THE ARCHITECTURE OF INTELLIGENT CITIES
Integrating human, collective, and artificial intelligence to enhance knowledge and innovation

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ABSTRACT

Intelligent communities and cities belong to an emerging movement targeting the creation of environments that improve cognitive skills and abilities to learn and innovate. They represent environments that enable superior cognitive capabilities and creativity to be collectively constructed from combinations of individual cognitive skills and information systems that operate in the physical, institutional, and digital spaces of cities.

Two academic traditions have been feeding the discussion concerning intelligent communities and cities: the literature on innovative environments and the planning of digital cities. Following an introduction on the meaning of ICs, we discuss the structuring of innovative environments such as clusters, technology districts and territorial systems of innovation, which rely on different architectures of knowledge networks enhancing product, process, and organizational innovation. Then we turn to digital cities and examine their concept, architecture, and constituent elements. In the final section of the paper we describe intelligent cities as overlapping of innovative clusters and digital cities. Intelligent cities integrate knowledge-intensive activities and clusters; embedded routines of social co-operation enabling knowledge sharing and innovation; advanced communication infrastructure and digital spaces for knowledge and innovation management; and proven ability to innovate and resolve problems that appear for the first time, since the capacity to innovate and manage uncertainty are critical factors in characterizing intelligence.

INTRODUCTION

The term 'intelligent city' (IC) has been used with various meanings. At least four different descriptions of what an intelligent city is can be found in the literature:

- ICs have been frequently defined as *virtual reconstructions* of cities, as virtual cities. The term has been used interchangeably as an equivalent of 'digital city', 'information city', 'wired city', 'telecity', 'knowledge-based city', 'electronic communities', 'electronic community spaces', 'flexicity', 'teletopia', 'cyberville', covering a wide range of electronic and digital applications related to digital spaces of communities and cities (1).
- Another meaning was given by the World Foundation for Smart Communities, which links *digital cities* with *smart growth*, a development based on information and commnication technologies. '*A Smart Community is a community that has made a conscious effort to use information technology to transform life and work within its region in significant and fundamental, rather than incremental, ways*' (2).
- ICs are defined as environments with *embedded information and communication technologies* creating interactive spaces that bring computation into the physical world. From this perspective, intelligent cities (or intelligent spaces more generally) refer to physical environments in which information and communication technologies and sensor systems disappear as they become embedded into physical objects and the surroundings in which we live, travel, and work (3).
- Intelligent cities are also defined as territories that bring *innovation systems and ICTs* within the same locality, combining the creativity of talented individuals that make up the population of the city, institutions that enhance learning and innovation, and digital innovation spaces facilitating innovation and knowledge management (4) and (5).

The diversity in understanding what intelligent cities are, is due to the multiple scientific and technology disciples and social movements that take part in their creation, namely the movements towards 'cybercities', 'smart growth', 'intelligent communities' and 'intelligent innovation environments'. We should underline, however, that major movements shaping intelligent cities, like Smart Communities and the Intelligent Community Forum, promote under ICs innovation, smart growth, and digital community spaces.

For us, intelligent cities and regions are territories with high capacity for learning and innovation, which is built-in the creativity of their population, their institutions of knowledge creation, and their digital infrastructure for communication and knowledge management.

The distinctive characteristic of intelligent cities is their increased performance in the field of innovation, because innovation and solving of new problems are distinctive features of intelligence. In this sense, intelligent cities and regions constitute advanced territorial systems of innovation, in which the institutional mechanisms for knowledge creation and application are facilitated by digital spaces and online tools for communication and knowledge management.

CLUSTERS AND SYSTEMS OF INNOVATION

The way for intelligent cities and regions is paved by clusters of innovative organizations forming networks, technology districts, poles, and systems of innovation.

Today, the mainstream view for innovation is that it is systemic. Theories of innovation have radically changed during the past few years. Both the traditional Schumpeterian model (6), regarding innovation as an internal activity of the firm and the linear innovation model in which new product development follows a step-by-step sequence from discovery, idea generation, business case analysis, to product development, testing, and launce (7), have been found inadequate. Innovation is increasingly regarded as a collaborative and evolutionary process taking place within environments augmenting discovery and idea generation and selecting the most plausible innovations.

