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Architectures Of Intelligence In Smart Cities: Pathways To Problem-Solving And Innovation

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Abstract

The discussion about intelligence and problem-solving capabilities has flourished in the literature of smart cities, under concepts such as spatial intelligence, connected intelligence, ambient intelligence, collective intelligence, new intelligence of cities, city smartness, and other. In this paper we take a quick overview of the literature that points to different types of intelligence into digital, smart, and intelligent cities. We then describe four architectures of intelligence (agglomeration, orchestration, empowerment, and instrumentation) that appear within smart city ecosystems. Cases studies from Bletchley Park UK, Cyberport Hong Kong, Smart Santander, and Amsterdam Smart City illustrate the above typology. These socio-technological experiments contribute to a better understanding the many faces that intelligence appear into smart cities, linking humans, organisations, and machines. In the last section, we attempt a synthesis by defining a universal architecture of city intelligence, based on variables such as the knowledge functions activated, the origin of intelligence used, and the connectivity between the digital and non-digital entities of the urban space.

Keywords

City intelligence, Spatial intelligence, Connected intelligence, Empowerment, Innovation, Governance

Note

A previous version of this paper has been published in Komninos, N. (2014). The Age of Intelligent Cities. Smart Environments and Innovation-for-all Strategies, Routledge: London and New York, chapter 4. It is published here with a few modifications.

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Introduction: What makes cities intelligent?

The new interdisciplinary paradigm of 'intelligent cities' or 'smart cities' bringing together theories, methodologies and practices from diverse fields, such as urban development, strategic planning, web and Internet technologies, engineering, knowledge and innovation management, is overturning established urban development and planning practices. The impact of this paradigm reaches far beyond the domain of cities as it influences the way we address global challenges of competitiveness, sustainability and climate change, employment and inclusion.

A very rich literature reflects the evolution of thinking and practice in the field of digital - intelligent - smart cities and outlines the contribution of information technologies and innovation processes to the development and planning of 21st century cities. From Mitchel (1996), Ishida and Isbister (2000) and Graham (2003) focusing on technologies, experiences, and case studies of digital cities, to Komninos (2002, 2008, and 2014), Bell et al. (2009) on intelligent cities and the nexus of ICTs, collective intelligence and innovation, to Caragliu et al. (2009), Belissent (2010), Deakin (2011), Schaffers et al. (2011) on smart cities, embedded systems and the future Internet, and Aggelidou (2015) and Chourabi et al. (2012) on forces shaping smart cities, this literature also highlights a trajectory of change. It describes the continuous evolution of digital technologies and innovation systems that feed intelligent cities and the creation of more open and innovative urban ecosystems deployed over the digital, social and physical space of cities. Such ecosystems enable citizens, end-users, enterprises and organisations to develop innovative behaviour, become more competitive and resource efficient, and more intelligent in decision-making.

Despite the great diversity of strategies and solutions that can be observed, intelligent and smart cities rely on a core of knowledge processes (Komninos, 2008). We call this core 'spatial intelligence of cities'. Spatial intelligence is made by informational, cognitive and innovation processes, which take place within cities and enable citizens and organisations to more efficiently address the challenges they face. It refers to the ability of a community or a city to combine its intellectual capital, institutions for collaboration, and smart infrastructure for setting up knowledge functions that optimise the use of resources in a wide range of city sectors and challenges.

Spatial intelligence is the ingredient that makes cities intelligent. Having said this, the aim of this paper is to discuss different architectures and trajectories that make spatial intelligence emerge. Furthermore, the aim is to describe the fundamental variables of spatial intelligence and how they change along the evolution that takes place in digital technologies and innovation systems. In previous publications (Komninos, 2008 and 2014) we have argued that the intelligence of cities is based on a series of knowledge functions which are collaboratively created and deployed, such as network-based information intelligence and forecasting, technology learning and acquisition, collaborative innovation, product and service promotion and dissemination. Here, we extend these arguments by showing how different forms of spatial intelligence are activated by arrangements of knowledge functions, source of capabilities, infrastructure and connectivity into cities.

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Intelligence in the smart city literature

In smart cities, intelligence emerges from the agglomeration and integration of three types of intelligence: human intelligence, the inventiveness, creativity and intellectual capital of the city's population; collective intelligence, organised by the city's organisations and institutions, relying on rules for collaboration and social capital; and machine intelligence offered by public and city wide smart infrastructure, virtual and smart environments, and ambient intelligence (Komninos, 2008, 122-123). These forms of intelligence are interconnected. Using spatially combined intellectual capacities, individual skills and organisational learning, smart cities can respond more effectively to changing socio-economic conditions, address challenges, optimize operations, plan more accurate for the future, and sustain the prosperity and well-being of citizens.

Thus, the intelligence of smart cities is based on informational and cognitive processes, such as information collection and processing, real-time alert, evidence-based decision-making, forecasting, learning, awareness, distributed problem-solving, co-creation and collaborative innovation that take place in cities. We may call it 'spatial intelligence', pointing out to space and agglomeration as preconditions of its appearance.

Collaboration has been a major driver of the spatial intelligence of cities. Partnerships, collaboration platforms and social networks nurture the development of technologies, skills, and learning. Social media have contributed enormously via crowdsourcing platforms, mash-ups, web-collaboration, and other means of participatory and distributed problem-solving. Media technologies and collaborative platforms remain a key instrument for connecting different types of intelligence into spatial agglomerations. However, the recent turn towards smart cities and systems highlight other routes as well. The widespread of Internet technologies promoting cloud-based services, the Internet of Things, the use of smart phones and smart meters, networks of sensors and RFIDs, analytics and more accurate semantic search, open new ways to connectivity and collaborative problem-solving.

