has never thought of before. Social media collaboration and collective intelligence can reach higher levels of efficiency and information accuracy. Future media research and technologies can offer a series of solutions that might work in parallel with the Internet-of-Things and embedded systems providing new opportunities for content management. Media Internet technologies at the crossroads of digital multimedia content and Internet technologies encompass media being delivered through Internet networking technologies and media being generated, consumed, shared and experienced on the web. Technologies enabled by the functionalities of the Future Internet Media, such as content and context fusion, immersive multi-sensory environments, location-based content dependent on user location and context, augmented reality applications, open and federated platforms for content storage and distribution, are expected to provide the ground for new e-services within the ecosystems of cities.

6. Cloud computing and smart cities

Cloud computing offers complementary to IoT and M2M communication advantages. It is based on several technological advances related to high-speed networks, virtualization and standardization of platforms and applications. However, "cloud computing is a new way of delivering computing resources, not a new technology", providing computer services through the Internet and new business models of outsourcing [13]. The cloud is another way to think of the Internet itself. People can access applications, software development tools, and store files remotely from a computer via the Internet. The cloud is Google's Gmail, Google Docs and Dropbox. In these type of applications data are not stored on the PC of the user, but on servers and at massive data centers of the hosting company. i-Phone applications which million of users download, and platform and development tools to build these applications are also cloud-based. The US National Institute for Standards and Technology offered a clear description of cloud computing as composed of *five essential characteristics* (on-demand self service, ubiquitous network access, metered use, elasticity, and resource pooling), *three* *service models* (software as a service - SaaS, platform as a service - PaaS, and infrastructure as a service -IaaS), and *four deployment modes* (private, community, public and hybrid clouds) [14].

Foresight estimations about developments in cloud computing were given by Gartner Hype Cycle for Cloud Computing, which positioned 38 technologies from this field at different stages of the Hype Cycle [14]. Expectations are very high. Most technologies, however, are at the 'technology trigger' stage, and cloud computing overall is at the 'peak of expectations' stage; a few solutions are at 'experimentation' stage and none at the stage of demonstrated results. The time frame for all solutions is from 2 to 10 years, and only virtualization and software-as-a-service are closer to mainstream adoption.

The impact of cloud computing on smart cities has been discussed in forecast studies for 2020 [7] [8]. While in the short-term cloud computing will be delivered by large commercial clouds, government G-clouds are promising models for (larger) cities, creating urban clouds that reduce IT costs, and offering platforms for small business applications and e-services. Fenn argues that Governments are realizing the benefits of cloud computing but are concerned about the level of security for their data in the private cloud [15]. Cloud computing is opening also new possibilities in the virtualization of physical spaces and their substitution by digital ones. Already because of the 2009 global crisis, many city activities relating to trade and services have gone virtual -killing their physical part- allowing companies and organizations to maintain operations in times of austerity, gain flexibility and lower fixed capital costs. Cloud computing is also expected to sustain new growth sectors of cities, which are now moving from manufacturing to services in the context of a wider movement from products to services, as material and intangible infrastructures start being provided by the cloud. Equally important is the expected standardization of smart city solutions, platforms, and applications, which is necessary to provide on-demand self services. Standardization will accelerate technology diffusion and learning curves as city administrations and their IT departments will become aware of proven solutions for main districts and sectors of the city. We should expect a standardization of platforms and applications in many different domains of cities related to economic activities (trade, manufacturing, services, logistics), quality of life (safety, environment, social care), utilities (transport, energy, water, broadband), and city management (administration, democracy, planning).

7. Internet of users and people in smart cities

The engagement of users and user-driven innovation are important preconditions for turning future Internet technologies to new services in smart cities. The Web 2.0 era has pushed cities to consider the Internet (including mobiles) as a more participative tool for engaging citizens and tourists. Many initiatives were launched by city-based Living Labs for investigating and anticipating how digital technologies will change the way people live in the city and their implications for urban dynamics. Future Internet, Living Labs and Smart Cities together form a new innovation ecosystem comprising users/citizens, ICT companies, research scientists and policy makers. In such ecosystems, Future Internet technologies are the technology push driver, Smart Cities represent the application pull demand, and Living Labs form the exploratory and participative playground in between.

Crowdsourcing is the usual form of citizen participation in smart cities. The word comes from the combination of 'crowd' and 'outsourcing' and the main idea is to assign a task to a large group of people or a community [16]. It is an extreme form of open innovation in which tasks are not assigned to selected external providers, but to crowds. Crowdsourcing is also strongly related to online platforms and collaborative web spaces because the participation of large communities (crowds) presupposes the use of digital media. It is an online, distributed problem-solving and production model. It also marks a distinctive stage in the evolution of the intelligent cities standard model during the first decades of 21st century.

