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Ecosystems of Industry 4.0 - combining technology and human powers

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ABSTRACT

IoT, digital twins, co-bots, drones, Artificial Intelligence, clouds are the system components of Industry 4.0, this trend born to face hypercompetition.

It aims in renewing processes using available technologies and impacts the whole industry ecosystems including people, information processing and business models. While most of research works focus on technology, the industrial systems objectives are economic with recent environmental concern.

This paper provides an overview of Industry 4.0 and discuss the importance of including knowledge, people and considers impacts. It focus on the role of digital twins in transforming industrial ecosystems, presented in the context of ecosystems and discuss the role of Knowledge Innovation, environmental impact and the place of the humans in I4.0.

CCS CONCEPTS

• **Computer systems organization** → **Embedded systems**; *Redundancy*; Robotics; • **Networks** → Network reliability.

KEYWORDS

Digital Twin, Cyber Physical System, Internet of Things, Cloud, Artificial Intelligence, Industry 4.0, Knowledge Innovation; Eco-design.

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1 INTRODUCTION

Globalization and search for low cost workforce according to « faster, cheaper (and not necessary) better » principle have modified the world industry landscape. To face Asian competition, the term of Industry 4.0 (I4) was probably proposed by German government in 2011 to promote digitalisation of manufacturing [1] , leverage European industry and create jobs.

I4 expresses the fourth industrial revolution and integrates known

and trendy technologies. It covers many concepts and purposes leading to greater flexibility and optimization of manufacturing processes, but the innovation process has also be included [2]. Among the main principles: decentralized decisions, interoperability, cyber-assistance, smart maintenance, customer centric, information transparency, green manufacturing. They are implemented in Future Factories, as for ex Schneider Electric, Vaudreuil [3], Safran, Dassault, Siemens and some others.

According to I4 principles people, appliances, sensors and machines must be able to communicate with each other for better efficiency. Cybernetic systems must be able to perform their tasks in the most autonomous way possible. Cyber-physical systems must offer support and collaboration to humans in all tasks that are dangerous, produce tiredness or fatigue, or are unpleasant. Decision support systems have to be able of adding of visual information intelligible to the human in order to predict the possible problems and / or solve them in the shortest possible time. Internet of Things (IoT) and digital twins plays important roles in I4.

Digital twins create a virtual copy of the physical world that surrounds them through the data collected by their sensors and other devices connected to their ecosystem [4]. The role of knowledge and experience in I4 is weakly addressed; the emphasis is on analytics/deeplearning considering by many newcomers as a magic wand to solve all kind of problems.

This research work aims in applying Knowledge Innovation [2] [5] principles to I4. We consider I4 from Ecosystems perspective where humans (employees and clients) have various roles to play. While many focus on economic impact we extend to the others including environmental [33].

After giving some definitions and elements of the context this article presents main challenges for this work and its first stage. State of the art provides an overview of related research and industrial context. Our scope and ecosystem view of I4 is followed by discussion of the multiple role of digital twins when including knowledge and people. Conclusions and future work end this article.

2 CHALLENGE

Some recent disasters such as Rio-Paris crash [6] and first Tesla autonomous car crash [7] demonstrated that fully automated systems are not 100% reliable, especially in case of missing data during the operation. The second accident was a consequence of undiscovered bugs during prototyping phase.

The main challenge of this work is to demonstrate the better efficiency and benefits of I4 when combining data and knowledge and integrating human into automated systems.

It is also to propose the systems able to combine the best of machine and human capacities [8] [2]. This was expressed by Einstein

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“Computers are incredibly fast, accurate and stupid. Human beings are incredibly slow, inaccurate brilliant. Together they are powerful beyond imagination”. Even computer-based devices, powered with AI need humans to solve problems never seen before, in case of missing data in critical situations, to “share” experiences, use knowledge and observations and to build collective knowledge for decision support systems.

We focus first on digital twins considered as a system component of the I4 and of eco-innovation process. Planet crisis requires minimizing the environmental impact of our activities. Simulation before doing has a potential to reduce this impact. Deducing the physical behavior of complex systems by analyzing data only is not sufficient to predict the failures that may happen in the future and to improve design, the use of materials and recycling. This is a reason to propose the system combining the results of data analysis with knowledge and experience already implemented in computers and know-how of specialists (Figure 2).

