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Technologies for smart cities: a reflection

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ABSTRACT

The use of the so-called 'smart' technologies has been pervasive. Here we briefly examine the most interesting technological systems that may allow cities to function in more efficient and effective ways for providing satisfactory experiences to their citizens and visitors. All of these are based on a heavy use of data that today might be available in huge quantities because generated by the intensive use of online applications. We then examine some issues related to the sustainability of the digital world. The final discussion remarks that good outcomes from the possible implementations can only be obtained when correctly considering the need for a thorough revision of operational and organizational processes, making them suitable for digital treatments. Objective that can be reached when adopting a good collaborative attitude of all the stakeholders involved.

KEYWORDS: information and communication technology, smart cities, data science, digital sustainability,

1 INTRODUCTION

The wide diffusion and evolution of digital technologies have profoundly changed all aspects of our lives and have had an incredible impact on all economic sectors. Their capabilities make us think that it is possible to attribute them some kind of intelligence which leads to the emergence of the concept of smartness for those environments (cities, organizations, territories, regions, etc.) that make intensive use of them.

Although many different definitions for 'smart' exist, in practice a smart environment can be loosely thought to be one in which the widespread use of Information and Communication Technologies (ICTs) allows all stakeholders to easily access knowledge and information thus facilitating and making more efficient their activities while providing value to their users, partners or customers.

A growing number of studies has been attempting to analyze, also empirically, the technological, organizational and business foundations of this concept along with the technologies and the architectures needed or employed. Further, most of the existing studies seem to suggest, at least implicitly, that the wide and pervasive use of technology alone might make it possible to consider an environment as being 'smart' [1].

This occurs even though, when assessing the relationships among the different stakeholders, it has been shown that the real (i.e. offline) and the virtual (i.e. technology-mediated or driven) components need to be considered as being structurally strongly coupled and co-evolving, thus forming a single system, without the prevalence of any component (see e.g. [2, 3]). Hence, it is crucial, for a smart approach, to pay good attention to everything that needs to be planned and implemented (e.g. revision of processes and practices, changes in organizational culture, etc.) to render this fascinating technology-driven model real and effective.

In a city, the adoption of cutting-edge technologies and their combination with efficient organizational models may promote cooperation, knowledge sharing, and open innovation among private and public service providers and offer innovative integrated services. The net result sought after is an increase in the quality of life for permanent or temporary citizens. Modern automated methods allow a better understanding of people's desires and behaviors by exploiting the huge quantities of data made available by the intensive use of online applications and new technological models (augmented reality, robotics, internet of things, blockchain applications, etc.) provide a variety of effective tools for reaching these objectives.

In what follows we examine briefly the most advanced and promising technological developments and discuss possible application frameworks and the basic requirements of integration and standardization for their effective and efficient use.

Finally, we consider that, to be effective, a city needs to measure and monitor constantly the basic parameters that concern its 'life' and the response of actual and potential citizens through a well-organized and planned dashboard to acquire all information needed for its activities and services.

2 INTERNET AND THE WEB

The birth date of the Internet is commonly set to 1969 when the first four computers were connected. In the next years, the network grew and stabilized its architecture adopting the TCP/IP (transmission control protocol/internet protocol) protocol suite. Internet came into broad public use with the emergence of the World Wide Web in the mid-1990s. and has become a mass phenomenon at the beginning of the current century. In some more than thirty years, then, an incredible number of technologies have been developed and widely diffused so that today practically any form of communication using any message format (text, numbers, sound, images, video) uses this fundamental infrastructure.

