Special Issue
of the Infocommunication Journal

Evolution of Digitization toward the Internet of Digital & Cognitive Realities and Smart Ecosystems

Gyula Sallai

Abstract—**The evolutionary phases and perspectives of the digitization process are presented focusing on the milestones of technological evolution. The digital convergence of communications, information technology and media, the concept of cognitive infocommunications, the extension of networking by Internet of Things, the immersive technologies as augmented reality and virtual reality and the artificial intelligence have relevant role in the shaping the concept of the Internet of Digital & Cognitive Realities (IoDC) and the Smart Ecosystems as Smart Cities and Smart Factories.**

Index Terms—**artificial intelligence, augmented and virtual reality, cognitive infocommunications, digital convergence, Digital Ecosystem, digitization process, Future Internet, Internet of Things, Smart Ecosystem, Smart City**

I. Introduction

Figure 1 shows the evolutionary phases of the digitization process [1].

Over the past 40-50 years, the unbroken progress of microelectronics has digitized communications and media technology, and has integrated communications, information technology and media. This process is called digital convergence, which includes not only technology but also the convergence of services and relevant markets and affects their regulation [2]. For unified digital communications of digitized contents, the Internet Protocol has been the most successful technology, which has become a global networking technology and has also proven useful in information processing and content management.

The process of digital convergence has led to the emergence of Digital Ecosystems, in which the synergic opportunities resulting from convergence and the extension of networking, the networking of objects, the Internet of Things (IoT) have played a main role.

Over the past decade, the goals of Internet development have largely been achieved, and solutions have strengthened. The most dynamic developments have been in the immersive technologies (augmented and virtual reality, AR/VR) and the artificial intelligence (AI). The concept of the IoT is broadening and beyond the concept of the Internet of

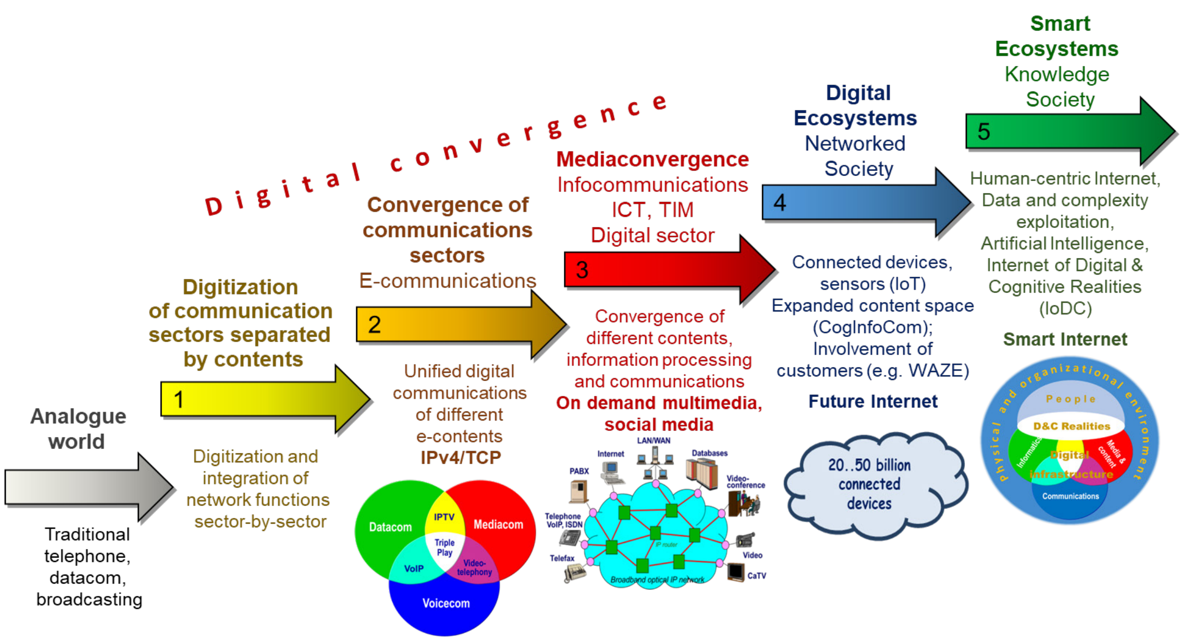

Fig. 1. Evolutionary phases of the digitization process

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This article is an extended version of the keynote paper of the First IEEE International Conference on Internet of Digital Reality presented at 23 June 2022. The conference discussions have concluded that the term “Internet of Digital Reality” is suggested to be renamed as “Internet of Digital & Cognitive Realities” to better refer to cognitive aspects and human factors.