Other components of I4 will be added in the future work, applying incremental approach.

3 RELATED WORK

3.1 Multidisciplinary aspects of I4

Industry 4.0 is characterized by smart manufacturing, implementation of Cyber Physical Systems (CPS) for production, i.e., embedded actuators and sensors, networks of microcomputers, and linking the machines to the value chain. Usually the value chain considers only tangible, while we are interested in Knowledge Value Chain including also intangible benefits [5].

The genesis of I4 is multiple: under the pressure of an increasingly competitive economic scenario enabled (and pushed) by technological levers such as IoT, cloud, big data and AI. It should be accompanied by a profound review of processes, culture and even corporate business models [9]. This is clearly management/economic/industrial origin and researchers from various disciplines bring their contribution, mainly from IT perspective, few from general management and human resources [10].

Klaus Schwab, the founder of World Economic Forum gives an overview of three contributing fields : physical, digital and biological [11] with the impacts on economy (business) and society. However he does not consider negative impacts of “almighty” business. Lee et al [12] focus on big data only and analytics seen as service for I4.

Brettel et al [13] point out the role of decentralization, virtualization and networks in the transformation of manufacturing.

Shamim et al. [10] put emphasis on importance of human resources « digital enhancement and re-engineering of products is also characterized by highly differentiated customized products, and well-coordinated combination of products and services, and also the value added services with the actual product or service, and efficient supply chain. All these challenges require continuous innovation and learning, which is dependent on people and enterprise’s capabilities. Appropriate management approaches can play a vital role in the development of dynamic capabilities, effective learning and innovation climate. »

The authors did not mention what managerial approaches are the best for I4. However we discover in this paper some elements of

Knowledge Management top-down.

Internet of Things (IoT) and Future Factory, Digital Twin (DT) technology has become cost-effective to implement and is gaining increasing acceptance in the Industrial Internet of Things (IIoT) community, which tends to focus on large, complex, capital-intensive equipment [14]. The aerospace, defence and energy industry has begun to invest in Digital Twin technology. Therefore it is most important to state that Industry 4.0 is not limited to the technical dimension of digitalizing modern businesses [15], as it is rather the complete new organization and network coordination of value and supply chains [16]. The role of the Digital Twin, a product avatar, or cyber-physical equivalence is to improve the business performance and costs in industry [17] [9].

3.2 Knowledge Management in Industry 4.0

While many papers are devoted to cyber-physical systems architecture and data analytics, only paper we found in available literature mentioning some element of knowledge management in Industry 4.0 is c However, industrial companies such as Siemens, Schneider Electric, Deimler, Tesla, Dassault, ABB and others practice Knowledge Management. Chief Knowledge Officers’ missions are managing internal social networks, projects, documents, training (learning organization) or quality separately [19]. Nonaka and Teece [20] provide a theoretical point of view on KM lifecycle, however, without mentioning the AI approaches for knowledge modeling for reusing and processing.

3.3 Innovation and Eco-Innovation

The industrial companies expect that I4 will enhance their innovative capacity. The link between Knowledge Management and innovation is clearly demonstrated in [5] [2]. Eco-Innovation [2] is closely connected to eco-design [21] and required not only respect of standards (ISO 26000) but also evaluation of impacts before the transformation phase.

4 ECOSYSTEM VIEW OF I4

To consider all elements mentioned previously we suggest considering I4 as ecosystem. The Figure 1 presents some components.

All component in the circle can exchange data, information, knowledge and feedback. This exchange may be envisioned as a knowledge flow [2] between elements and humans involved in the processes, as well as employees as clients (stakeholders). Technological components (inside of the circle) produce and exchange data. The optimal functioning of the whole system depends of human capacity and their capability to take the best from technology. Training is also necessary for optimized use of technology, feedback helps improving applications and processes.

Finally a new culture of I4 should emerge from doing and is enhanced by systematic learning and practice of the innovation culture [2].

Governments encourage I4, seen as generator of growth and jobs and of leadership. They set policies, but it is difficult to influence their policies by sharing feedback from the field. The whole ecosystem has to be powered and the use of energy should be smart, combining renewable and circular energy [22].