The Internet is a foundational technology, a basic 'invention' that does not provide a disruptive application per se but enables progress and applications in a variety of areas and creates a complex (digital) ecosystem able to modify profoundly the domains affected. Foundational technologies may take decades to penetrate and integrate with economic and social infrastructures, usually with a gradual and steady process of adoption that depends on the novelty of the applications and the coordination efforts needed to make them practicable. Low levels of novelty and complexity help a fast acceptance. Technologies with high novelty and complexity may take years or decades to evolve but then have a great transforming power for the social and economic environment. Some elements, however, might greatly speed up a wide adoption. For the Internet (and the Web) these are the technical choices that underlie their structure and functioning [4, 5]:

- *Openness and standardization*: the system is an open system. The basis is a set of standard protocols collaboratively agreed upon and shared between the different actors. The standards are public and freely available to anyone who wants to use them.
- *Protocol layering*: functions are performed by different levels of software that communicate between them. Each level performs a specific set of operations and may contain multiple entities (applications, processes, hardware, etc..).
- *Modularity and interoperability*: objects, systems, and programs are composed of (small) independent parts that can be combined to provide functions of greater complexity. The use of standard protocols and formats allows a smooth interoperability of hardware and software devices.
- *Neutrality*: the system behaves neutrally about the capabilities of any kind of application and of the terminals connected (end-to-end).

In this virtual world, we have seen the most creative and innovative accomplishments. As a set of general-purpose technologies, the Internet creates value in itself and forms a particularly prolific *humus*, extremely effective for the production of applications that help people and companies do their work or help them to do so more efficiently. This huge influence on the very essence of social and economic environments, and the integration with them, has generated the perception that the difference between the 'real' and the 'virtual' worlds disappears. As Wellman stated some years ago [6], computer networks, more than technological systems have become *"inherently social networks, linking people, organizations, and knowledge"* and have evolved into "*social institutions that should not be studied in isolation but as integrated into everyday lives.*" Luciano Floridi in his *Onlife Manifesto* [7] reinforces this view stating that: "*the ever-increasing pervasiveness of ICTs shakes established reference frameworks through the following transformations:*

i. *the blurring of the distinction between reality and virtuality;*
ii. *the blurring of the distinctions between human, machine and nature;*
iii. *the reversal from information scarcity to information abundance; and*
iv. *the shift from the primacy of entities to the primacy of interactions.*"

3 DATA AND ARTIFICIAL INTELLIGENCE

One consequence of the global diffusion of modern ICTs, mainly in the form of Internet online platforms, is the creation of a vast number of digital traces that can be collected, stored, and studied. Moreover, the relatively recent addition of connected physical devices and sensors (devices that sense their environments), that can transmit their recordings, has further widened this possibility.

The term commonly used for this phenomenon is 'big data'. Although the large quantity is the most visible feature, other characteristics are worthy of attention because they drive the issues and the opportunities associated with this occurrence: the variety of the forms they take on (texts, videos, images, etc.) and their dynamicity and variability. These are intrinsic features of most unstructured elements that can assume different meanings in different contexts even if they have similar forms, meanings that, what is more, can vary over time.

Traditional statistical methods for the analysis of big data have shown to be insufficient or unable to provide meaningful outcomes. Their basic features may need an extensive use of resources (hardware and software) and new approaches such as those made available in the framework of artificial intelligence (AI) and machine learning (ML). These terms have almost become synonyms, but machine learning, as part of the wider field of AI, is the fastest-growing field and has produced the most commonly used techniques for automatically treating data.

AI was originally defined by Minsky [8] as a technology (or machine) that can perform a task that, if conducted by a human, would require *intelligence* to complete. Subsequent definitions ascribe AI with the capacity to learn, sense, reason and take action as well as to detect, deliberate and develop on its own to *"discover which elements or attributes in a bunch of data are the most predictive*" [8, 9].

Machine learning is [10]: "*programming of a digital computer to behave in a way which, if done by human beings or animals, would be described as involving the process of learning*". Thus, it implicates giving a software program the ability to modify its behavior according to events (input data) and outcomes (outputs) provided, without being explicitly programmed to handle each specific situation. Applications range from data mining programs that discover general rules or patterns in large data sets, to information filtering systems that automatically identify users based on interests or preferences, to clustering large collections of objects into a small number of classes, to recognizing shapes or sounds, and so on. In addition, the most recent developments have offered also the capacity to generate seemingly novel objects: texts, images, videos [11, 12].

Many applications today, and for what is foreseeable in the near future, make available useful and effective methods for the general practice of the analysis of behaviors, needs, and desires, for general business intelligence, and for predictive capabilities that can make more effective various forecasting activities [13, 14].

