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Smart Cities

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The new paradigm of *smart city* (*intelligent city* is an equivalent term) has emerged from academic research and experimental city projects over the past several decades. A series of publications and planning initiatives demonstrate how Internet technologies can be used to empower citizens and organizations in developing innovative and collaborative solutions that make cities more efficient, sustainable, and inclusive.

The smart city paradigm marks a turning point in the evolution of urban development and planning, disrupting traditional planning models of the high density city of towers and suburban sprawl and more recent models of new urbanism and compact city, which dominated city making during the 20th century. The new urban reality of the smart city emerges from broadband networks, software applications, data from sensors, and user engagement, which make cities interactive, measurable, innovative, and real-time responding entities. The promise of smart cities is that they can resolve complex urban challenges and problems of growth and sustainability where previous models have failed and implement a more efficient use of resources and more intelligent systems of decision making.

The higher effectiveness and efficiency of the smart city paradigm is due to an interdisciplinary and holistic perspective, which is given form through the engagement of multiple disciplines of engineering, social sciences, knowledge management, and information technology (IT). With this engagement, the city becomes a participatory, measurable, and transparent system, and city planning, a quantitative interdisciplinary science.

This entry examines the concept of smart cities; how digital spaces are conceived of within urban environments; Internet-enabled innovation; the structure, intelligence, and architecture of smart cities; and some strategies driving the evolution of smart cities around the world.

Concept

The concept of the smart city has been shaped in a literature that spans over 30 years, since the first writings on the subject at the end of the 1980s to the current explosion of smart city publications. An early phase in the use of the term and formation of the concept can be traced to the 1985–1995 period, while it began to be systematically used in urban development, planning, IT, and engineering literatures after 2000.

The first reference to the term *smart city* is found in the 1988–1990 period, and it was used to capture innovations in urban mobility sustained by ITs, the use of IT for the provision of city services, and the better performance of cities in environmental, economic, and social objectives. Earlier, the term *intelligent city* appeared in the context of the literature on innovation-led urban development and the Japanese technopolis program. From late 1980 to early 1990, several research teams outlined how the use of IT and Internet networks could sustain the technological development and the competitive advantages of cities.

The decade that followed (2000–2010) marked the academic and technological establishment of the smart city paradigm. The literature of this period reflects how a technological base (telecoms, Internet, software, data) that is enriched with various forms of networking and social intelligence could produce an innovative and effective functionality for cities.

Since the early writings on smart/intelligent cities, multiple definitions have been proposed about what a smart city is, which show diversity in the smart city concept. However, an analysis of the ontology of many formal definitions of *smart city* and *intelligent city* reveals that three blocks of entities characterize this concept: (1) the city, citizen, user, activities, infrastructure, and flows in cities; (2) the information, knowledge, intelligence, and innovation institutions and processes within cities; and (3) the smart systems, urban technologies, the Internet, broadband networks, and e-services of cities. The conceptual space produced by the definitions of smart city indicates a convergence in the understanding of smart cities as entities that deploy and use Internet and web technologies, social networking, and user engagement to improve their innovation and problem-solving capabilities.

Digital Spaces of Cities

The digital space of cities, as an enabler of higher problem-solving and innovative behavior, is a composite construction. It has been described as a system of rings superimposed and bonded together, each one having specific characteristics and functionality. At the center are broadband networks, wired and wireless, enabling communication and connectivity, sensor networks, and various types of access devices. Then there is a ring of data and web technologies enabling data creation, data processing, visualization, and insight from data. The third ring is composed of software applications in many different domains of the city, from entrepreneurship to education, health care, transportation, energy, public safety, and others. Applications can be classified in the main subsystems of cities: (a) the economy, (b) quality of life, (c) city infrastructure and utilities, and (d) city governance. The outer ring is composed of e-services; a few applications are adopted by the market and offered on a regular basis as e-services.

The creation of the digital space of cities followed an evolutionary process, well-described by William J. Mitchell in 2007: The elements of urban intelligence appeared through a process of technological emergence and integration into larger systems that started with packet switching, the Ethernet, the Internet and the World Wide Web, and wired and wireless communication channels, and the process continued with computer miniaturization, laptops, mobile phones, embedded microprocessors, digital sensors, radio-frequency identification (RFID) tags, GPS, embedded smart objects, and then moved on to large-scale software, business and retail applications, social media, and finally the emergence of cognitive hierarchies.