The literature on digital, intelligent and smart cities, which spans a period of twenty years, highlights different forms of spatial intelligence which appeared with respect to different web technologies, knowledge and innovation processes, and forms of community engagement. Since the 1980s, urban development has been linked to innovation ecosystems, technology-driven localities, innovation clusters, and creative hubs, in which R&D, knowledge, and innovation were connected by agglomeration and locality. In the 1990s, a new digital spatiality started expanding over the physical and institutional space of cities. However, ICTs, the Internet and the web alone would not have had a strong impact on cities if contemporary urban agglomerations had not rooted their development in knowledge and innovation. In the 1990s a digital spatiality joined the spatiality of cities in multiple ways, enhancing communication, city representation, virtualisation of infrastructures, transforming urban activities, optimisation of city functions, and enabling more participatory governance. These different roles of the digital space and the different forms of integration between physical, institutional and digital spaces gave birth to different forms of spatial intelligence within 'cyber', 'digital', 'intelligent', and 'smart' city environments.

Cyber-intelligence: The cyber literature marked the initial stage of the digital trajectory of cities. Cybercities and cyberspace refer to any type of virtual space generated by a collection of data within the Internet (Shiode, 1997), but the concept also contains the sense of inspection and control with communication and information feedback as preconditions of effective action. It carried some seeds from the ideas of cybernetics that appeared in the 1940s on communication with machines

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and feedback loops in decision-making. This perspective led to early e-government applications for city management and more recently to technologies for security and control over the urban space, and in some cases the transfer of military methods of tracking, identification and targeting into the governance of urban civil society (Graham, 2010). In a broader sense, a Cybercity is conceived as a web-based city in which people interact with each other through and exclusively over the cyber space. Antorroiko (2005) points out that the 'cyber' prefix refers also to the dark side of the virtual space, to 'cyberterrorism' and 'cyborg' dimensions.

Representational intelligence: A more neutral discussion opened within the digital city literature with the work of Ishida and Isbister (2000), Hiramatsu and Ishida (2001), Van den Besselaar and Koizumi (2005). It concerned the representation of the city, in early forms via portal-type webpages, panoramic and 3D representations of cities, and later with augmented reality technologies, and urban tagging. Digital cities are connected communities that combine "broadband communications infrastructure; a flexible, service-oriented computing infrastructure based on open industry standards; and innovative services to meet the needs of governments and their employees, citizens and businesses" (Yovanof and Hazapis, 2009). The digital city is a metaphor of the city: an understanding of the city through its virtual representation. Digital cities were described as 'mirror-city metaphors', as their logic was to offer "a comprehensive, web-based representation, or reproduction, of several aspects or functions of a specific real city, open to non-experts" (Couclelis, 2004). The spatial intelligence related to solutions of this type was based on advantages of representation and visualisation. "A picture is worth a thousand words" reflects this idea that complex environments can be described and understood better via a virtual representation or visual metaphor.

Collective intelligence: The discussion about city intelligence emerges also at the crossroads between the knowledge-based development of cities (knowledge cities) and the digital cities of media. These perspectives offer quasi-similar understandings of city intelligence. Mitchell attributes city intelligence to a combination of telecommunication networks, sensors and tags, and software improving the knowledge and cognitive competences (Mitchell, 2007). City intelligence comes from partnerships and social capital in organising the development of technologies, skills, and learning, and engaging citizens to become involved in creative community participation (Deakin and Allwinkle, 2007). The intelligence of cities is based on a combination of the creative capabilities of the population, knowledge-sharing institutions, and digital applications organising collective intelligence, which altogether increase the ability to innovate that is the ultimate indication of intelligence. Thus, the spatial intelligence of cities builds on collective intelligence, web 2.0 solutions for user engagement, and social capital for collaboration (Segaran, 2007). It is based on people-driven innovation and experimental environments supporting the principles of openness, realism, and empowerment of users in the development of new solutions (Bergvall-Kåreborn and Ståhlbröst, 2009).

Intelligence into data: The recent turn towards -and interest in- smart systems and cloud computing link city intelligence to data provided by the Internet, smart phones, smart devices, sensors, RFIDs, social media, and the Internet of Things. Smart city solutions on the cloud (Kakderi et al., 2016; Tsarchopoulos et al., 2016) using sensors and smart devices improve the ability to gather information, forecast and manage urban activities and flows, and advance city intelligence (Chen-Ritzo et al., 2009). Within this environment, spatial intelligence moves out of applications and enters the domain of data: the meaning of data becomes part of data, affluent data are provided in real-time, real-time data enable real-time response, analytics, and more informed-decisions.

Critical questions within this large landscape of practices for digital transformation concern the

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sources of the spatial intelligence of cities: the structures, mechanisms and architectures that sustain the problem-solving capability of cities. What makes a city intelligent or smart? Which type of spatial intelligence is activated within each district and sector of the city? Is it a spatial intelligence common to all districts or are different structuring forms activated within different city districts depending on their functional characteristics and governance?