DOI: 10.36244/ICJ.2023.SI-IODCR.1

Everything (IoE), which unites the Internet of people and objects, the new concept of the Internet of Digital & Cognitive Realities (IoDC) already encompasses the networking of the widest range of cognitive entities, and consciously builds on and integrates AI and AR/VR [3][4]. The concept of the Digital Ecosystem is evolving into a Smart Internet-based Ecosystem (Smart Ecosystem) that exploits these opportunities, with three distinct holistic appearances for the time being: smart cities, smart industrial systems and, in the longer term, smart agricultural systems.

The five evolutionary phases of the digitization process are detailed below.

II. The Phases Of Digital Convergence

We can identify three main overlapping evolutionary phases of the digital convergence.

In Phase 1, the digitization and integration of network functions was implemented separately for each communications sector. Among the network functions, first the transmission, then the control, and finally the switching technology have been digitized.

In Phase 2, integrated, unified digital communication of different contents was created. Voice, data, text, image, video, or other media content can be efficiently transmitted when digitized and combined into a digital stream. Horizontal convergences and some integration of the services, networks and terminals can be identified (Figure 2) [2][5]. A unified communication sector has emerged, which is formally called electronic communications. In deploying these horizontal convergences, uniform regulation was introduced for e-communications in the European Union [6].

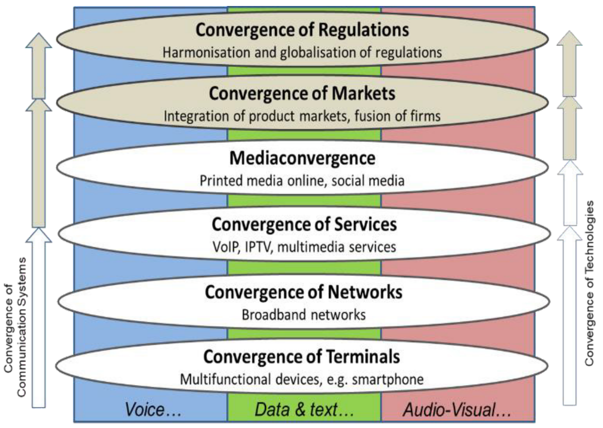

Fig. 2. Horizontal levels of the digital convergence

Phase 3 is the digital convergence of e-communications, information processing and digitized media sectors, providing synergic convergent areas as telematics, mediacommunications, mediainformatics and the area of full integration. Figure 3 illustrates the relation of the basic sectors (represented by blue, green and red primary colors according to the additive RGB color model) and the convergent areas by their combination (represented by cyan, magenta, yellow and white). There are new terms as:

- communications are expanding into *infocommunications (InfoCom)* by encompassing areas compounded with communications [7][8];
- the concept of *Information and Communication Technology (ICT)* is emerging as a union of information technology, communications and the convergent areas [9]; and
- *a unified digital sector* (so-called Telecommunications - Information technology – Media, TIM sector) is shaped, including mediaconvergence, the integrated digital management of various electronic and non-electronic contents [10][11].