Key instances of the current technology stack of the digital space of cities include (a) 4G and 5G wireless networks and next-generation networks (VDSL2, FTTH) and network interoperability enabling Internet usage everywhere; (b) mobile devices enabling ubiquitous access to data and the web; (c) cloud-based infrastructure, platforms, and software for data storage, integration, processing, and analytics; (d) real-world user interfaces, quick response codes over buildings, RFID, mesh sensor networks, low-energy consumption meters, and control devices; (e) applications for the web and smartphones, GPS devices, voice control, and augmented reality visualization; and (f) public data over the web, open access to data from sensors, linked data, and Semantic Web for mobile-to-mobile communication.

Internet-Enabled Innovation

Cities change because of broadband networks, software applications, e-services, and data sets. These resources enable new forms of collaboration and innovation to appear. In the first place, the urban innovation system is enriched, its nodes acquire digital companions, and networking is intensified locally and extended globally. Innovation micronetworks at city level meet the global digital networks enabled by the Internet. Digital identities facilitate innovation processes; marketplaces and crowdsourcing platforms bring additional capabilities, turning passive consumers into active producers of services; city decision making becomes more transparent and inclusive. All these changes mark a deep transformation that affects the innovation system of cities.

All components of the urban system of innovation—research, funding, supply chain, production, and market access—are digitally augmented: Online technology brokers and customer immersion labs improve research and development with technologies and user experience; crowdfunding is added to mainstream funding; global suppliers join the supply chains; online marketplaces broaden regional and national markets. Most of these digital actors are already available, and proper online applications add capabilities for communication, trade, transactions, and the delivery of services.

A special issue on digital disruption (Capgemini Consulting, 2015) and a series of reports on digital business transformation (Networked Society Lab, 2015) highlight how digital environments make sense for all companies, enabling innovation for companies and start-ups. The market-push logic changes to a demand-driven logic with the rise of open marketplaces, content-driven marketing, social media marketing, and on-demand manufacturing. All highlight the priority given to users, consumers, as well as the transition toward the economy of intention and attention.

Structure and Intelligence of Smart Cities

The structure of smart cities is usually described as a multilayer edifice characterized by flexibility, interoperability, and scalability of its constitutive elements. Toru Ishida (2005) describes the structure of digital cities using three layers: (1) an interaction layer, with agent-supported social interaction among residents and users; (2) an interface layer, with 2D and 3D graphics and real-time animation of interface agents; and (3) an information layer, with web and digital archives and real-time sensory data from the physical world. Paolo Gemma (2015) refers to a sensing layer (e.g., Scada, sensors, cameras, RFID readers), network layer (e.g., xDSL, FTTx, Wi-Fi), a data and support layer (cloud computing, urban database), and an application layer (many domains of city services). The Living PlanIT smart city operational system contains four layers: (1) physical world challenges, (2) people and processes, (3) applications and solution areas, and (4) the technology platform.

The structure of smart cities can be better described by a combination of three layers and multiple components within each layer. While the three layers are always present, their components vary with respect to choices made concerning technology, information, software, and physical world context.

The city layer includes the city's population, knowledge-intensive activities, and infrastructure. The population of the city (knowledge workers and innovative companies) and its clusters are the fundamental elements on which smart cities are built. A critical factor in this layer is the agglomeration of intellectual capital and human intelligence of the city's population.

The information and knowledge layer includes institutional settings for knowledge flows and cooperation in technology and innovation. Institutions actualize and manage knowledge flows, cooperation in research and innovation, and funding and allocation of resources; organize networks of distributed intelligence; and produce collective intelligence. Critical factors at this layer are institutional thickness, social capital for collaboration, trust, and knowledge spillovers within the city.