Four architectures of intelligence in smart cities

We discuss these questions with respect to case studies from Bletchley Park UK, Cyberport Hong Kong, and Smart Amsterdam, and the corresponding forms of spatial intelligence. We start from the baseline, intelligence created by the agglomeration of applications, and then we present three forms of spatial intelligence which rely on different arrangements and connectivity within the urban space. The case studies show that spatial intelligence of cities takes many different forms and follows diverse trajectories as well. The variable connections between the digital, social and physical space of cities, and the large number of digital applications gathered over cities actualise many mechanisms that both give structure to and sustain city intelligence. These forms are orchestration intelligence, which is based on collaboration and distributed problem-solving within a community having full control over information and knowledge processes; empowerment intelligence, which is based on people's competences through up-skilling provided by experimental facilities, open platforms and city infrastructure; and instrumentation intelligence, based big data, real-time information, data analytics, and predictive modelling for better decision-making across city districts and utilities. These trajectories of spatial intelligence can work in isolation or in a complementary way. They provide different ways of problem-solving, but always taking place with networks and connections between the physical, institutional, and digital space of cities.

(i) Baseline: Agglomeration intelligence through connected variety

From the moment they emerged, cities were based on advantages created by spatial proximity, the division of labour and collaboration, use of common infrastructure, face-to-face communication, the development of trust and alliance. The spatial agglomeration of people, activities, and buildings was made possible by advances in the division of labour and exchange of goods, and in turn generated a series of positive social and economic externalities. Soja (2003), writing about the first urban settlements and cities insists on "putting cities first", attributing to Synekism -the physical agglomeration of people with a form of political coordination- the capacity to advance creativity, innovation, territorial identity, and societal development which arise from living in dense and heterogeneous agglomerations.

Soja refers extensively to "The Economies of Cities" by Jane Jacobs (1969) and the findings at Catal Huyuk, the largest and most developed early city in southern Anatolia, where Jacobs located major innovations and transformations from hunting and gathering to agriculture, the first metallurgy, weaving and crude pottery, which took place because of the existence of the city. These innovations, he argues, as well as every major innovation in human society come from cooperation, synergy, and multiple savings obtained from living in dense urban settlements. The externalities of cities and the various types of agglomeration economies (external, scale, scope, location, urbanisation) stem, on the one hand, from savings in energy, time and materials, and on the other hand, from collaboration and the creation of synergies. The spatial agglomeration of people and activities produces both savings and synergies.

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The new industrial geography has described how proximity generates additional externalities in the innovation economy because of informal collaboration, untraded interdependences, knowledge spillovers, trust, and diffusion of tacit knowledge. It is the diversity of cities, the connected variety of the urban agglomeration that increases individual intelligence by bridging fields of knowledge. 'Related variety' (Boschma and Frenken, 2011) has been an influential concept in innovation-led regional development over 20 years, sustained by studies on innovative industrial districts containing many and diverse skills, on high technology regions with a variety of machinery and knowledge infrastructure, and on innovative cities with a variety of science and technology fields in world class research institutes and universities. The industrial innovation literature uses also similar 'brokering' concepts to explain how innovation derives from connecting various fields of research and technology and insights from connecting different fields of science and technology (Hargadon, 2003).

When digital applications begin to appear over the urban environment, collaboration and synergies scale-up. As citizens come into the digital space and use applications, they share more and share it quicker. Interaction becomes easier and synergy stronger. The holy triad of synergies (proximity, trust, communication) is strengthened: proximity increases because the 'other' is just a few clicks away; trust deepens because digital interaction leave traces; and communication intensifies because we have more means and tools to this end. Digital interaction enables wider collaboration, more extended supply chains, and more end-user participation. The agglomeration of digital applications and e-services, created by the engagement of the population of the city, scales-up collaboration with content management systems, co-design tools, collaborative work environments, crowdsourcing platforms, and content mash-ups.

As computers, devices, and information systems become embedded into cities, the collaboration patterns among citizens change substantially. Change does not concern scalability only, but above all the architectures of cooperation. New networking architectures emerge, involving both humans and machines. As digital technology transfers tasks from humans to machines, workflows become more complex, more tasks are performed in cooperation, machines inspect the workflow of collaboration, and storage capacity skyrockets. The city ends up with quicker responses, better quality procedures, lower operation costs, higher problem-solving capability; in other words, with higher spatial intelligence. This happens because machine intelligence is added to the human intelligence of citizens and to the collective intelligence of the community. The agglomeration of digital applications is the beginning of spatial intelligence in smart cities, in the same way that the spatial agglomeration was the beginning of cities.

(ii) Orchestration intelligence: Bletchley Park, the first intelligent community ever

The first community that successfully practised this type of human-machine cooperation and integration of individual, collective, and machine intelligence was Bletchley Park in the UK. The story of Bletchley Park is well known in the WWII code-breaking literature. However, it was never referred as an intelligent city or intelligent community.

Bletchley Park is located eighty kilometres north-west of London. Bletchley is an ordinary town, a regional urban centre in the county of Buckinghamshire, at the intersection of London and North-Western Railway with a line linking Oxford to Cambridge. Just off the junction, within walking distance from the station, lies Bletchley Park, an estate of about 100 hectares with a grand Victorian mansion at the centre of the estate.

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The development of Bletchley Park started in August 1939 when the Government Code and Cypher School moved from London to Bletchley Park to carry out their code-breaking work in a safer environment. A small group of people was initially settled at Bletchley composed of code-breaking experts, cryptanalytic personnel, and university professors from the exact sciences and mathematics. Alan Turing arrived at Bletchley Park in 1939 together with other professors from Cambridge to help set up the methods of analysis and workflow of cryptanalysis. Bletchley Park carries the mark of A. Turing and his ideas on intelligence, logic and software priority over hardware, and solutions over a universal computing process.