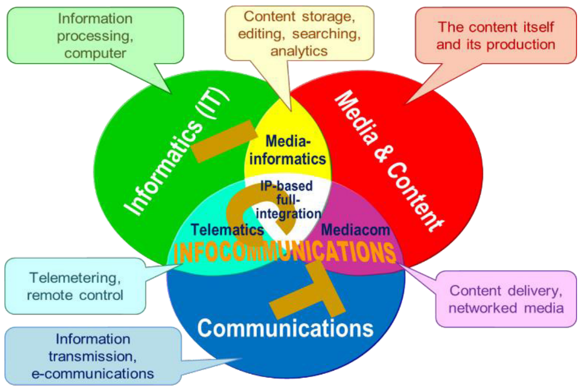

Fig. 3. Convergence of Communications, IT and Media

Internet Protocol version 4 (IPv4/TCP) has become a fundamental technology for a global network and has also been accepted in information processing and content management [12]. As a result of convergence processes, the Internet is emerging in all areas of society and the economy, an integrated ICT infrastructure is established, which is socialized through the services and applications built on it. Users are no longer just consumers of digital content, but can control where, when and how they consume content and participate in the creation and distribution of digital content, becoming members of a digital community.

III. Internet Of Things And Digital Ecosystems

The process of digital convergence was leading to the emergence of Digital Ecosystems, the concept of which was first mentioned in 2002 [13] and then formally laid down by the World Economic Forum (WEF) in 2007 (Figure 1, Phase 4) [10]. In addition to the synergies arising from digital convergence, the extension of networking, the networking of objects, *the Internet of Things (IoT)* [14] and the new Internet objectives, which respond to the challenges posed by it (Figure 4) [15][16], played key roles in the creation of Digital Ecosystems.

At the same time, advances in human-oriented technologies have also led to an expansion of the range of handled content with cognitive contents (gestures, emotions, perceptions), allowing interaction of human and artificial cognitive abilities, and resulting in new types of cognitive entities and human ICT technologies such as *Cognitive Infocommunications* (CogInfoCom), immersive technologies (AR/VR) [17][18]. A multitude of Internet-based services have been implemented, with some services seeking to actively engage users (crowdsensing, community perception, e.g. WAZE).

The objectives for the further development of the Internet have been brought together in the concept of *Future Internet,* resulting in relevant new Internet functions and solutions [19][20][21][22]. Fig. 4. shows the objectives of the Future Internet research, as service, resource, data and environmental awareness, as well as societal awareness, and the ultimate goals, the smart applications.

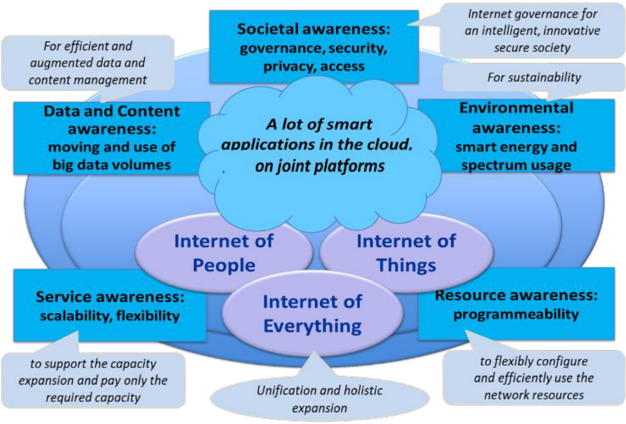

Fig. 4. Future Internet concept and objectives

Digital Ecosystems are created and evolved for some useful purposes, and their interconnected components are:

- *the digital community:* a community of digital users (cognitive entities) consuming, producing and exchanging digital content, whose members can be accessible persons, objects/things and organizations (economic, government and civil organizations);
- *the digital infrastructure* (technical environment), which enables interaction between the members of the digital community, facilitates the collection, processing and sharing of data.

The Digital Ecosystem thus symbolizes the symbiosis of digital infrastructure and the digital community, their mutually beneficial coexistence, and, from an engineering point of view, the union of the technical world and its environment [10]. The concept of Digital Ecosystem has been borrowed from biology, given that their functioning shows similarities. Digital Ecosystem models are based on knowledge from the ecosystems of living things, such as the cooperation and competition of different beings and the role of the environment in which the ecosystem operates and is affected by its functioning. The general model of Digital Ecosystems is displayed in Figure 5, which shows organizations in addition to the natural and built environment (together: physical environment), both as organizational users and as an organizational (business, administrative and civic) environment.