4 INTERNET OF THINGS AND ROBOTICS

When well coupled with some mechanical device, artificial intelligence and machine learning software form robotic assemblies, that is machines capable of carrying out a complex series of actions automatically, guided by some control device or, in some cases, autonomously. Widely used in manufacturing plants and other settings for dangerous or repetitive tasks, robots have recently made their appearance also in many other fields [15].

Internet of Things (IoT) has become a common term for indicating the wide array of environmental sensors and actuators or other devices endowed with some communication capabilities and connected through the Internet, often via cloud services. In the many domains, IoT systems are spreading and used for several purposes. In a building, for example, it is possible to personalize all the environmental settings (temperature, lights, water flows, etc.), to control accesses, or to check the operational status of different devices and appliances for predictive repairs and maintenance. Rather obviously the two areas are merging, recognizing that IoT, together with the Web of Things (WoT) could provide many benefits to robotic systems [16]. This combination, named IoRT (Internet of Robotic Things) is, more or less, the backbone for the so-called Industry 4.0 in which innovation in digital systems is providing (or can provide) new possibilities in both industrial and research fields, embracing various domains such as manufacturing, agriculture, health, surveillance, travel, and education, to name but a few [17]. Besides pure recording, a wise application of machine learning algorithms allows using IoT assemblies for optimizing or managing automatically many processes. This is, without any doubt, an essential aspect for ensuring the construction and development of a smart environment [18].

5 VIRTUAL AND AUGMENTED REALITY

We can add here the different implementations of mixed reality, i.e. the combination of the twin technologies of virtual reality (VR) and augmented reality (AR). This is the ‘blending’ together of real and virtual objects, where virtual elements are placed and aligned to appear to the user as part of a tangible world and provide context-sensitive intelligence about the users' immediate surroundings. Beyond gaming and entertainment, many useful applications have been (and continue to be) implemented in many domains [19] and are increasingly used as marketing, information, and experience means for their capability to provide different layers of contextual information.

Besides that, there is a recognition of AR’s organizational value as a good communication channel presenting opportunities to improve processes, functions, and relationships. Finally, the possibility to capture and retain customers’ attention through the provision of more engaging and interactive content is highly appreciated as it greatly contributes to increasing their access to information and improving their desire for knowledge and as a novelty factor. This reinforces the advantages of AR, in comparison to traditional forms of media, such as text and audio [20].

6 BLOCKCHAIN

Blockchain technology is one of the most talked about technologies in this period. Digital currencies such as Bitcoin and Ethereum have used this technology and made it popular for their rapid and large diffusion. However, more than that, blockchain is a general foundational technology that is finding numerous applications in many different domains [21, 22] even if less easily employable than previously thought for its technical peculiarities [23].

A blockchain is a list of digital records in packages (called blocks) that are linked and secured using cryptographic techniques; the digital records can be transactions, contracts, or documents of any nature. These digitally recorded "blocks" of data are stored in a linear chain. Each block in the chain contains data (e.g. bitcoin transaction), is cryptographically hashed, and time stamped. The blocks of hashed data draw upon the block that comes before in the chain, ensuring all data in the overall chain has not been altered thus providing a strong security layer, naturally and directly embedded into the system. Actually, Blockchain systems are part of the wider set of distributed ledger technologies (DLTs). These are replicated, shared, and synchronized digital databases, geographically spread across multiple sites, countries, or institutions. For their design, based on peer-to-peer networks, DLTs offer significant benefits in terms of efficiency and economy and create a more robust environment for real-time and secure data sharing.

Besides the arrangement in secured blocks, the second component of a blockchain system is a consensus mechanism (protocol) that allows participants in the system to validate the single blocks and insert them into the chain. The rights to validate can be attributed to selected participants, or the organizers of the chain, or rendered 'public' allowing, in principle, any participant to undertake the task. In this latter case, however, experience with the cryptocurrencies that use these methods has shown that when the system grows in size, the requirements in terms of computing power and resources become incredibly high and only a few 'giant' providers could have the necessary means [24, 25].