The mission of Bletchley Park was to find the daily settings of the Enigma machines used by the German Army to encode all transmitted messages between the army headquarters, divisions, warships, submarines, port and railway stations, military installations and other installations, and then decode all these messages. It is estimated that by 1942 the German Army had a least a hundred thousand Enigma machines, which produced an enormous traffic of codified messages of vital importance for the daily operation of all army units. The Enigma machine was an electro-mechanical device for encryption and decryption of messages based on polyalphabetic substitution. It relied on interchangeable rotors of 26 letters, initially three and later five, moving rings, and a plugboard which permitted variable electrical wiring connecting letters in pairs. Every key pressed on the keyboard caused one step on the first rotor - after a full rotation the other rotors also moved - and then electrical connections were made that changed the substitution alphabet used for encryption. Decoding was symmetrical. The receiver had to settle the machine in its initial setting of rotors, rings, and plugging, type the coded message and recover the original. The combination of rotor order, the initial position of rotors, and plug settings, created a very large number of possible permutations. For each setting of rotors there were trillions of ways to connect ten pairs of letters on the plugboard. It was practically impossible to break the encryption by hand.

The Park was an 'industry' for information collection, processing, decoding, and distribution. Thousand messages were intercepted daily, while overall 200,000 – 500,000 German messages were decoded between 1940 and 1945. The impact was also extremely high. The strategic role of Bletchley Park was in the battle for supplies, defeating the U-boats in the Atlantic and securing the inflow of materials, foods and ammunition to Britain. By the end of 1941 the British announced that the problem of maritime supplies had been solved. Historians estimate that the work done in Bletchley Park shortened the war by two to four years and saved millions of lives. The philosopher George Steiner described Bletchley Park as the greatest achievement of Britain during the war and perhaps during the whole 20th century.

The amount of collaborative knowledge work carried out was enormous. That is important for Bletchley as an intelligent community. The work in Bletchley was done in wooden huts, designated by numbers, and brick-built blocks that were constructed after 1939 to house the different sectors of cryptanalysis. In the years thereafter, the personnel of Bletchley Park increased in number at a spectacular rate and by the end of the war they numbered about ten thousand. People came from all fighting services, and were seconded to Bletchley Park because of their skills; authors, diplomats, bankers, journalists, and teachers, and many women who received training in information processing tasks.

The workflow at Bletchley Park in breaking German communications codes was based on a collaborative schedule between scientists, experts, trained workers, and machines that offered increased intelligence to deal with this challenge. The methodological solutions about how to break the Enigma

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ciphers were given by a group of British cryptanalysts and mathematicians at Bletchley Park who continued and enriched the methods devised by Polish mathematicians in previous and simpler models of Enigma machines. The wiring structure of the machines and some fundamental design flaws -no letter could ever be encrypted as itself- were exploited. The breaking of the codes was based on human factors and mistakes made by the Germans. Alan Turing and Cambridge mathematician Gordon Welchman, who also invented the method of perforated sheets, provided the designs for the new machine -the British Bombe- that could break any Enigma cipher, provided an accurate assumption could be made of about twenty letters in the message. Alan Turing contributed with several insights to breaking the Enigma cipher, while also somehow continuing his theoretical work on computable numbers and the Turing universal machine.

The key to the success of Bletchley Park was large-scale collaboration and an organised workflow that integrated a variety of information sources and processes. Cryptanalysts worked as a team. They had to analyse all the messages of the day to make assumptions out the basic setting of the rotors. Codebooks found in sunken submarines or captured ships were also very helpful and provided Enigma ground settings and abbreviations. They had to simulate the entire German classification system, mapping, and acronyms. Cryptanalysis acquired meaning only through the coordination of different activities across an extended workflow, and solving ciphers was only part of it. There was an organised division of labour and specialisation for different tasks along the process of intercepting the messages, transferring them to Bletchley Park, code breaking, verification, and dissemination of the information to recipients. The raw material came from a web of wireless intercept stations around Britain and overseas. Code-breakers based in the huts were supported by teams who turned the deciphered messages into intelligence reports. The letter from Turing, Welchman, Alexander and Milner-Barry to Churchill in October 1941, asking for more resources at Bletchley Park, personnel, night shifts, interception stations, specialised decoders, support to the Bombes, shows this integrated large-scale functioning of the community.

When a cryptanalyst developed an assumption about a possible way of breaking the code in a message, he prepared a menu (called a crib –plain text that corresponded to the cipher text) which was sent to be tested on a 'Bombe' machine. This was an electromechanical machine used to discover the set of rotors, the settings of the alphabet rings, and the wiring of the plugboard. The machine would check a million permutations, exclude those containing contradictions, and finally reveal how the Enigma machine had been set in order to produce this crib. The 'Bombe' would then provide a solution by discounting every incorrect one in turn. The first 'Bombe' was based on Turing's design and was installed at Bletchley Park in 1940. Subsequent versions were equipped with Welchman's diagonal board which could substantially decrease the number of possible rotor settings. In 1944 Colossus, the first digital electronic computer, became operational at Bletchley Park. Colossus was designed to break messages coded on Lorenz machines. The Lorenz machine created more complex ciphers using a code in which each letter of the alphabet was represented by a series of five electrical impulses. Obscuring letters were also generated by Lorenz's 12 rotors. The first Colossus arrived at Bletchley Park in December 1943. In practical terms Bletchley Park used the world's first electronic computer and digital information processing machine.