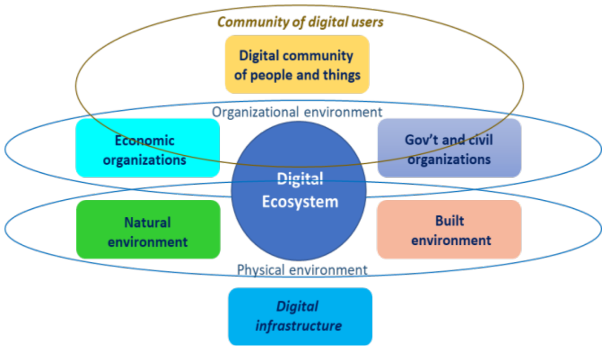

Fig. 5. General model for Digital Ecosystems

The concept of the Digital Ecosystem has unfolded recently. Online marketplaces first appeared, e.g. Amazon, then application support platforms were born, e.g. FIware. Deeper digital integrations in some areas, so-called verticals are formed, e.g. automotive industry, logistics, healthcare, pharmaceuticals, finance. Sometimes the term ecosystem refers to a set of IoT solutions, or e.g. a range of integrated solutions for smart home. The Digital Ecosystem has first emerged in a holistic approach under the names as digital, intelligent and smart cities, smart factories [23][24].

IV. Internet of Digital & Cognitive Realities

Over the past decade, the objectives of the Future Internet have been largely achieved, and the solutions have been strengthened (Figure 6).

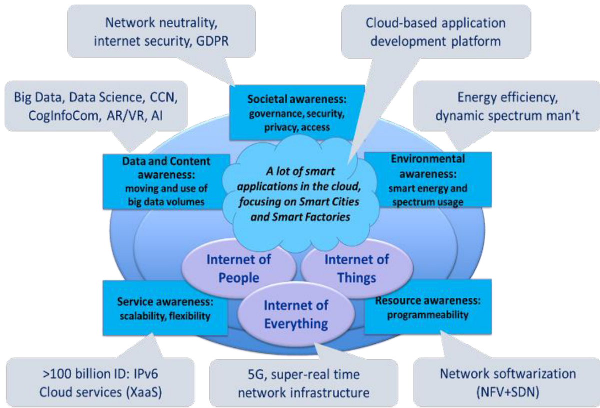

Fig. 6. Future Internet solutions

The IoT is still a driving force, we have seen tremendous developments on the field of sensor networks. 5G network systems integrate several new concepts (cloud-based environment, NFV - network functions virtualization, SDN - software-defined networks, etc.) and have become a key technology for Future Internet-based solutions. Data science, which grows out of the Big Data phenomenon, is leading to a wider spread of data analytics. Augmented and virtual reality (AR/VR) techniques are matured, their widespread use in industry, commerce and education is emerging, the hitherto hidden layers of human capabilities come to the fore, and the concept of the cognitive entity expands with their involvement [17]. The name Digital Ecosystem is increasingly being replaced by the name Internet Ecosystem, which more aptly expresses the Internet-based implementation, and the networking and social character.

However, the most dynamic developments are in the field of artificial intelligence (AI), especially in the field of artificial narrow intelligence (ANI). While in 2015 the IoT was still at the top of the Gartner's "Hype-cycle" curve, in 2017 the focus is already on Deep Learning and Machine Learning, which have been estimated to take 2–5 years to become widespread (Figure 7) [25]. The Hype curve of 2019 also featured AI-related technologies that directly help to build Digital Ecosystems, such as Digital Twins, Knowledge Graphs, DigitalOps. The Hype curves of 2020 and 2021 are also dominated by new AI solutions, signaling the proliferation of AI platforms and the involvement of AI in software development (AI-augmented software engineering) and, in the long run, in design and innovation [26].