The systemic theory of innovation was initially formulated at national level. Founding publications by Lundvall (8) and Nelson (9) described and focused on national systems of innovation. Gradually however, there was a shift towards the regional and local levels. A series of publications have shown that innovation processes are embedded in regional conditions shaping regional systems of innovation (10), (11). Kaufmann and Todtling (12) identified five major mechanisms than explain the regional embeddedness of innovation:

- Many of the preconditions of innovation, such as qualifications of the labor force, education, research institutions, knowledge externalities and spillovers, are immobile, giving some regions advantages over others.
- Industrial clusters are localized giving rise to specific innovation patterns within networks and industry sectors.
- A common technical culture may develop through collective learning taking place into a regional productive system.
- University-industry links and knowledge spillovers are region specific.
- Regional policy is playing an active role in innovation providing support through institutions and agencies.

The structure of such regional agglomerations and territorial systems of innovation (technology districts, technopoles, innovative clusters, technology parks, innovating regions) can be described in terms of components, knowledge networks, institutions, and innovation outcomes.

In innovation-led clusters, main actors come from the company, the R&D, the technology transfer, and the funding sectors. Components of the systems are innovative firms; supplier firms; customer firms; universities; research organizations; technology transfer institutions; IPR lawyers; consultants; training institutions; incubators; funding organizations; government agencies; monitoring organizations.

Components are organized in networks because innovation is based on their combined action. What gives value to components is their cooperation. The reason for the networks' existence is to enable innovation, facilitate and augment creativity at the company level, the latter being the ultimate producer and beneficiary of innovation. Various forms of networks appear within innovation systems: clusters, technology districts, small innovation systems, flexible short term alliances. The connecting substance of all networks is knowledge. What flows within innovation networks is mainly knowledge.

All kinds of knowledge flow within innovation networks. Dawes (13), reviewing the literature on knowledge types argues that knowledge can be divided into three categories: declarative (about facts), procedural (dealing with know-how), and conditional (linking conditions and effects); it can also take two forms, 'explicit knowledge' that is transmittable in formal languages, codified and captured in libraries, archives and databases; and 'tacit ' knowledge which has a personal dimension that makes it hard to formalize and transmit in other ways than personal communication. Morgan (14) has explained that tacit knowledge is spatially sticky, and this quality sustains the trend of innovative activities towards agglomeration.

A critical element for the operation of knowledge networks is institutional action. Institutions for knowledge creation, information dissemination, intellectual property management, knowledge assessment and funding act as switches which turn funding on and off and take 'kill' or 'go' decisions in the innovation process. To do so, institutions are placed upon the knowledge networks linking the company with its external partners. Knowledge networks and institutional regulation change from one innovation round to the other, enabling a constant renewal of technologies and avoiding technology lock-in.

Knowledge networks architecture changes with respect to the innovation processes that take place in the system. Innovation routes, such as cooperative R&D, strategic intelligence, product innovation, process innovation, spin-off creation, opening new markets, attraction of knowledge-intensive organizations, involve fundamentally different knowledge networks. Different forms of innovation demand different partners and alliances. A cooperative R&D project demands quite different network architecture from a cooperative project of strategic intelligence for a cluster.

The entire landscape of knowledge networks within innovative clusters is extremely complex and variable. In the connectivity of components (partners) two conditions predominate:

- The creation of knowledge networks with various architectures, which are separated by science and technology borders; and
- The operation of switches regulating the flow of knowledge between the components, which are administrated by knowledge creation, transfer, and application institutions, namely R&D centers, technology intermediary organizations, and companies.

Major forms of innovation within clusters (product, process, and organizational innovations) stand on different architectures of knowledge networks, focusing on new product development, technology transfer, and the supply chain. Because innovation relies on knowledge and information networks, digital spaces and collaborative IT applications have become an important source of novel product, process, and organizational solutions.