Bletchley Park had all the four essential characteristics that we now attribute to intelligent cities: (1) a creative population working in information and knowledge-intensive activities; (2) institutions and routines for collaboration in knowledge creation and sharing; (3) technological infrastructure for communication, data processing and information analysis; and (4) a proven ability to innovate and solve problems that appear for the first time. Bletchley Park was the first intelligent community ever

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created.

Bletchley Park, as a prototype of an intelligent community, was an urban ecosystem in which the organised division of labour and the orchestration of distributed tasks based on institutional rules with the support of intelligent machines produced radical innovations. The military organisation in this district and the absence of the spontaneous complexity we usually find in cities, should not lead us to undervalue the innovativeness of its design and its effectiveness in dealing with extremely complex problems. It represents a top-down solution that was feasible under extreme conditions when the social division of labour within cities becomes a technical division also.

(iii) Empowerment intelligence: Cyberport Hong Kong up-skilling platforms

There are, however, other routes to spatial intelligence, which stand on the contribution of city districts and urban infrastructure to knowledge and skills development.

The spatial structure of intelligent cities is actually taking the form of 'knowledge ecosystems' and 'innovative districts' over 'smart networks'. This form is produced by the decentralisation of urban management and the development of smart urban networks. The literature on the clustering of innovation has explained the causes of spatial gathering and the creation of islands of innovation (Morgan, 2004; Simmie, 1998). Many types of clusters, such as cohesion clusters, industrial districts, innovative milieu, planned technology parks (Hart, 2000) with different sizes, activities, degrees of internal association, and input-output relationships operate over urban infrastructures. City networks for mobility, energy and utilities, on the other hand, are becoming smarter in the pursuit of environmental sustainability and resource savings. It is estimated that smart infrastructure, smart grids, sensors, wireless meters, and actuators, might have a higher impact on energy savings and CO2 reduction than the total positive effect from renewable energy sources.

Metropolitan strategic plans like the "Melbourne 2030 Plan" and Stockholm's "Vision 2030" have clearly adopted this strategy of organising innovation ecosystems and knowledge-intensive districts over advanced infrastructure, including broadband, telecommunications, energy, smart transport and logistics. Melbourne has institutionalised this district-led development via "knowledge precincts", areas surrounding university campuses in which special land use regulations favour the location of activities that link to university infrastructure and R&D, offering opportunities for technology diffusion and cross fertilisation between high-tech businesses, academia, and public facilities (Yigitcanlar et al., 2008). This architecture is beneficial for all innovation ecosystems of a city, which profit from technology networking, knowledge spillovers, and knowledge transfer.

Moreover, some urban ecosystems are pursuing conscious strategies for involving the wider population of the city, not just producers and technologists, and are creating large-scale up-skilling with education and learning on experimental facilities and ICT infrastructure. Living Labs, for instance, offer a good case of user involvement and large-scale creativity development. Users take part in new product development and testing within real urban environments and participatory innovation processes integrating co-creation activities, bringing together technology push and application pull, exploration activities engaging user communities in an earlier stage of the co-creation process, experimentation activities, implementing the proper level of technological artefacts to experience live scenarios, and evaluation of new ideas and innovative concepts and technological artefacts in real life situations (Pallot, 2009). Such open and user-centric innovation ecosystems operate in many and diverse sectors, such as mobile communications, media, agriculture, food industry, health, medicine,

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e-government services, smart cities, sports, education, and social work.

There are also city ecosystems that act as 'innovation universities' or 'intelligent campuses', which use the built environment of the city and experimental facilities to disseminate learning and innovation. Large-scale up-skilling strategies thus become possible; thereby improving the creativity, intelligence and inventiveness of the population, and introducing 'innovation-for-all' environments, in which every citizen or company can become a producer of services and active innovator.

Cyberport Hong Kong is an innovation ecosystem that has effectively advanced this strategy of up-skilling, using advanced telecommunication infrastructure and multimedia technologies organised into knowledge district. Cyberport is a new district located on the west side of Aberdeen Country Park on Hong Kong Island. The district has been developed as a government programme aimed at developing the knowledge economy of Hong Kong. As an autonomous technology district, Cyberport is focusing on professional and enterprise development, offering an open platform for innovative ideas to flourish and for start-ups in the field of media technologies. The district is wholly owned by the Hong Kong SAR Government and managed by Cyberport Management Company Limited.

Cyberport includes many different activities, land uses, and zones. Within a relatively small piece of land of 24 hectares there is an enterprise zone with four quality buildings that host about 100 information technology and media companies, a research institute, business incubator, conference centre, shopping mall, 5-star Le Meridien hotel, a huge housing complex, and a large park at the heart of Cyberport which extends along the coastline. The area is served by fibre optic and copper networks offering high speed broadband connections and a wide range of digital services and laboratory equipment. Buildings in the technology zone are grade-A intelligent office buildings. All these activities are organised into four different zones: the technology zone with Cyberport 1, 2, 3, and 4 buildings; the commercial zone with the mall and the hotel; the residential zone; and the park and open green area zone. Despite this functional division, the relatively small surface of the district and the openness here create a continuum of uses as all the spaces are accessible to the community of the district.