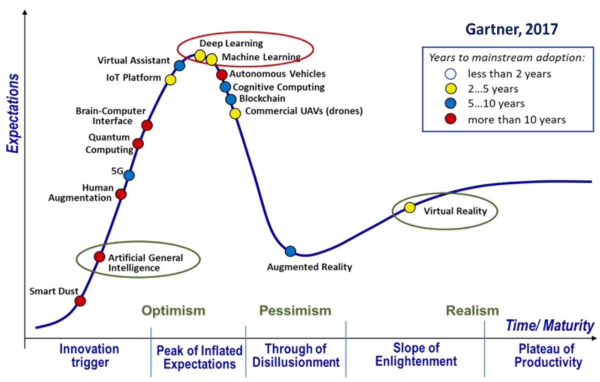

Fig. 7. Hype Curve for emerging ICT innovations in 2017

The concept of IoT is also expanding, and beyond the concept of the Internet of Everything (IoE), which unites the Internet of people and things, *the Internet of Digital & Cognitive Realities* (IoDC) already encompasses the networking of complete digital realities, including the widest range of cognitive entities such as avatars, digital twins, 3D collaborative sites, 3D marketplaces and consciously building on and integrating AI and immersive AR/VR technologies [3][4].

Towards 2020, the planning of the next generation of Internet (temporarily called *Smart Internet*) has begun intensively, the objectives of which include [27][28]:

- the use of artificial intelligence, the exploitation of data in general, which can lead to the widespread adoption of smart, innovative solutions;
- enhancing the human centricity of the Internet, the key points of which are significantly improving the security of the Internet and the protection of privacy, and
- digitization of manufacturing processes, which could trigger a new era of production.

V. Smart Ecosystems

With these capabilities, including IoDC, the Digital Ecosystems are evolving toward Smart Internet-based Ecosystems, shortly *Smart Ecosystems* (Figure 1, Phase 5) for which now three universal, holistic examples can be identified: Smart Cities, Smart Factories (smart industrial systems) and, in the longer term, Smart Farms (smart agricultural systems).

Figure 8 shows a vision of holistic Smart Ecosystems with their six key functional areas as strategic components. Each key area is supported by a wide range of smart solutions. The upper, cardinal key area is related to the fundamental goal of the ecosystem. The other key areas represent the associate energy, mobility, environmental and managerial functions, and the joint ICT background. Figure 8 also indicates the overall role of smart digital infrastructure [29].

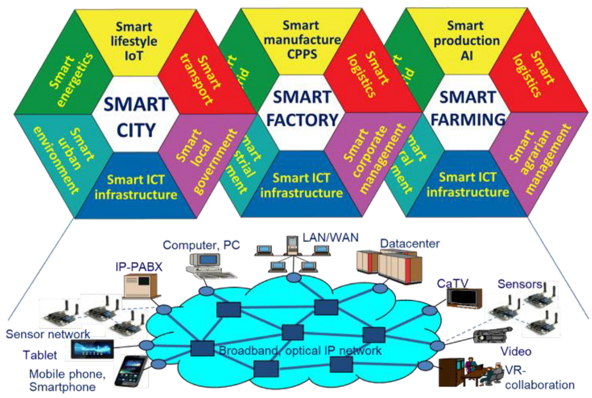

Fig. 8. Hexagonal model of holistic Smart Ecosystems

Smart Cities respond to the challenges of urbanization. The concept is based on IoT and the active involvement of customers and completed using AI and AR/VR methods. A Smart City is obviously characterized by a multitude of Smart City applications, but the concept presupposes the integrated implementation of smart applications and its functioning as an ecosystem. The impact of the transformation process extends to all areas of our lives, environments and sustainability [27]. The key areas as strategic components are smart lifestyle, smart energetics, smart transport, smart urban environment, smart local government and smart ICT infrastructure. Figure 9 shows the interpretation for each Smart City key functional area [30].

A city (as collective term for metropolis, town, district, township, village, region, etc.) can be considered a Smart City Ecosystem if the goals – depending on the nature of the city – affect all key areas, and the goals are achieved with the help of smart ICT solutions by:

- integrated management of city resources and solutions, based on a joint digital infrastructure,
- adaptively, using the possibilities of real-time data control,

- environmental awareness, energy efficient, sustainable way,
- social inclusion, active participation of the community, involving its stakeholders,
- economical self-supporting, innovative way,
- ensuring a higher quality of life (well-being), making the city more livable.