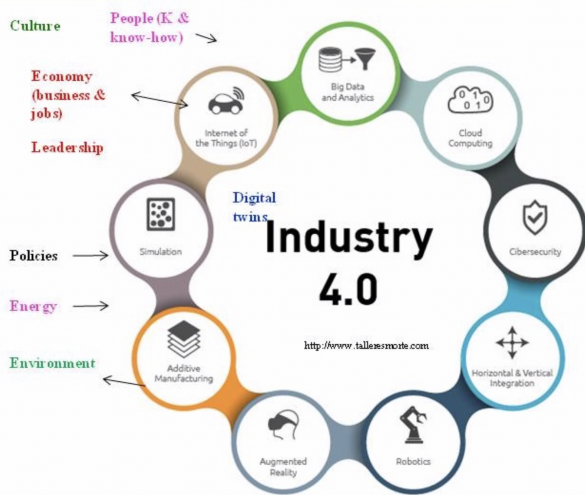


Figure 1: Ecosystem view of Industry 4.0 with influences and impacts ((inside of the circle <https://www.colourbox.com/>; outside of the circle elements added by authors.)

The green software approach will be preferred for designing of applications and communication between them in aim to minimize the environmental impact.

Environmental impact is considered by some actors, but for the most they focus on economic first.

Some I4 players are aware of the environmental impact but its systematic evaluation is not fully integrated into the processes and they privilege the economic impact. Principles of eco-innovation and eco-design provide a help for managing such impact [21]. Digital twins have their great role to play in simulation and optimizing maintenance, among others.

5 DIGITAL TWINS – IMPORTANCE OF KNOWLEDGE MANAGEMENT

The concept of “Digital Twin” is probably over ten years old. It has been applied for digital communication[23], aerospace applications, wind turbine blade diagnostic [24] and many others. It is currently used most of industries such as Siemens for simulation and validation of product properties [25], to test and optimize in advance all elements, including environmental impact, for design of aircraft, for virtual testing and maintenance.

A definition proposed by researchers of Fraunhofer IPK “A Digital Twin is the digital representation of a unique asset (product, machine, service, product service system or other intangible asset), that alters its properties, condition and behaviour by means of models, information and data”[25]. Currently a digital twin integrates data from various sources in different phases of the product lifecycle. The information included may be in different formats from different tools and not necessarily be deployed in one central repository. A digital twin helps to reduce the effort required to access and manage information – eg, it can obviate the need for manual maintenance of engineering documents to reflect on-site changes during operation.

The information contained in a digital twin can be used to learn from the current performance of assets and derive a feedback for future systems. But it can be used in the phase of product design for simulation before doing.

Knowledge Management can improve the exchange of information and knowledge from applications and from experts.

According to ABB [26] « it is not feasible to exchange information across organizations in a seamless way. For example, information about the behavior of a product sold by ABB in the customer’s environment is only visible for the type designer if the customer sends warranty claims or shares service reports created by service engineers, or the customer explicitly shares feedback to the vendor, eg, via a salesperson. However, all these sources are incomplete and possibly inaccurate, meaning that the product type designer has only limited and uncertain information available for the design of the next-generation product » Introducing an adequate approach of Knowledge Management will helps overcome this barriers. While digital twin is considered as a key enabler to exchange information across organizations, many of them ignore that this process can be optimized with organized Knowledge flow [2].

For example, selected operational and maintenance information can be managed within the digital twin and exchanged with stakeholders in an appropriate way. Particularly the process data and models provided in a digital twin, as well as the real-time simulation results, help to predict the requirements and improve the design for the next generations of asset types. Predictive analytics help manufacturers to confidently calculate future challenges. In this use case, the digital twin approach allows continuous improvement of the asset type designs, based on real data.

According to Rodic [15] an important aspect of the Digital Twin concept is the accumulation of knowledge - the information created at every stage of the product lifecycle is stored and made available to the following development stages. This greatly improves the knowledge management aspect of product development. Knowledge is ubiquitous in the whole life cycle, but not necessary collected from persons in an appropriate way to be immediately available.

Digital Twin is useful for training - an operator can train on a virtual machine until they have the skills and confidence needed to operate the real machine, without the expense of a dedicated training simulator and avoid damage to the machine in case of insufficient training. A high-fidelity physics model running in parallel with the real machine can immediately indicate a potential malfunction in the physical machine by detecting a drift between the machine’s performance and the behaviour of the model.