Activities and land uses have been selected to promote the mission of the district and ensure its sustainability. Cyberport was developed on public land and the construction work took place from 2000 to 2008. The funding scheme foresaw a split into two parts, the Cyberport zone and the ancillary residential zone. The mission of the Cyberport zone was to create a strategic cluster of leading information technology and information services companies and a critical mass of professionals in these sectors. The mission of the residential zone was to generate revenue for the Cyberport project. A development company acquired part of the land (about 20% of the plot) together with the infrastructure already on site to build the residential zone. The developer (Cyber-Port Limited) was responsible for the total construction costs of both the Cyberport and the housing complex (Hong King Legislative Council, 2002). The residential zone includes eight 50-storey high buildings and two lower complexes - two to five storeys - for high income residences along the coast. Overall 2,800 homes were built. In return for the concession of the land and infrastructure of the residential zone, the developer delivered the technology zone as a turn-key solution, with Cyberport 1, 2, 3, and 4, the shopping mall arcade, the 5-star hotel operated by Le Meridien, and the central park. Revenues generated by the commercial zone -mall and hotel– go to the technology zone and cover training, learning, and incubation expenses. The district was publicly funded and serves the public interest. This genuine funding model contributes both to development and operation of Cyberport 1, 2, 3, 4, and to the public and open character of the district.

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Cyberport should not be seen as usual technology district or a technology park. It is a community that nurtures talent in the media industry, turning skills and talent into start-ups. It amplifies the skills and creativities of the Hong Kong population using experimental digital infrastructure and open platforms. The objectives are technology diffusion, up-skilling, and the enhancement of human capabilities. Cyberport is a creative community supplied with advanced communication and media infrastructure and digital connectivity. "Cyberport identifies, nurtures, attracts and sustains talent so it is able mobilise ideas, talents and creative organisations. It is a creative milieu; a place that contains the necessary requirements in terms of hard and soft infrastructure to generate a flow of ideas and inventions' (Interview with CEO of Cyberport N. Yang). The focus of the district is the IT and multimedia sector, where it sustains a creative community. Technologies and digital applications that have been developed in Hong Kong Universities or the Technology Park can be transferred to the younger generation though practical learning and experimental training. Training from the world's leading media and IT companies is provided together with the laboratory equipment and start-up funding for follow-up training that promotes entrepreneurship.

To achieve these objectives Cyberport has developed state-of-the-art infrastructure, media equipment and digital services which are organised as open technology learning platforms. Each platform serves a specific objective of training, creativity, and entrepreneurship.
•The Digital Entertainment Incubation and Training Programme is a platform whose objective is to build and promote entrepreneurship and competence in the digital entertainment industry, focusing on business skills, games, animation and digital entertainment, and to enhance networking with industry, as well as to promote the awareness and interest of the younger generation in digital entertainment.
•The Digital Media Centre is a unique state-of-the-art digital multimedia creation facility, whose objective is to offer software and hardware support to content developers, multimedia professionals, small- and medium-sized enterprises.
•The iResource Centre is a digital content storage platform, which serves as a trusted marketplace and clearing house for the aggregation, protection, license issuance and distribution of digital content.
•The Testing and Certification of Wireless Communication Platform provides continuous mobile communication services and coverage of mobile phone signals (3G, GSM, CDMA and PCS) in both outdoor and indoor areas within Cyberport in cooperation with major mobile communications service operators.
•The Cyberport Institute was established by the University of Hong Kong to introduce and run IT courses for talented people and to support various IT development and related businesses in Hong Kong.

These open technology platforms are operated in cooperation with industry leaders who are the founding industrial partners. CISCO, Hewlett Packard, IBM, Microsoft, Oracle and PCCW have been involved through sponsorship programmes, while the students benefit from access to top-of-the-market technologies, scholarships, placement opportunities, and employment.

The dual mechanism described above entailing (1) the open digital technology platforms, and (2) the real-estate based sustainability, provides an open-ended mechanism for professional training, learning, and up-skilling (Fig. 1). The setting enhances human capabilities and intelligence by simultaneously providing hard urban infrastructure and soft digital technologies and services. Developed on public land, Cyberport is creating intelligence through up-skilling funded by real estate business models, and spreading out skills and capabilities into the entire urban system of Hong Kong.
(iv) Instrumentation intelligence: Amsterdam and Santander smart metering projects for envi-

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ronmental sustainability

Among the most influential contributions to the creation of city intelligence has been the IBM Smart Planet - Smarter Cities initiative based on the combination of broadband networks, smart meters, and predictive modelling. City intelligence is improved by making the city systems 'interconnected' and 'instrumented' and by using the information gathered to identify patterns of behaviour, develop predictive models of likely outcomes, and more informed decision-making (Dirks and Keeling 2009; IBM, 2010). It is estimated that this instrumentation intelligence might offer significant savings in city traffic, energy, health, and public safety costs (Kaiserswerth, 2010). IBM is testing this concept through partnerships with cities worldwide. In many cities, the company and local administrations work together to provide this type of solutions in energy, water management, and transportation, reducing the city's footprint on the environment.

This concept of spatial intelligence is clearly applied in the experimental facility of Smart Santander in the city of Santander, in northern Spain. The facility, funded by FP7, has installed a city-wide network of sensors and devices to monitor pollution, noise, traffic and parking. The test bed is composed of around 3,000 IEEE 802.15.4 devices, 200 GPRS modules and 2,000 joint RFID tag/QR code labels deployed over the built environment of the city and moving vehicles, buses and taxis. A long term plan envisions the deployment of about 20,000 sensors. Devices work over a common IP infrastructure using cellular, radio meshed networks, and available broadband (Krco, 2010). 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', such as bus tracking, air quality monitoring, urban waste management, and others. The facility is open to researchers and service providers to test architectures, enabling technologies, and pilot applications, the interaction and management of protocols, and support services such as discovery, identity management and security, and the social acceptance of services related to the Internet of Things (Smart Santander). The OSWINDS Group, for instance, run the SEN2SOC experiment over Smart Santander, connecting sensor measurements and social network interactions and producing new user-oriented services which can test and improve the infrastructure itself (Vakali et al., 2013).