The two cases below illustrate the contribution of crowdsourcing to smart cities: 'NYC Simplicity Idea Market' and 'Improve-my-City' correspond to applications for citizen participation and city improvement that can be found in many places all over the world.

'NYC Simplicity Idea Market' was launched in February 2011 by the City of New York and remained in operation for about one year. Employees of all levels of administration and city agencies were invited to suggest and share ideas about improvements to city government. Each one could upload ideas, comment on the ideas of others, and vote for those considered best. Then most popular proposals were reviewed by experts and the best ones were implemented by the city administration [25]. A large community of the city, estimated at 300,000 employees, was invited to elaborate ideas about education, safety, and maintenance of the city's infrastructure. Innovation was based on the combination of ideas generated by employees, user-driven evaluation of ideas, feasibility assessment by experts, and idea implementation by the city. A content management system and crowdsourcing platform was used to enable employee participation and assessment through voting. Everything revolved around crowdsourcing, the engagement of a large community of the city, selecting ideas based on the preferences of the same community, and enabling participation through social media.

'Improve-my-City' was developed by URENIO in 2012 in the context of the project 'People', a smart city project of the EU Competitiveness and Innovation Programme (CIP-ICT-PSP). Improve-my-City is an open source application created under AGPL v3 license. Anyone can download the code from the GitHub for use or improvement. Because ImC is a free application it has been used already in many cities in Europe and America. It is already offered in about 20 languages. Citizens can report local problems and suggest improvements, write comments on other posts, and vote to support suggestions and demands. Reported issues go directly into the city's government queue for resolution, and users are informed by the responsible authority about the progress of their request. Again the main concept is about motivated crowdsourcing. The entire community of a city can be involved. Citizen reporting ideas and suggestions are listed in 25 categories related to improvement of the environment. Innovation is based on a combination of crowdsourcing about city problems and solutions, while implementation relies on institutional action from city hall.

In crowdsourcing and user-driven innovation, user involvement is the main driver of spatial intelligence. In the first step, the city, citizens and communities define challenges that need to be addressed. Any form of intelligence starts by defining the problems to address, which also sets the metrics of success. Challenges are specific to each city, its sectors, districts, utilities, quality of life and governance. From the open innovation – crowdsourcing perspective challenges are defined collectively by aggregation and prioritization of citizens' views and demands. Then a problem-solving roadmap is prepared. User-driven innovation is called upon to customize the building blocks of the roadmap in terms of information collection, use of proven solutions, inventing new solutions, and disseminating selected solutions. Digital media and open platforms facilitate the entire process by offering e-tools that help a large number of participants to become involved, sharing insights, combining skills and aggregating resources. The outcome is urban empowerment: an increase of collective capability in defining problems and solutions, and implementation mechanisms through collaboration and agglomeration of resources.

8. Innovation ecosystems of embedded spatial intelligence

The instances of Future Internet described in previous the sections – Internet-of-Things, semantic web, cloud computing, Internet of people – are cornerstones of the new innovation ecosystems emerging in smart environments. Within environments of embedded spatial intelligence, the building blocks of innovation - products, markets, business models, funding – take on new forms and new types of innovation ecosystems are formed. The nodes of ecosystems multiply geometrically, become sentient and interactive; hybrid identities are formed with semantically rich labels; all interactions become location-aware [17].

Technologies and products: Products and services based on future Internet technologies are not stand-alone products. Complex system are needed to offer them, composed of broadband infrastructure comprised of wired and wireless networks; systems embedded into the physical space of cities, sensors, smart devices and smart meters; APIs for interoperability and data integration; data hosting and security; predictive modeling; applications for optimization of smart city utilities and activities; provision of e-services, and much else besides. Layers of hardware, devices, and software are interwoven with the physical space, infrastructure and functions of cities. Sensors, activators, RFID, smart meters, cameras, routers, switches, storage, authentication and firewall servers have to work together in order to capture and process the information generated by the operation of cities.

