The Overview of Digital Twins in Industry 4.0: Managing the Whole Ecosystem

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Abstract: Industry 4.0 aims in renewing processes using available technologies such as robots and other AI techniques implemented in IoT, drones, digital twins and clouds. This metamorphose impacts the whole industry ecosystems including people, information processing and business models. In this context, the accumulated knowledge and know-how can be reused but has also to evolve. This paper focus on the role of digital twins in transforming industrial ecosystems and discuss also the environmental impact.

1 INTRODUCTION

The industry sector has now embarked on a path of profound transformation.

An important change of pace, which arises under the pressure of an increasingly competitive economic scenario enabled by technological levers such as Artificial Intelligence (AI) IoT and Cloud, accompanied by a profound review of processes, culture and even corporate business models (Madni et al., 2019). In particular, with the advent of the 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 (Moeuf et al., 2018).

At the same time, the aerospace and defense industry, which continues to invest in Industry 4.0, 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 (Felser et al., 2015), as it is rather the complete new organization and network coordination of value and supply chains (PlatformI40, 2018).

The role of the Digital Twin, a product avatar or cyber-physical equivalence, is to improve the business performance and costs in industry (Holler et al., 2016) (Madni et al., 2019).

According to (Gartenr, 2018), by 2021 nearly half the major industrial companies will be leveraging digital twin technology to facilitate the assessment of system performance and technical risks, while achieving approximately 10% improvement in system effectiveness. In particular, the digital twin is at the top of the peak of expectations in the hype cycle of ”Top 10 Strategic Technology Trends 2018” proposed by (Gartenr, 2018).

The research have been reported that the research company expects that by 2020 at least 50% of producers with annual revenues exceeding 5 billion dollars will have launched at least one initiative for digital twins for their products or assets. A trend that will lead to tripling the number of companies that use these solutions by 2022, considering also that the companies that are implementing projects based on the Internet of Things are already using or planning to use ”digital twin”.

This paper presents our study of digital twins, their applications and impacts.

2 INTERCONNECTION OF DIGITAL TWIN AND IOT

The digital twin has long since established itself in industry, where it’s revolutionizing processes along the entire value chain of a product, production process, or performance, it enables the individual process stages to be seamlessly linked,Figure 1.

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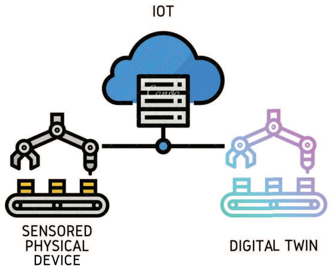

Figure 1: Digital Twin.

As a virtual representation it was used in the aerospace context within NASA's Apollo program, where two equal space shuttle , one - the physical device - in the space and the other - the virtual device- at NASA's Center, have worked in real time and in mirror condition during the flight (Boschert and Rosen, 2016). The possibility to work in real time and in dynamic conditions, creates a consistent improvement in efficiency, minimizes failure rates, shortens development cycles, and opens up new business opportunities: in other words, it creates a lasting competitive edge (Boschert and Rosen, 2016)(Holler et al., 2016).

It seems that the notion "Digital Twin" appears the first time in the year 2000 (Grieves and Vickers, 2017) characterizes a digital twin concept by three main components. "Physical products in real space, virtual products in virtual space, and the connections of data and information that ties the virtual and real products together". Almost ten years later, it is provided (Glaessgen and Stargel, 2012) a more fine-grained conceptualization (Holler et al., 2016).

"A digital twin is an integrated multiphysics, multiscale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, fleet history to mirror the life of its corresponding flying twin " (Glaessgen and Stargel, 2012)(p.7).

This multiphysics and sensored integration is made thanks to the Cyber Physical System (CPS) and Artificial Intelligence (AI) platform, which radically increased system where the re-configurability and flexibility allows a predictive planning and control in order to prevent and solve the potential failure in a production or in a physical system (Yue et al., 2015). The CPS allows to control and monitor the industrial process via algorithms directly integrated in the systems and users around them (Moeuf et al., 2018).

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 life-cycle 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 (Jósvai et al., 2018).

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 maximise 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 (Moeuf et al., 2018).