The smart environments layer is the technology stack and includes broadband networks, software applications, and e-services that enhance collaboration and the functioning of cities in real time. These technologies make the innovation ecosystems of cities more open and participatory and the functioning of cities more efficient due to streams of data, real-time information, and automated control. Critical factors at this level are broadband communication, data and content management technologies, information processing, digital networking, and various forms of machine-to-machine communication and intelligence.

Multiple components can be found within each layer. For instance, many different activities can be actualized within the city layer, combined with many different knowledge flows and innovation patterns of the knowledge layer, and many digital technologies, from Web 1.0 for one-way communication to Web 2.0 interactive and participatory content management systems, social media and crowdsourcing, and solutions of the Internet of Things and sensor networks. Because of the diversity of components within each layer, the “Standard Model” of smart cities with its three layers takes multiple forms, and each smart city is a unique construction over the social and physical space of the city.

Architectures of Intelligence

Layers and components within each layer make up the horizontal dimension of smart cities: the different elements from which it is made. The vertical dimension is created by networks and connectors across layers and components. Vertical networks appear as knowledge flows and links of capabilities. They connect human capabilities (e.g., skills, creativity, knowledge), institutional capabilities (e.g., specialization, coordination, scale in learning and innovation), and digital capabilities (e.g., communication, storage, processing). Networks of distributed capabilities across layers offer the problem-solving capability of smart cities, their smartness or intelligence.

The simplest form of such spatial or connected intelligence is the *representational intelligence* offered by mirror-type digital cities, whose only function is to represent the city. More advanced forms of intelligence are orchestration, empowerment, and instrumentation intelligence.

Orchestration intelligence is based on large-scale division of work and integration of knowledge tasks that are distributed among the population, the institutions, and infrastructure of a smart city. 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 impressive.

Empowerment intelligence rests on improvements of human skills and know-how realized through a combination of institutional and digital means. It is an individual learning process, but when practiced on a massive scale across the entire city, it can produce great results.

Instrumentation intelligence concerns the gathering of information from sensors, social media, and urban activities; processing this information; and providing real-time information, alerts, forecasts, and hopefully wiser decisions. Instrumentation intelligence becomes possible thanks to recent Internet technologies based on sensor networks and the Semantic Web, and it appears as a new form of collective intelligence captured by devices embedded into the physical space of cities.

All forms of spatial intelligence are based on knowledge processing, such as information collection, learning, new knowledge creation, and information dissemination, which are distributed over the heterogeneous three layers of smart cities.

From Structure to Innovation

There is somehow a consensus in the literature that smart cities and the specific resources they mobilize (broadband networks, sensors, data sets, software, e-services, user engagement, global and local networking) introduce innovations and optimize the working of cities. Smart cities provide solutions and innovations where new conditions of urbanization and available resources make the established models outdated. Improvements tend to occur by three innovation circuits that work in parallel.

The *first innovation circuit* is the creation of the digital urban space per se. The digital edifice—or digital skin of cities—emerges either from many uncoordinated initiatives of telecom companies, IT developers, producers, and users—each one adding some digital component, or from top-down planning and strategy. Local solutions coexist with global platforms and systems customized to local needs. The digital spatiality of cities arises as a dynamic agglomeration of heterogeneous systems and solutions, in the same way that cities have arisen as agglomerations of heterogeneous practices, buildings, and infrastructure.

Innovation circuit 2 is about the improvement of the city's system of innovation and decision making. In fact, various innovation ecosystems coexist within each city, as each urban subsystem (industrial area, marketplace, financial district, technology district, port, and airport hubs, and transportation, energy, water, and waste networks) or each sector of economic activity may have its own ecology of organizations, decision-making processes, and governance of change. Digital solutions and applications improve the governance of innovation and the way cities decide about change. Applications such as "Improve-my-City," crowdsourcing platforms, and City 2.0 solutions are a few examples of how technology can contribute to decision making and stakeholder engagement in urban change.

Innovation circuit 3 starts from another type of digital applications and smart systems that do not intend to change the decision making of the city but optimize citizens' behavior and the way in which the urban space and infrastructure are used. Intelligent transportation systems and GPS-guided urban mobility, sensor-based solutions and social media applications for finding parking places in the city, smart energy metering in housing areas, sensor-based street lighting, and sensor-based waste collection are examples of solutions that provide advice on a better way to use the city. Most innovations in circuit 3 are about saving resources and dematerialization, that is, transferring practices from the physical to the digital space of cities. In the long run, they induce a behavioral change on the citizens' or consumers' side, diffusing a culture of sustainability and making more with less. Such a behavioral change is a sign of higher city intelligence, stemming directly from the culture and social capital of the population.