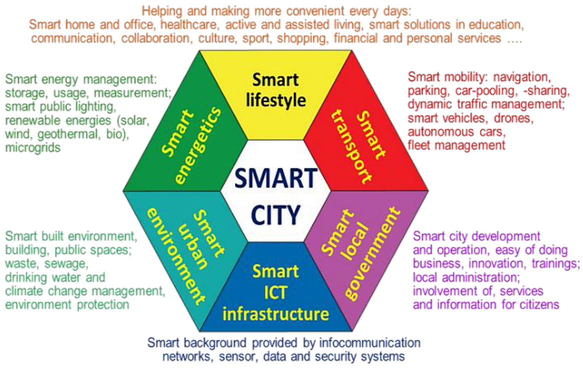

Fig. 9. Interpretation of Smart City key areas

The positive impact for the local community and the sustainability is expressed by the terms Smart City and Community (SCC) [31], and Smart Sustainable City (SSC), resp. Recommendations, standards are adopted for the transformation process [32][33] and the smart solutions [33]. The meta-architecture of the Smart Cities, based on [32][35] are shown on Figure 10, depicting the sandwiched ICT layers of sensors, infocommunication network, data center, digital platforms and smart applications between the urban environment and the urban life. Where the availability and affordability of the digital infrastructure (including some digital platforms) is guaranteed, it is considered a digital public utility [36].

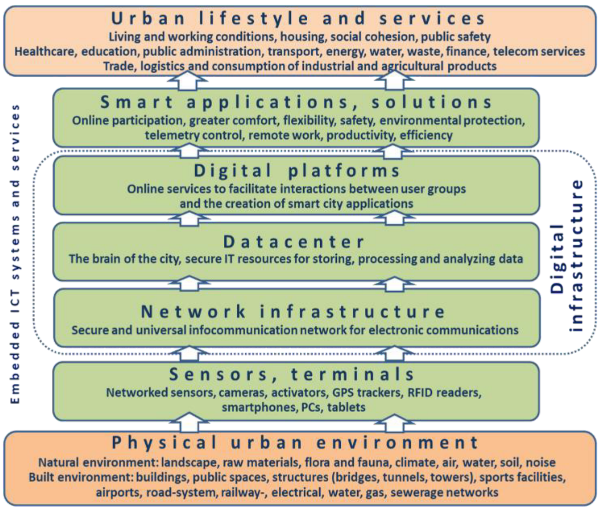

Fig. 10. The meta-architecture of Smart Cities

Diverse standardization, academic, industrial, consulting and urban organizations defined indicators to measure the performances of the cities on determined areas, e.g. [23][37][38]. Recently the most elaborated and recognized international indicator-system is the *United for Smart Sustainable Cities* (U4SSC), which is the initiation of the United Nations (UN) and coordinated by the International Telecommunication Union (ITU), and aims to provide guidance to cities in increasing smartness and sustainability [39][40]. The U4SSC has 91 key performance indicators (KPIs) in economic, environment and society dimensions (Figure 11), which are based on the ITU recommendation for evaluating the contribution of the use of ICT in making cities smarter [41], and the Sustainable Development Goals adopted by UN[42].

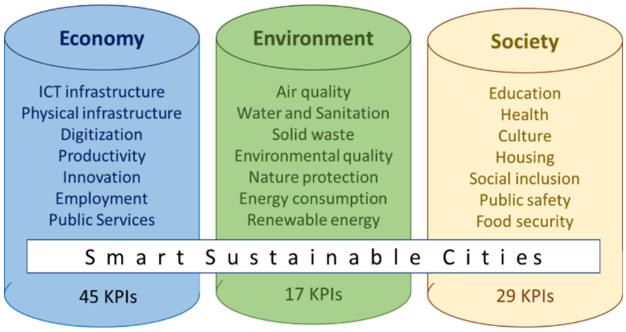

Fig. 11. The U4SSC indicator-system

Smart Factories are responses to the challenges of industrial production, building on the declining cost of sensors and actuators, the proliferation of the Industrial IoT (IIoT) and Cyber-Physical Production Systems (CPPS), the innovations in AI, AR/VR and robotics, as well as the secure information transmission provided by 5G. Business units located even at significant geographical distances from each other operate as an interconnected network, and all layers within the organization are interconnected from the manufacture to sales (horizontal and vertical integrations). The creation of a digital twin for manufacturing processes is yielding breakthroughs in many areas. Smart industrial systems are launching the fourth industrial revolution (Industry 4.0) [27][43]. Figure 12 depicts the three-dimensional Reference Architecture Model for Industry 4.0 (RAMI4.0), which was developed to support Industry 4.0 initiatives and gained broad acceptance by representing the different aspects and interactions [44][45][46]. At the same time, Industry 5.0 concepts are already pointing toward a sustainable, human-centric and resilient industry [47] .