DIGITAL CITIES

The digital city is the dominant form of community space corresponding to a territory. Digital cities cover a very wide range of digital networks and software applications facilitating multiple aspects of the social and economic life of cities: commerce, transactions, security, health, education, work, leisure, transport, and others.

Authors of two important books on digital cities claim that the concept of digital city is a metaphor (15), (16).

> '*As a platform for community networks, information spaces using the city metaphor are being developed in worldwide*' (p. 87) (17).
>
> '*It is evident that "digital city" is a metaphor. Metaphors (from Greek metaphora – transfer) serve to create new meanings by transferring the semantics of one concept into the semantics of another concept. Metaphors are habitually used to interpret an unknown "world" (perception, experience, etc.) – the target – in terms of a familiar world – the source. Metaphorical explanation often helps us understand highly abstract and complex phenomena by relating them to phenomena we know well (or, at least, better). In so doing, a metaphor preserves (part of) structure of the original concept, but substitutes its functional contents, anticipating the corresponding change in its properties and meaning.*' (p. 57-58) (18).

This understanding is based on an assumption of strong similarity between the physical city and its digital counterpart; a similarity that goes beyond the image of physical space and includes structural and functional characteristics as well. The '*digital city is a metaphor called to denote a complex digital product with properties structurally similar to the ones of physical cities*' (p. 66) (18).

We won't agree with this description. It is common knowledge that a digital city is structurally different from the physical city of reference. Not all elements of the physical city have their equivalent digital representation. Imaginary elements may also take part in the digital construction. Proximity in terms of distance and time is warped. Even in simulations, 2D in the case of urban transport agents and 3D in the case of reconstruction of historical spaces and city buildings, similarity does not go beyond the form of the city. The functional aspects of the city are poorly represented through extreme simplification; social and economic relations are not represented at all.

For us, a digital city is a community digital space, which is used to facilitate and augment the activities and functions taking place within the physical space of the city. The community space is built as network of distorted representations of the city. The representation is distorted for two reasons. First, it represents a city partially and not accurately; and second, it may include virtual elements non-existent in the physical space. The community space is network-based because each element of the digital city is linked to an element of the physical city, and to other digital elements of the community space; and limitless relationships and dynamic combinations between its constituting digital elements are possible.

The distorted digital representations reflect both the space and the functions of the physical city. The informational part of the digital city represents the activities of the city; the site-seeing part represents the physical space of the city; e-market applications represent commerce and stores of the city; e-health applications represent health services, and so forth. Through these representations and their links to physical city infrastructure and services, a digital city may inform and mediate in transactions and provision of real services of commerce, health, education, government.

Understanding the digital city more as a distorted representation than a metaphor or simulation of the physical city implies that the architecture of digital cities is not homologous to physical ones; it doesn't derive from the physical city and its functions, but from the qualities of the digital elements and the scope of their existence. The digital dimension has its own rationality; it is not merely a derivative of physical space.

Ishida (17) gives a good account of the diversity of digital cities' architecture. He compares four different types of cities on the web, and looks at their architecture of data, form, and functions:

- A commercial digital city, which concentrates on commercial information with principal scope of making money for its owners. Digital cities created by America Online (AOL) follow this model and are structured as portals similar to 'yellow pages'. They provide local information, relevant news, community resources, entertainment, and commerce, together with advertising local markets such as auto, real estate, employment, and health.
- A policy-driven or governmental digital city, the digital city of Amsterdam, which was created to facilitate communication between the municipal council and the citizens.
- A virtual city, the virtual Helsinki, which represents the city using 3D models of buildings and public spaces, offering virtual tours and broadband communication between the citizens and various service providers located in the city.
- A multi-purpose digital city, the digital city of Kyoto, in which people can get information on traffic, weather, parking, shopping, take a view of the physical environment and sightseeing thought 3D models and panoramic pictures, and have opportunities for interaction with other residents and visitors.