Today, a digital twin consists of connected products, typically utilizing the IoT, and a digital thread. The digital thread provides connectivity throughout the system’s lifecycle and collects data from the physical twin to update the models in the Digital Twin.

In this context, the cloud technology provides flexible and elastic computing services for multiple types of functions, this is one the innovative element in the industry production [28]. Connected to the physical devices, it offers broader connectivity and data storage/management resources. Meanwhile, the cyber function mentioned above, e.g.data processing, simulation, and optimisation, can also be executed in the cloud by its stronger computing power. To maximize the system performance, the real-time control tasks can be deployed in the local controllers, while the resource-insensitive

tasks, like task planning, supervisory control, and mobile worker assistance, can be migrated to the remote computing clouds. However, for security and confidentiality reasons it is vital to be careful with on cloud processing.

The interconnection between IoT and Digital Twin system is based on CPS, where the physical and software components are tightly coupled to each other while the physical world (robots, monitors, products, etc.) is reflected and controlled by the cyber world models, monitoring data, software, task plans, and so forth through Cloud [29].

In particular, the interactions between the cyber and physical worlds can be further improved with the help of the latest ICT achievements. The concept “cyber-physical equivalence” is emerging in the domain of computer science. According to Monostori[30], a cyber-physical equivalence represents “a virtual representation (a virtual replica) of a production system which is fully synchronized with the physical one in all aspects: geometry, function, and behavior”.

It's necessary to consider this definition in the context of cyber-physical systems which are “integrations of computation with physical processes, where embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa” [29]. Main research works employing this nomenclature cope with visual computing [31] [17]. Digital twin, by definition, requires a physical twin for data acquisition and context-driven interaction. The virtual system model in the digital twin can change in real-time as the state of the physical system changes.

5.1 Combining data and knowledge

Today we observe a strong general trend to solve all kind of problems with analytics applied to collected data and deep learning on past data. Predict the future behaviors of complex devices based only on exploring of past data is risky. We expect that in the nearest future the insufficiency of these approaches will be understood from experience. It is impossible to apply the same techniques for prediction of sales and for complex autonomous devices that must be reliable. We suggest an approach combining data-driven machine learning with existing knowledge and experience, as shown in Figure 2.

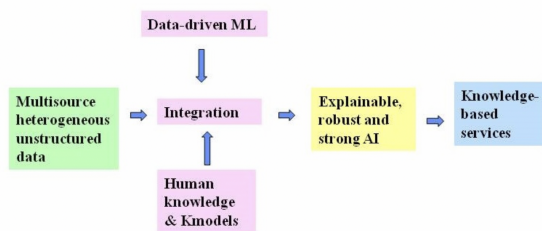


Figure 2: Integration of data and knowledge (Mercier-Laurent)

As generic, this approach fits also to I4. The integration of the results of multisource heterogeneous data mining, knowledge models and human expertise combined leads to robust and explainable

decision support systems. Holistic and systems thinking applied to complex problem solving allow the deep problem understanding and the selection of the adequate techniques, often implemented in hybrid systems [2] [22].

5.2 Human in the loop

Pioneers of Smart Factory have understood that human presence and expertise is necessary for the overall functioning of the system and ensures acceptability of new tools. We believe that the deep understanding of these aspects by the designers of digital twins and I4 as a whole will lead to more accurate and effective human-machine ecosystems. In case of missing data or cyberattacks, experienced people are able to manage the situation.

PLM and smart manufacturing need to add to the processes the most important one – those of innovation and in particular Knowledge Eco-Innovation [5] [2] [33], where client is a stakeholder in the whole cycle. Approaches such as Design thinking place client in the center, but for “long-life” innovation the combination of Knowledge Management, Eco-innovation seen as systems and CPS is vital.

6 CONCLUSIONS AND FUTURE WORK

Managing the whole system I4 requires not only connecting elements and collecting data for processing, but deep comprehension of the interrelations between all components including people and environment. Many focus on machines and fully autonomous systems considering that our resource are infinite, while they are not. Few companies pay attention on right integration of humans and on competencies/management (right man on the right place). In this context our research work aims in better exploring the synergy human-machine in digital twins and extend to Industry 4.0.

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