Instrumentation intelligence is also widely implemented in Amsterdam Smart City. Smart devices and wireless meters transmit information over broadband networks and provide intelligence to citizens and organisations of the city to optimise energy saving practices. Decisions can be made with respect to accurate and on time information provided by smart devices or by the crowd. Many solutions for this type of logic are being implemented in different districts of the city: housing and living (West Orange, Geuzenveld, Haarlem, Onze Energie), working (ITO Tower, monumental buildings, employee contest), mobility (Ship to Grid, Moet je Watt), and public space (Climate Street, smart schools, ZonSpot, smart swimming) (Baron, 2011). Overall 43 projects are being implemented in three areas (Ijburg, Nieuw West, Zuid Oost) and five themes (Living, Working, Mobility, Public Facilities, Open Data) (Amsterdam Smart City).

In the Haarlem area for instance, 250 users can test an energy management system and get insight into the energy consumption of appliances, enabling monitoring of energy usage and appliances to be remotely switched on and off. In the Geuzenveld neighbourhood, 500 homes have been provided with smart metres and energy displays to become aware of energy consumption and discuss energy savings at brainstorming sessions. In the West Orange project, 500 households have been provided with smart metres and displays and a personal energy saving goal is set for every household. The

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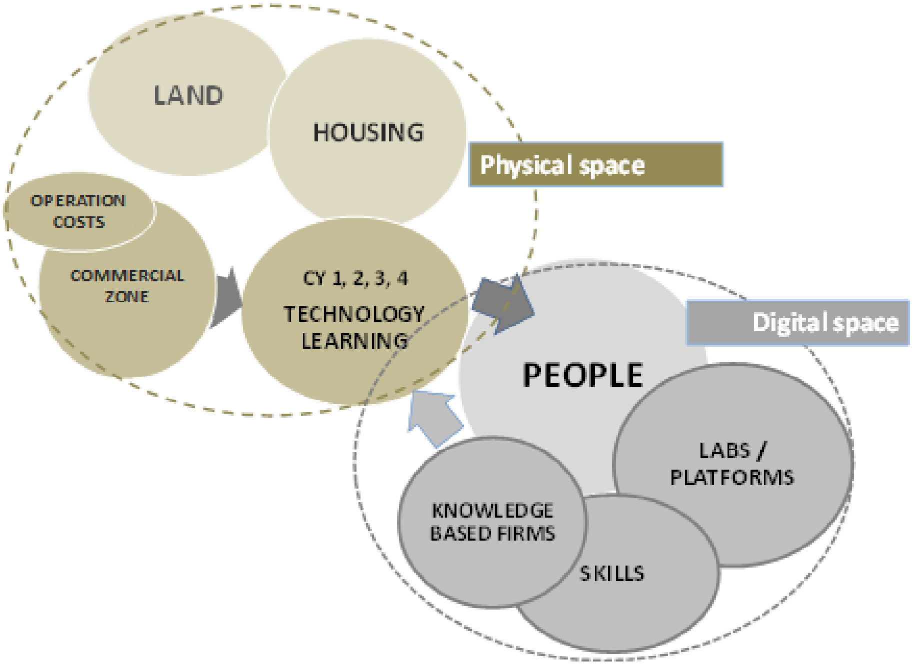

Figure 1. Cyberport up-skilling and empowerment infrastructure and circuits.