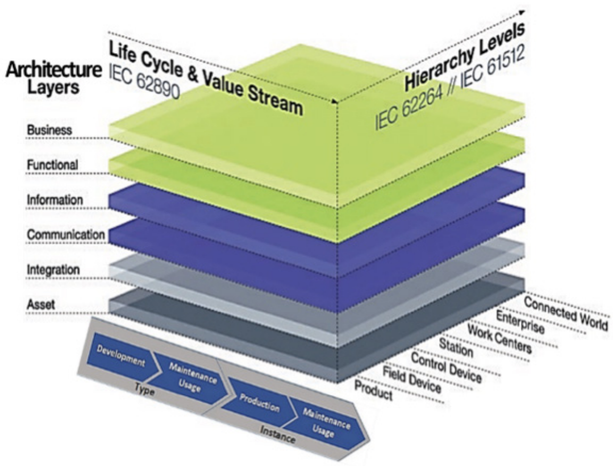

Fig. 12. Reference Architecture Model Industry 4.0

Smart Farms are emerging in agriculture and food industry [48]. Smart solutions appear, spread and combine for robotization, automation of operations, data-based, precision (location-specific) operations; there are self-driving tractors, drones; there are smart solutions for sowing, irrigation, fertilization, harvesting etc., mainly driven by the use of AI.

VI. Conclusion

The five evolutionary phases of the digitization process are presented, from the digitization of communication functions to the Smart Ecosystems. The digital convergence of communications, informatics and media technology, the concept of cognitive infocommunications, the extension of networking (namely the IoT), the immersive technologies (augmented and virtual reality) and the artificial intelligence have relevant role in the shaping of the concept of the Internet of Digital & Cognitive Realities and the Smart Ecosystems as Smart Cities, Smart Factories and others.

It is a natural evolutionary process due to the interaction of the technological evolution and the social demands, that the original concept of the Internet is expanding, involving the relevant results of the technological evolution, and becomes more and more universal. It happened in the case of the Internet of Things, and probably now with the Internet of Digital & Cognitive Realities. The next step is in question.

While digital convergence and networking have been the main drivers of Digital Ecosystems (networked society), Smart Ecosystems are already the products of the next, data-driven phase of digitization (knowledge society).

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During his career, he worked on different fields of telecommunications and infocommunications. He was researcher in network planning, then the director of the Research Institute of the Hungarian PTT (PKI), afterward the strategic director, later the deputy CEO with the Hungarian Telecom Company; then vice president for the ICT regulation and international affairs with the Communication Authority of Hungary.

From 1984 he was regularly invited by the International Telecommunication Union to deliver lectures on digital network planning and computer-aided design methods. For more than twenty years he was a member of the editorial board of Telecommunications Systems Journal, published by Springer.

Since 1997 he is full-professor at the BME, from 2002 to 2010 he was the head of the Department of Telecommunications and Media Informatics, and from 2004 to 2008 the vice-rector of the BME as well. From 2005 to 2011 he was also the chairman of the Telecommunication Committee of the Hungarian Academy of Sciences and the president of the Hungarian Scientific Association for Infocommunications (HTE). Recently he is professor emeritus at the BME, and honorary president of the HTE. He is also a member of the Hungarian Academy of Engineering.

He was awarded with several medals and prizes, inter alia Loránd Eötvös, Tivadar Puskás, George Békésy, Dennis Gabor and the Hungarian Order of Merit Commander's Cross.

His main fields of interest are the digitization trends, strategic, cognitive, management and regulatory issues, Future Internet technologies, Smart City strategies.