To deal with such complex systems, leading ICT organizations have advanced the concept of *Urban Operating Systems* or *Integrated Urban Infrastructure* enabling all smart city components, applications and services to run on a common system. The argument is that an urban operating system can provide the protocols for the operation of cities, collect data about everything going on in a city and respond in real time. While the concept of one common operating system integrating all devices and smart solutions is an exciting prospect, offering potential economies of scale and scope, the structure and governance of cities does not endorse a unified global architecture. Data integration is feasible at the level of city districts or smaller city clusters only, which are endowed with governance and control capacity, but not at the level of the entire city. The reason is that within market economies there is no overall authority with full control over cities. On the contrary, there are pockets of decentralized decision making, exercising control over different city districts. Technology solutions should adapt to existing city governance instead of assuming an all-inclusive city administration and management. City districts, clusters and utility sectors are appropriate levels for organizing smart infrastructures and services using future Internet technologies rather than the entire city with its different subsystems and fragmented governance.

Markets: Within this ecosystem of data generation and integration, products and services circulate with their virtual identities. The Internet-of-Things and smart objects blur the line between digital and physical worlds, making their distinction hard to define. In every vertical market, the aspects of product design, development, marketing and exchange work primarily with the digital identities involved. Because of the priority of the virtual, the potential market of smart city solutions covers all vertical markets located within the city. Estimations about the size of smart city market vary considerably, but in all cases forecasts describe huge markets. The smart city market was estimated at 8 billion in 2010 and 39 billion in 2016 by ABI Research; at 108 billion for the period 2010-2020 by Pike Research; at 160 trillion for the next 30 years by the Center for Urban Science and Progress. Ovum predicted a spending per city at 35-55 billion of which 15% would be on software and 85% on hardware and services. A recent report from Pike Research estimates that explosive urbanization will create smart city markets covering the fields of sustainability, citizen well-being, and economic development. "The smart city technology market will surpass $20 billion in annual value by 2020. This represents a compound annual growth rate of 16.2%" [18]. Many of the market drivers, continues the report, technology innovations, and decision-making processes associated with smart cities are focused on existing industry and operational silos: energy, water, transportation, buildings management, and/or government services. Now, though, the smart city is also becoming a space for the testing and implementation of cross-functional technologies and solutions. IDC Government Insights estimation for the smart city market in 2013 predicts that 70% of worldwide spending on smart city projects will be focused on energy, transportation, and public safety; smart city information challenges will begin to be framed as big data cases, and cities with open data initiatives will drive 50% more private, citizen, and crowdsourced mobile applications [19].

Cloud-based business models: In creating smart city products and services, cloud computing offers significant advantages, such as external economies, lower capital entry requirements and maintenance costs, and security, while its scalability enables quick adjustment to changing demand. There are also technical advantages related to software updates and new version installations, which become easier if applications are maintained on the cloud. However, the transition to the cloud should be done by taking cautious steps because these technologies are still evolving and have not yet fully addressed the issues of service standardization, security, and privacy. Policy white papers provide valuable guidance to city authorities about the deployment of cloud-based services. An important source of advice is the report of the Australian government, which provides information about public policies and programmes addressing the transition to cloud computing in the US, UK, EU, Canada, and Japan [11]. The recommendation is for streams of consultation work, providing public agencies with guidance and documentation, cost - benefit analyses, testing of services in less important areas initially, and then moving on full deployment of new cloud-based services, and eventually the creation of G-city clouds.

Creativity and funding: The new technology stack of 'IoT- Semantic web- Cloud' does not automatically lead to the development of new e-services. User involvement is necessary to provide skills and resources for new product / services designs and development. User-driven approaches, such as Living Lab and open innovation initiatives, promote a more proactive role for end users and citizens in service innovation, assuring a good coordination between the technology offer from vendors and the service demand from citizens. In developing such smart city solutions, there are a number of methods for involving users which are described in abundant detail in the literature, such as Lead Users, User Driven Innovation, User Centered Design, User Created Content, and User Co-Creation perspectives. Crowdsourcing platforms can make citizen participation a reality. A large collection of platforms is presented on *Crowdsourcing Landscape* that can support the entire cycle of innovation. As crowdsourcing rises in popularity and use, platforms are evolving and specializing. A recent report on crowdfunding presented 41 platforms for different funding purposes: general crowdfunding platforms, crowdfunding for social causes, for health and medical, for small and local businesses, for science, for music, for education, for gaming and apps, crowdfunding for startups and companies [20]. Two types of innovation funding are supported. Innovators can pledge support for an idea or project as a donation or in exchange of some kind of reward or use value. On the other hand, innovations can ask for 'crowdinvesting'. However, the latter requires that funding regulations been loosened to permit more people to invest in what they consider a promising venture to take part.