Strategies for Smart Cities

The start of the 21st century has been marked by new challenges relating to growth, sustainability, inequality, and safety, thereby increasing the importance of research, innovation, and efficient governance for their resolution. Growth and poverty form a complex nexus that changes with geography and scale. One size does not fit all, and growth challenges are not the same across countries and regions. Some countries in the developing world, such as China, India, Thailand, and Vietnam, are growing faster and are converging with the developed world. In other areas of Latin America and Sub-Saharan Africa, growth has slowed down. Growth in developed counties is slow and is linked to increases of productivity, while in developing counties, growth comes with diversification from traditional to higher value products. National growth is not reflected equally at regional and local level. All cities and regions of a country do not follow the same development path nor do they exhibit the same growth rates.

Sustainability is related to another nexus of challenges with a wide range of focus areas, including the preservation of natural habitats and ecosystems, sustainable use of land, management of sea and ocean ecosystems, air quality, CO_2 emissions, climate adaptation, energy savings and the transition to renewable energy, sanitation, water management and reuse, recycling of materials, and rise of a circular economy. As the world continues to urbanize, these sustainable development challenges will be increasingly concentrated in cities, particularly in cities where urbanization is happening very rapidly. Cities face also a series of safety challenges related to human-made and natural threats, such as crime, terrorism, attacks on infrastructure and vandalism, natural catastrophes, urban accidents, and other types of emergencies.

Smart cities attempt to address these complex challenges of growth, sustainability, and safety and provide better living conditions and an improved daily life for people. They offer hundreds of solutions that enable communities to improve the economy, infrastructure and utilities, and the environment. They do it in very different ways, but in all cases, improvements come through the three innovation circuits—and their architectures of intelligence—previously described in this entry. Smart cities offer new technology and information resources, improve governance and operational efficiency in public and private sectors, and induce changes in the behavior of citizens by offering better, real-time solutions.

Tan Yigitcanlar (2016) presents 10 case studies of cities in Asia, Europe, the Middle East, the United States, and Oceania that have implemented smart city strategies and the solutions that have been adopted.

1. *Songdo, Korea:* part of national program of economic development, broadband networks and sensor-based solutions for smart living, a test-bed for RFID, and R&D (research and development) on smart technologies
2. *Tianjin, China:* Information and communication technologies (ICTs) for eco-city; intelligent building management systems; and sensing technologies
3. *Amsterdam, the Netherlands:* ICTs for better urban environment and reduction of CO_2 emissions; ICTs for user-engagement; smart city projects for mobility, living, working, public space, and open data; a retrofitting approach
4. *Barcelona, Spain:* Area 22@Barcelona as an innovation district; Sant Cugat sensor-based solutions for parking, jam avoidance, garbage collection, environment monitoring, and street lighting; smart buildings, smart grid, and smart metering
5. *Mazdar, Abu-Dhabi:* creation of a global clean technology cluster, electrified mass transit, and energy-saving and metering systems
6. *Istanbul, Turkey:* ICTs for transport and dynamic intersections signalized, traffic data analytics, and earthquake monitoring, real-time alert, and safety in case of event
7. *Rio de Janeiro, Brazil:* IBM’s Intelligent Operations Center with a dozen control systems for electricity, water, gas, transport, and traffic; safety and emergency response and crime control; data from cameras; analytics; and smart meters for energy saving
8. *San Francisco, United States:* ICTs for sustainability, zero waste, recycling, and CO_2

reduction; applications, such as energy map, energy use challenge, honest buildings; open data; and living labs

9. *Auckland, New Zealand:* ICTs for innovation in energy, transport, waste management, buildings, food production, and agriculture; digital learning and skills development; enterprise development; innovation-led companies
10. *Brisbane, Australia:* ICTs for growth, knowledge-based development, and knowledge precincts; Brisbane knowledge corridor; ICTs for sustainability and energy saving; closed-circuit television cameras for road intelligence and traffic signals; Wi-Fi in parks and libraries

These cases highlight the diversity of strategies for the development of smart cities and the uniqueness of each case. Diversity is also high as strategies differ with respect to focus (sector focused, district focused, infrastructure), process (bottom-up, top-down, mixed), and area of coverage (national, regional, citywide, neighborhood, or district). But there is some order beneath the apparent chaos.