7 THE METAVERSE

In times of technological innovation and digital transformation, the systems known as Metaverse do not introduce any particularly new technological instruments. They rather try to organize a diverse set of technologies such as augmented reality (AR), virtual reality (VR), blockchain, 3D modeling and simulation, cloud and edge computing environments into a single interconnected digital space where users can engage through computer-generated applications. This convergence defines its relevance and potential, mainly when thinking about the possible integration of state-of-the-art artificial intelligence with its ability to recognize spoken and written language, understand intentions, interpret different languages, and engage in conversations that mimic human behavior using voice communication [26, 27].

Quite popular a couple of years ago, the public attention seems to have faded away so we might ask whether the Metaverse is merely hype or a pivotal moment steering us into a new era. Even if there are uncertainties about its future, the coming years seem to promise significant developments. While the hype on the Metaverse has declined, the fundamental concepts, underlying technologies, potential advancements, and associated challenges remain as relevant as ever. As some maintain, the reduced media spotlight may pave the way for a more fertile ground for future opportunities to flourish and suggests the possibility of a rich array of applications in the near future despite the many big challenges in the economic, social, legal, and technical areas of which, probably, the most relevant is a lack of standardization and interoperability [28, 29].

8 DIGITAL SUSTAINABILITY

When thinking about the implementation of smart systems we cannot help considering the issues related to sustainability matters. When facing the many significant global challenges, we deal with today, the pursuit of a balanced social and economic development and the preservation of natural resources are of fundamental importance. In this regard, the role of science, technology, and innovation in promoting sustainability is crucial [30].

Digital sustainability can be defined as "*the convergence of digital and sustainability imperatives that involves a trans-disciplinary approach of deploying digital technologies in tackling sustainability issues*" [31]. The increasing interest in digital sustainability emerges from two important socio-technological trends: the urge for a global environmentally sustainable development and the blurring boundaries between human activities and the digital sphere. These topics are not new but have seen an expansion in recent times as a result of the ubiquity of digital technologies and the increased frequency of extreme climate-related events. Besides the environmental concerns, however, social and economic issues need to be concurrently considered for a digital sustainable development. Across all three domains, the development and use of digital ICTs can have both positive and negative impacts. In short, "*the concept of digital sustainability underlines the consideration of digital technologies' potential negative effects on the environment, society, individuals and the economy.*" [32].

The recent pandemic has worked as a catalyst for an expanded adoption and integration of ICTs into various aspects of our lives. Remote work, online education, virtual healthcare, electronic commerce and digital communications have become integral components of the daily routines even for those who had no previous familiarity [33]. This digital acceleration has profoundly transformed our understanding of sustainability and how we relate to the external environment, in terms of its socio-political, economic, and environmental factors.

Digital sustainability plays an important role as it involves deploying digital technologies to tackle sustainability issues [30]. Central to this concept is the recognition that ICTs are not just tools but instrumental technologies that significantly shape our perception of reality [7, 34]. This consideration implies the need to avoid any form of technological determinism, where technology is seen as the sole driver of change, and instead recognize the value of a nuanced approach to the interplay between science, technology, and society. Technology, in short, should not be considered solely as a utilitarian tool but as a means of interpreting reality [35] and its prominence over knowledge needs to be questioned to rebalance science, technology, and ethics [36]. In a way, the distributed morality of complex ecosystems should involve an acknowledgment that ethical considerations must be extended beyond human actors to embrace the broader set of interactions that bind technologies, nature, and society [37]. Attributing responsibility and accountability to actions and decisions in a dynamic, networked ecosystem is challenging, particularly when artificial or autonomous entities interact with human, non-human, and hybrid agents [38]. Emphasizing this aspect of epistemic responsibility can thus help in informing ethical decision-making and policy formulation in the domain of digital sustainability.

For what concerns the environment, smart ICTs can improve the efficiency of energy, transportation, manufacturing or water systems. However, in doing that, they contribute to increased energy consumption, e-waste, and carbon emissions. In the domain of economics, the debates on sustainable development have been historically influenced by the market-based ideas of growth and by the instrumental approaches to ICTs in the production and consumption dynamics. The current digital economy rests upon this narrow view, with its concentration of wealth and technological *moligopoly* (i.e., monopoly and oligopoly combined) and lacks a holistic sustainable approach, essential for systemic transformation and the decoupling of digital resources use from their negative impacts [39, 40].