The architecture of the four cases varies enormously (on the same see also, Schuler (19). In the most advanced multi-purpose and multi-functional digital city of Kyoto, the construction of the city is based on three layers. The first, which Ishida calls 'information layer', contains data; it is a repository of raw material, html archives, real-time sensory data, media, text, and other data organized in geographical databases. The second layer is the 'interface layer', which contains maps of the city, 3D representations, city furniture, cars, buses, trains, avatars that simulate the human presence and all the graphic design and objects that visualize the city. The third layer is the 'interaction layer' where people interact with each other, exchange information and communicate. In the other cases (commercial city-portal, communication platform, and virtual city) architectures are simpler. The city is reduced to just a directory of urban information organized as a portal of logical and meaningful categories; to a platform for communication, a forum giving access to the municipal discussion and debate; to an aggregate of visual data.

Through this comparative study, it becomes clear that the architecture of digital cities is not uniform, but it is objective-driven, designed to fulfill scopes of information, communication, and service delivery. However, it seems possible to devise a universal model of digital cities from which all combinations and alternative designs may derive.

Looking at a large number of digital cities on the web, we found that their architecture may be described by a four level structure. The first is the *information storehouse*, a database including all digital content, in any form, texts, images, diagrams, sounds, video, and multimedia. The digital content is usually organized according to the logical patterns, the districts, and the hierarchy of the city. The second is the *applications* level, which structure the digital content and provide online services. A digital city that offers information services, e-market, and e-government, includes at least three applications, which assume the tasks of delivering information, commercial, and governmental services. The third and upper level is *user interface*, which includes all the web pages that users visit in order to get the services provided by the digital city. Driving a user in the different areas of the digital city, the user interface may utilize maps, 3D images, texts, and diagrams. Then, a fourth level is *administration*, a tool crossing the database and the applications, which enables managing the user rights to the applications and the digital content of the database.

This universal architecture of digital cities is composed of three vertical levels (content, applications, and interface) and multiple horizontal applications (functions), depending on the breadth of the digital city services (representation, information, work, leisure, commerce, transactions, etc.) (Fig. 1). The model is generic and by customization may serve any concept of digital city, specialized in site-seeing, e-government or e-work. The structure is independent of the medium on which the city runs. The latter may be the Internet, a municipal network or a metropolitan network made of fiber optic lines or wireless links.

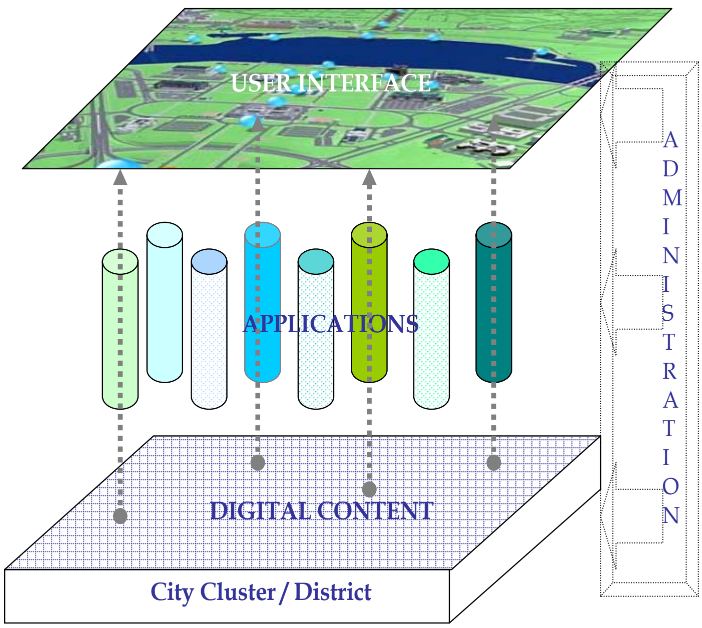

Figure 1: Digital Cities Structure

This conception, which is common to many digital city developers, suffers from overplanning. The digital city is conceived as a fully controlled digital construction created by a central agency, which has absolute control over all its elements and functions. This would never happen in a real city. Cities emerge from multiple actions of their people rather than being created by a central planning agency of absolute power. They materialize the effect of countless simultaneous preferences, choices, and actions, rather than the will of a central planning authority.