First, there is concern about certain challenges and problems. Growth is a priority in many cases, coupled with the creation of knowledge and innovation districts, clusters, and digital business environments for growth. There is a very strong concern for sustainability, efficiency of the city infrastructure, energy savings, the use of renewable energy, water savings, waste management, and green transportation. There is also concern for better living, e-health, social care, and safety and security against natural disasters.

Second, there is convergence about the intervention logic that underlies the strategies. Beside their diversity, all strategies identify and address problems using processes that connect software applications, knowledge functions, and user-driven or data-driven innovations. It makes no difference whether the level of implementation is the entire city, a city cluster, a network, or a sector of activity. Strategies induce innovations by (a) enriching the urban system with smart environments, sensors, and applications for information processing, and real-time alert and response and (b) enabling user-driven innovation, involving citizens, customers, and users, and opening up innovation ecosystems to collaboration with suppliers, researchers, and innovators from within and outside the city.

From Strategy to Applications

Any smart city strategy includes applications and IT solutions as essential components and means of implementation. But strategies differ from smart city software applications in their holistic perspective. Software is a key element for data integration and transformation of information into knowledge and innovation. To understand the continuum from strategy to software, Nicos Komninos and colleagues have developed a roadmap of three stages and seven steps that captures the entire process of smart city planning.

As the smart city paradigm progresses, more and more applications are made available, and city authorities become aware of software that can be used in response to challenges and needs. Large-scale software repositories, such as GitHub, SourceForge, and Bitbucket, are important sources of software for cities and pillars for the dissemination of the smart city paradigm. The same holds for smaller and dedicated repositories of smart city solutions, such as the Code for America, Best Apps for Barcelona, and applications produced in the context of hackathons and competitions.

Open source licenses, modular software architectures, and cloud-based solutions can facilitate the uptake of smart cities. Sharing and replicability of solutions are maturity indexes of smart city development, especially the deployment of repeatable standard processes, the adoption of service-oriented architecture, and the use of open platforms across the various administrative departments of cities.

Impact Assessment

Monitoring and assessment is usually the last component and final stage of a smart city planning roadmap. It is a key activity to capture the intangible impact of smart cities, hidden in log files and administration registers. Measurement and assessment of intelligent city performance is about using key performance indicators, the creation of scoreboards, gathering of data, using analytics, and identifying factors that shape the performance of cities.

Different measurement methodologies are applied to capture the impact of smart cities. They vary with respect to the perspective and variables that are measured and assessed. Policy-focused measurement uses indicators that capture the effort of policies and planning; city-focused measurement is based on the characteristics and performance of cities; infrastructure-focused measurement relies on sensor data and can capture the usage patterns of urban utilities.

A good methodology of assessment should include a clear statement of objectives, define indicators that account for the entire process of urban intelligence, and combine a policy-focused and city-focused approach. Komninos and colleagues propose using key performance indicators from the building blocks of smart cities: knowledge skills, innovation ecosystem features, and digital spaces for the baseline condition; measuring efforts by investments and the use of broadband, ICT, and e-services; and documenting the outcome on typical subsystems of cities, such as the urban economy, quality of life, infrastructure, and government using widely accepted indicators (e.g., ISO 37120:2014).

In the current discussion on intelligence, super intelligence, or small artificial intelligence beating human competence in specific domains, smart cities show an alternative trajectory: a way toward coordination and integration. They paint a picture of how human intelligence and rule-based institutional intelligence can be augmented by machine intelligence and Internet technologies. It is a promising trajectory, not only for the future of cities but also for the future of humankind.

See also Smart Energy Systems; Smart Grids

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Further Readings

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