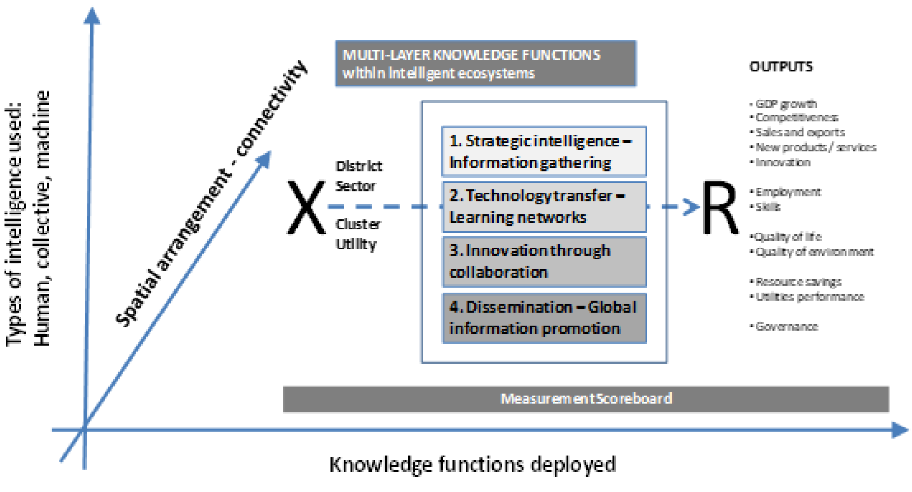

Figure 2. Generic dimensions of city intelligence

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overall goal is to save at least 14% energy and reduce CO2 emissions by an equal amount. The ITO tower, a large multi-tenant office building, is testing which smart building technologies, cooperative agreements and practices can make office buildings more sustainable. Information gained by smart plugs and insight based on data analysis are used to provide more efficient solutions. In the Utrecht-sestraat, a shopping street with numerous cafés and restaurants, 140 small enterprises are testing solutions for a more sustainable environment: logistics using electric vehicles, energy saving lamps for street lighting dimmed during quiet times, solar-powered garbage compacters, smart metres and displays for energy consumption, and incentives and benefits arising from energy savings (Amsterdam Smart City, 2009). The city also is experimenting with crowdsourcing, co-creation, open data, and open innovation to involve citizens in finding better solutions for public space and mobility. Ambitious goals were set to reduce CO2 emissions by 40% and achieve a 20% energy reduction in 2025 compared to a 1990 baseline. Key performance indicators show that these goals can be achieved. In the Climate Street already more than 50% sustainable waste collection and 10% energy savings have been recorded.

Towards a universal architecture of intelligence in smart cities

Moving beyond the baseline of agglomeration intelligence, orchestration, empowerment, and instrumentation intelligence show different architectures of connectivity between digital and non-digital entities, which cities adopt to increase their problem-solving capability. Spatial intelligence actualises arrays of knowledge functions and smart systems to more efficiently manage available city resources and human capital. They articulate large-scale and city-wide endowments of different types of intelligence, namely collective, human, and machine intelligence. All architectures of spatial intelligence increase the efficiency of cities to address complex and non-linear problems, but they do it in very different ways. They constitute different pathways to problem-solving and innovation.

A few variables, however, generate the above types of spatial intelligence:

- the knowledge functions involved, which might relate to information-in, information-out, learning, creation of new knowledge;
- the intelligence used, which might be primarily human, collective from collaboration, or machine intelligence relying on sensors, data, software, and self-control systems;
- the connectivity, workflow and arrays followed, which might entail different complementarities between the spatial, institutional, and digital dimensions of cities.

Orchestration is based on the large-scale division of work and integration of knowledge tasks which are distributed among the members of a community. Each task may be simple, but the size of the collaboration defines the complexity of the entire knowledge process. The overall result may be truly innovative. Empowerment rests on improvements of individual skills, capabilities, and know-how. It is an individual learning process, but when practiced massively on the entire city can produce great results. Instrumentation intelligence replicates computer processes at city level, gathering information from sensors, social media, and urban activities, processing this information, and providing real-time information, alerts, forecasts, and hopefully wiser decisions.

Clearly, orchestration, empowerment and instrumentation are not the only feasible forms of spatial intelligence produced from these variables. Evidently, many more combinations are possible. Future Internet technologies and future media research, for instance, are bringing in new solutions in terms physical – digital relationships, with new infrastructure (cloud computing, RFIDs, sensors, real world user interfaces, mobile devices), data (open data, linked data), and trusted services.

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Such forms of spatial intelligence can be practiced in all domains of cities: the innovation economy of cities with the different city districts, sectors of economic activity, clusters and the ecosystems that they contain; the quality of life with e-services for social care, health, safety, environmental monitoring and alert; the utilities of cities with their different networks, flows and infrastructures for energy, transport, water and waste; and the governance of cities with services to citizens, decision-making procedures, participation and more direct democracy. At least twenty-five different domains of cities or ecosystems can be identified as potential fields for deploying spatial intelligence using hundreds of applications and e-services.

Thus, in each of city ecosystem (district, sector or network) spatial intelligence emerges from the combination of knowledge processes, the type of intelligence involved, and the type of spatial arrangement installed (Fig. 2). Outputs and effectiveness in terms of city growth, employment and environmental sustainability depend on how these variables are combined. It is a critical issue for smart city planning and governance to select the most effective combination of variables with respect to the character of the city and the problems in focus. Instrumentation, for instance, seems more suitable for providing resource efficient urban networks, and sustainable transport, energy, and environment; orchestration offers advantages in terms of quality of service and operation costs in well-structured areas such as ports and technology districts; empowerment is a good solution for innovative clusters, start-ups, employment generation, leading to more competitive places.

Intelligent cities are expected to and have promised more efficiently address contemporary urban challenges. However, to date intelligent city strategies seem to have a rather limited impact on the great challenges of cities concerning competitiveness, employment, and environmental sustainability. This mismatch signifies several things: that smart environments are not well targeted at city challenges; that solutions are more technology push than need driven; or that cities have not developed sufficient spatial intelligence. All explanations can be true, and cities with all the technology and institutions they actually have are not yet sufficiently intelligent. By and large, contemporary solutions are lagging in terms of radical innovation achievement (Komninos et al., 2016) and the social impact reached by Bletchley Park.

We have entered the age of intelligent cities, but we still lack a deeper understanding of the processes that create city intelligence. Most conceptualizations of intelligent / smart cities stress the use of information and communications technologies to make cities more innovative and efficient. But, they do not equally stress other dimensions of spatial intelligence and forms of integration among the digital space and open connected communities, innovation institutions and networks, regeneration strategies, measurement and assessment systems, decision-making capabilities, which generate the intelligence of cities. It is important to underline that city intelligence does not concern the digital space of cities only, but the connectivity and integration of digital solutions with city institutions and skills and competences of citizens (Komninos et al. 2014). In this sense, connected intelligence is concept that captures better the intelligence of cities. We should engineer solutions based on connected intelligence, adapted to every sector, district, and innovation ecosystem of a city, as integration and connectivity are keys to higher spatial intelligence, innovation and efficiency.

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