Further, for what regards the socio-cultural domain, the pervasive use of data, algorithms, and social media raises ethical concerns over privacy, bias, surveillance, and psychological well-being. In today's hyperconnected reality, within which the distinction between online and offline is blurring, ICTs are not neutral or value-free tools but expression of the current social, political and economic paradigms and may act as important proactive agents of socio-cultural changes. This despite the risk, unfortunately well present already, of a cultural or economic gap between peoples and regions for the access to modern ICTs, the so-called digital divide, can hinder an effective and efficient use and must be well addressed in an early design phase [41]. Environmental issues related to the huge computing power needed, economic concerns for the large costs, and social questions arising from the training data collection practices and the concentration of power on a few large platforms are even more evident when considering the recent advances in artificial intelligence conveyed by the generative AI applications [42].

9 CONCLUDING REMARKS: PUTTING ALL TOGETHER

At the end of this brief overview of the most recent developments in the technologies that are available and continue to advance, some considerations are in order.

The first one is that today the only limit to what is possible to achieve seems to be the imagination and the creativity of those who use the modern technologies. In particular, for a smart city, practically all possible interventions can be based on sound layers of computerized procedures. However, it must be noted that, for really successful realizations some important precautions must be taken. A truly *smart* city provides a pleasing and responsive environment for its citizens, leveraging technology and data to deal effectively with their needs and wishes. Using advanced digital systems, it achieves good decision-making capabilities that result in improvements in areas such as cultural and leisure services, urban transportation networks, energy distribution, or waste management services. To this extent a smart city is a complex and dynamic ecosystem where all components, digital or real, are strongly coupled and co-evolve forming a single entity [43]. This means that the digital component, by itself, is not a sufficient condition for ensuring smartness. On the contrary, a digital injection can support the transformation of a city toward smartness if and only if the physical ecosystem's component is deeply restructured. That is to say that operational and organizational processes need to be profoundly and rationally redesigned and reengineered adapting them to the functions and he possibilities available [1, 44].

This approach is also well expressed by the new focus the European Commission has put on the evolved technological world, known as *Industry 5.0*. This starts from the consideration that the recent crises have brought out the need to move past the narrow and traditional emphasis on technology or economic enabled growth of the existing economic model and head on a more transformative human-centered view, shifting operations and consumption attitudes towards new forms of sustainable, circular and regenerative value creation and equitable prosperity [45]. In essence the move is from purely technologically oriented systems, focused on the automation and digitization of processes, to a perspective that combines the abilities of human beings and machines to achieve more flexible, adaptive and personalized environments.

On the technological side, an important success factor is the possibility to make wide use of the basic infrastructures and to allow room for growing not only in intensity of usage but also, more importantly, in extension of functionalities. These can be successfully designed and implemented only if based on a continuous efficient monitoring of the usages and the needs or wishes of all stakeholders involved, including the local population. This can be achieved if the technological layer is designed as an open and interoperable architecture, in which all the elements, from the data to the basic software functionalities are made freely and publicly available to all interested parties, adopting some open standardization process that ensures this interoperability [46].

One more crucial requirement is that all stakeholders need to be educated and informed on how technologies can ease operations and improve their competitiveness, and that of their city, only if they support a cultural and organizational change and transform the way they manage their intra and inter-organizational processes and relationships. Finally, policy makers should persuade all stakeholders that a city is the expression of a collective effort by different actors belonging to different (but interlinked) sectors and sub-sectors, that requires a strong attitude to participate and cooperate so that dissemination, transfer, and absorption of knowledge can occur smoothly and help improving innovativeness, attractiveness and competitiveness [47].

This is a very important and central issue since the organization and the composition of a smart city create unique issues linked to the integration of physical and digital systems and to the responsibilities of public and private stakeholders [48]. In particular, it must be noted that the governing body of a city is a central player that needs to adopt an attitude which favors innovative decision-making styles, the formation of efficient connections with all stakeholders, and *smart* collaborative, open, and citizen-centric governance capabilities [49].

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