Transferring the organization principles of physical cities on the level of digital ones implies avoiding the characterizations of individual websites as digital cities. On the contrary, the sum of websites referring to the form, activities, and functions of a city should be considered a digital city, regardless of the number of these websites and their hosting in various cities and regions of the globe.

ARCHITECTURE OF INTELLIGENT CITIES

Intelligent cities are created by the fusion of innovative clusters and digital cities, with the purpose to enhance knowledge and innovation. The fusion is based on two objective conditions: (1) innovation and digital cities are both community-based processes, and (2) innovation and digital cities are both knowledge-based processes. The fusion stands on **collaborative knowledge networks** and online regulation of knowledge and innovation processes.

Integration of innovation and broadband is quite obvious in the criteria of the Intelligent Community Forum (ICF) for the selection of Top Intelligent Communities.

> *'ICF has developed a list of Intelligent Community Indicators that provide the first global framework for understanding how communities and regions can gain a competitive edge in today's Broadband Economy. The Indicators demonstrate that being an Intelligent Community takes more than "being wired." It takes a combination of —*
>
> *• Significant deployment of **broadband communications** to businesses, government facilities and residences, with government providing a catalyst through regulation, incentives and even network construction when necessary.*
>
> *• Effective education, training and workforce development that builds a labor force able to perform "**knowledge work.**"*
>
> *• Government and private-sector programs that promote **digital democracy** by bridging the Digital Divide to ensure that all sectors of society benefit from the broadband revolution and by expanding citizen participation in government decision-making.*
>
> *• **Innovation** in the public and private sectors, ranging from egovernment initiatives and efforts to create economic "clusters" to the formation of risk capital to fund the development of new businesses, which are the engine of economic growth.*
>
> *• Effective economic development **marketing** that leverages the community's broadband, labor and other assets to attract new employers.* (4)

Intelligent cities and regions are not lifeless spaces, complexes of buildings, physical infrastructures, and electronic components and digital applications. On the contrary, they correspond to vivid human communities, which creatively deploy the skills of the population, their collective institutions for learning and innovation, and physico-digital infrastructures for communication and online cooperation.

From this point of view, an intelligent city is a multiplayer territorial innovation system. It combines knowledge-intensive activities, institutions for cooperation and distributed problem solving, and digital communication infrastructure and tools to maximize this problem-solving capability. As fusion of innovative clusters and digital community spaces, it is structured in three levels.

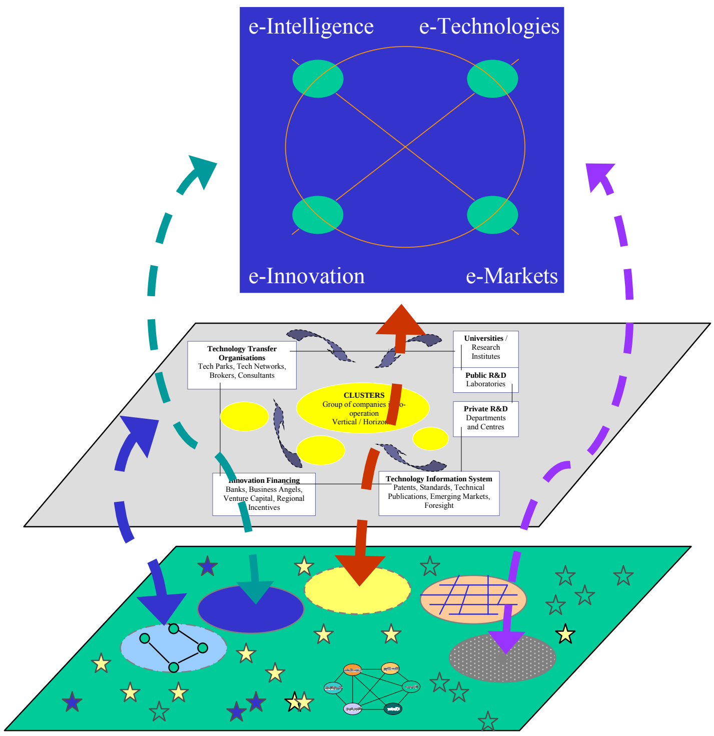

Figure 2: Architecture of Intelligent Cities

L1: The basic level of an intelligent city is the city's productive clusters, in manufacturing and services. This level gathers the creative class of the city made by knowledgeable and talented people, scientists, artists, entrepreneurs, venture capitalists and other creative people, determining how the workplace is organized and how the city is developing. Proximity in physical space is an important factor that facilitates knowledge cooperation and exchange among producers, suppliers, service providers, and knowledge workers.