City authorities are gradually becoming aware of solutions, applications and use cases based on the Future Internet technology stack. Moving toward such solutions substantially increases the demand for broadband connections because of the transition from connecting people to connecting things. Network interoperability and merging of network and media technologies, as well as mobile-to-mobile communication (M2M) become necessary to manage and give meaning to the streams of data generated. Policy and experimentation are needed to turn these possibilities into a reality. The OECD report on the future Internet economy [11] provides a series of policy recommendations to deal with these challenges, such as building next generation network infrastructure, making Internet access available to everyone and everywhere, promoting Internet-based innovation, competition and user choice, empowering consumers, creating public digital content and user-driven content, ensuring the protection of personal data, intellectual property rights, trusted Internet-based services, and creating environments that encourage infrastructure investment, broadband connectivity and innovative services and applications.

References

1. Deakin, M. The embedded intelligence of smart cities. Intelligent Buildings International, 2011, 3(3), 189-197.
2. Komninos, N. Intelligent cities: Variable geometries of spatial intelligence. Intelligent Buildings International, 2011, 3(3), 172-188.
3. Mitchell, W. Intelligent cities. e-Journal on the Knowledge Society. 2007.
4. IBM Institute for Business Value. A vision of smarter cities: How cities can lead the way into a prosperous and sustainable future. 2009. IBM Global Business Services Executive Report.
5. Carter, P., Rojas, B., and Sahni, M. Delivering Next-Generation Citizen Services: Assessing the Environmental, Social and Economic Impact of Intelligent X on Future Cities and Communities. IDC White Paper, 2011.
6. Accenture. Building and Managing an Intelligent City. Accenture Management Consulting. 2011.
7. Townsend, A., Soojung-Kim Pang, A., and Weddle, R. Future Knowledge Ecosystems: The Next Twenty Years of Technology-Led Economic Development. 2009. Institute for the Future, IFTF Report Number SR-12361.
8. Townsend, A., Maguire, R., Liebhold, M., Crawford, M. A Planet of Civic Laboratories. The Future of Cities, Information and Inclusion. 2011. Institute for the Future.
9. Frey, T. Empowering “Things” for Our Internet of Things. 2012. Online http://www.wfs.org/blogs/thomas-frey/empowering-%E2%80%9Cthings%E2%80%9D-for-our-internet-things. Accessed 12-2-2013.
10. Hernández-Muñoz, J.M., Vercher, J.B., Muñoz, L., Galache, J.A., Presser, M., Hernández Gómez L. A., and Pettersson, J.. Smart Cities at the Forefront of the Future Internet. In: J. Domingue et al. (Eds.), The Future Internet, Springer, 2011, 447-462.
11. OECD (2008). Shaping Policies for the Future of the Internet Economy. OECD Ministerial meeting on the Future of the Internet Economy, Seoul, Korea, 17-18 June.
12. Hildenbrand, D., A World Full of Sensors. 2011. Online http://www.vector1media.com/article/features/22047-a-world-full-of-sensors.html,
13. Australian Government (2011). Cloud computing strategic direction paper. Department of Finance and Deregulation.
14. Mell, P., Grance, T. The NIST Definition of Cloud Computing. 2011,NIST Special Publication.
15. Fenn, J. Emerging Technology Hype Cycle 2010: What’s Hot and What’s Not, Gartner. Online http://blog.bimeanalytics.com/english/analysis-gartners-emerging-technology-hype-cycle-2010-hot. Accessed 12-2-2013.
16. Howe, J. The rise of crowdsourcing. Wired Magazine, 2006, No 14.6.
17. Komninos, N. Smart Cities and the Future Internet: Innovation for All within Smart Environments. 11th Students Spring Symposium, Thessaloniki, 18 May 2012. Online http://www.urenio.org/wp-content/uploads/2008/11/Smart-Cities-and-Future-Internet-Innovation-for-All.pdf.
18. Pyke Research. Smart Cities: Infrastructure, Information, and Communications Technologies for Energy, Transportation, Buildings, and Government. 2012. Online http://www.pikeresearch.com/research/smart-cities. Accessed 17-2-2013.
19. Clarke, R.Y., Yates, M., Chulani, M., Brooks, A. Wu L., Sasahara, E. Worldwide Smart City 2013 Top 10 Predictions. IDC Government Insights. 2013. Online http://www.idc-gi.com/getdoc.jsp?containerId=GI239209. Accessed 17-2-2013.
20. Kim, R. A GigaOM guide to Kickstarter wannabes. Online http://gigaom.com/2012/11/28/kickstarter-copycats/. Accessed 17-2-2013.