L2: A second level is made of institutional mechanisms regulating knowledge flows and co-operation in learning and innovation. This level gathers institutions enhancing innovation: R&D, venture capital funds, technology transfer and training centers, intellectual property, spin-off incubators, technology and marketing consultants. Institutions manage intangible mechanisms of social capital and collective intelligence that guide the matching of individual capabilities and skills, and actualize the complex processes of innovation within the clusters of the city.

L3: The third level is made up by information technology and communication infrastructures, digital tools and spaces for learning and innovation. These technologies create a virtual innovation environment, based on multimedia tools, expert systems, and interactive technologies, which facilitate market and technology intelligence, technology transfer, spin-off creation, collaborative new product development, and process innovation. This is a working environment operating in close connection with innovative organizations and institutions regulating knowledge and innovation.

The three levels are integrated and work complementary to each other. Within innovative clusters, digital city applications complement knowledge networks and institutional switches regulating innovations. Four functions, which are characteristic of intelligent cities, emerge out of this integration.

F1: Collective strategic intelligence

A field of innovation which has enormously profited on the information society is strategic intelligence. Digital cities may promote a particular form of strategic intelligence, 'collective strategic intelligence', in which information collection, assessment, and dissemination rely on the combined action of a group of people, a community, or a business cluster.

Collective strategic intelligence differs substantially from business intelligence, the most known form of intelligence. The latter concerns the exploitation of company information gathered from suppliers and customers; it uses data from enterprise resource planning (ERP) and customer relationship management (CRM), and applying data mining and data compilation techniques produces reports elucidating hidden aspects of the business environment and activity. Collective strategic intelligence, on the contrary, is cooperative. Data comes from a group of organizations or other actors, which disclose and share internal information. Information assessment is also collective and combines individual views and evaluations from the group members. Outcomes are more robust and provide information about wider trends and landscapes.

Cooperative digital platforms for collective strategic intelligence combine two types of applications: technology/market watch, and benchmarking. Technology watch is a systematic form of collection, analysis, understanding and diffusion of information concerning new product announcement, technologies, industrial statistics, performance indicators, market shares, price trends, etc. Data are stored into databases, portals, blogs and other digital repositories according to predefined templates. Data may focus on an industry sector or a territorial entity. Benchmarking is a form of analysis, which compares performances and drawn lessons from the best. It has proven a powerful tool of intelligence and the techniques of comparative analysis have spread out in many fields of management and policy development. Benchmarking started from companies, and has spread out to clusters, territories, and policies as well. It provides insights to any type of organization or institution, company, R&D lab, education institution, hospital, financing institution, etc. or collective subject, such as the industry sector, cluster, region, policy and strategy as well. The methodology seeks to define the range of performance variation in any field of activity, the best performance, the distance from the best, and the practices that sustain performances. Identification of best performance and the underlying best practice are the essential pillars of any form of benchmarking (see for instance, http://www.urenio.org/metaforesight/).

F2: Technology transfer

Technology transfer process usually involves moving know-how from an R&D organization to a receptor organization (20). Major forms of technology transfer involve licensing, cooperative R&D, and spin-offs. *Licensing* agreements concern the transfer of intellectual property rights in order to make, use, and sell a certain product, design, or service by a party that has the right to give this permission. *Cooperative R&D* or *contract R&D* agreements are comprehensive legal agreements to share research personnel, equipment, and intellectual property in a common research objective /project. *Spin-off creation* offers a mechanism to commercialize technologies originated from a university lab, a government R&D centre or private R&D organization. It involves the creation of a new company from the parent organization, which undertakes the commercial exploitation of a technology. Types of technology transfer closer to the market also include consultancy and technical services provision, purchase of equipment, and training (21).

Digital platforms facilitating technology transfer are based on data bases of technologies and R&D results. Technologies are stored into the databases and online marketplaces of technology for license are created.

Organizations offering technologies introduce their offers and the conditions of exploitation. Users may seek solutions to their technology needs, and then contact the provider. There is a fundamental difference from patent data bases, which store patent abstracts designed to protect an idea from violation. In most cases patent databases obscure the technology, making it difficult to foresee relevant applications. On the contrary technology transfer platforms seek to elucidate possible uses and application of technology in different industry sectors and activities.

Technology marketplaces are coupled with other online services related to technology transfer: consultative services assessing a portfolio of intellectual property; evaluation of better solutions to a given problem or need; legal assistance through the deal-making process. The objective is to digitalize as much as possible the practices of technology transfer enabling an online interaction and technology cooperation (see for instance the toolbox on http://www.newventuretools.net/).

F3: Collaborative innovation

This newest form of innovation recognizes the critical role of communities and networks as fundamental conditions of innovation. Interactions within scientific communities bridging separate knowledge fields, complementary roles and skills along the innovation chain, information flows among suppliers, producers, and customers, are all ingredients of participatory creative processes leading to new products. Innovation is less of an individual achievement than the joint effort of a group of people working together, interacting, and sharing the same values and goals. The leading role of communities and systems in the field of innovation is acknowledged by most contemporary explanations of how innovation is produced: brokering theories, systemic theories, and tacit knowledge explanations of the innovation process.

The supply of innovation communities with digital platforms and cooperative work environments enables the formation of virtual clusters equipped with online innovation management tools, such as creativity tools, virtual customers, collaborative product design tools, market research, and marketing tools. These platforms offer collaborative environments for product development; may lead the user to problem resolution step-by-step, for instance through the stages of new product development; include advanced methodologies and tools; and learning and experimentation through simulation (see, i.e. http://www.vrc.gr:8080/npd-net/en/npd/index.html). The result is a substantial improvement of human innovation skills, because of collaboration and offering of advanced technologies and product development tools to even the most remote knowledge worker.

F4: Promotion of clusters and localities

Promotion and electronic commerce is a mainstream function of digital cities. It may take multiple forms: direct marketing, attraction of people and investments, procurement and purchasing, auctions, travel, community and e-government services.

The focus is the supply chain of products and services produced by a cluster or locality. Information and knowledge networks are necessary for the functioning and optimization of the supply chain. The partners are connected by information channels and the flow of information between two partners has to be monitored to ensure the optimization of the system.

Within the supply and trade channels, digital cities have multiple added-values. Virtual spaces may facilitate, enhance, and reduce costs in all forms of transactions: logistics in the supply chain; marketing and advertising; information on policies, regulations, technical standards, and incentives; finding partners, buyers, sellers, and services (22).

The difference from individual promotion and e-commerce is that collective applications promote a cluster or locality together with its products and services. For small producers and global markets, this is an advantage. For new products in niche markets, a global market is necessary, which cannot be reached without digital tools.

Apart from the intra-functional integration among knowledge networks operating within clusters, institutions regulating learning and innovation, and digital spaces, which takes place within each of the above mentioned functions (F1, F2, F3, and F4), intelligent cities are environments for inter-functional integration also. Collective strategic intelligence is truly important for technology transfer, product innovation, and marketing. In many cases technology transfer is a precondition for product innovation. The latter depends on promotion and opening of new markets. Knowledge networks traverse innovation forms and processes, and digital spaces do the same as well.

Intelligent cities are still in their early days. To date, most applications are being developed with respect to innovative clusters and technology parks, as intelligent clusters, technology districts, and technology parks. In these islands of innovation, the innovation system is being enriched with communication infrastructure, expert systems, and knowledge management tools, creating an integrated physico-virtual innovation system. Its architecture, as described, includes three levels (physical, institutional, digital) and four functions (intelligence, technology transfer, innovation, and promotion). Within the physico-digital innovation environment, human and institutional factors predominate. Digital spaces and the online expert tools act as facilitators of human and collective intelligence.

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