Indeed 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 (Lee et al., 2015).

In particular, the interactions between the cyber and physical worlds can be further improved with the help of the latest ICT achievements (Monostori, 2014).

It's necessary to consider this aspect in the context of cyber-physical systems which are "integration 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" (Lee, 2008)(p.1). Main research works employing this nomenclature cope with visual computing (Stork, 2015) (Holler et al., 2016). 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 (during operation).

3 LEVERAGE OF THE DIGITAL TWIN IN INDUSTRY 4.0

Digital twins are becoming a business imperative, covering the entire life-cycle of an asset or process and forming the foundation for connected products and services and allows analysis of data and monitoring of systems to head off problems before they even occur, prevent downtime, developing,in a cloud-based system, new opportunities and even plan for the future by using simulations, thinking of a digital twin as a bridge between the physical and digital world (Mussomeli et al., 2018).

Simulating before doing helps understanding not only the main processes about also interconnections and impacts in aim optimizing design and minimizing the footprint (Mercier-Laurent, 2013).

However, Industry 4.0 is a multi-faceted problem, and it is unlikely that all aspects of it will be applicable to all businesses.

Whilst the area of Intelligent Manufacturing is itself a multifaceted problem, the recurring element that underpins much of this revolution is the collection, utilization and understanding of data, or the study of ‘Informatics’; almost all of the areas linked with the intelligent manufacturing research area rely on the capture and analysis of data in some way,(Dworschak and Zaiser, 2014)(Shapira et al., 2013).

To this end the use of advanced analytic, suited machine learning techniques and knowledge-based AI is a key technology to develop to further these other technologies; and the next step in this chain lies in utilizing the vast reserves of data through data mining and knowledge discovery, to better understand these manufacturing processes. The performance indicators for a company which invest in new technologies are : lower costs, improved quality, improved flexibility,improved productivity (Raymond, 2005) (Moeuf et al., 2018).

The DT allows greater levels at technological level and management level. As presented on the following sections, in particular the DT allows a high level of operational efficiency: reduction of breakdowns, reduction of machine downtime, reduction of defects, optimization of raw material procurement and logistics, Figure 2.

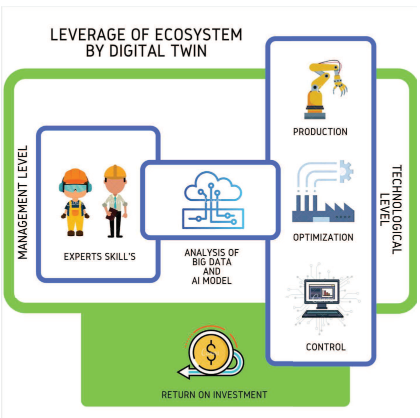

Figure 2: Leverage of Digital Twin at management and technological level.

In the same time, the management of the company wants to explore new business models, in which the service component and ”recurring revenue” (recurring business) plays an increasingly important role (Madni et al., 2019).

3.1 Leverage of DT at Technological Level

Today, DT has a crucial role in the smart industry production, with an important impact on leveraging also the revenue stream of the industry and it provides an edge-to-cloud architecture that is able to optimize operational costs through the division between various infrastructures.

Digital twin concepts span from aerospace (Kraft, 2016) to naval (Wuest et al., 2015), 2015) industry. Up to the present day, most applications target these industries.(Wuest et al., 2015) plan extensions to luxury products and white goods in the future. In that regard, identifying the relevant information for the stakeholders represents an increasing challenge. In line with these developments, it may be interesting to examine applications in other manufacturing industries in the engineer-to-order to make-to-stock-planning spectrum (Holler et al., 2016).

This may be due to the current hype cycle of where the technology stands at the time of writing, as reported by (Gartenr, 2018). Digital twin is almost at the peak of inflate expectations where we are seeing some early adopters producing success stories, while others may be failing or not starting to invest at all (Eyre and Freeman, 2018).

The DT leverage many industrial sectors, like :

- Automotive: The convergence of physical and their virtual products has the potential to address many challenges which exists in the automotive value chain today. The ‘digital twin’ in automotive industry can enable convergence of existing gaps between physical and virtual versions of product prototypes, shop floor and actual vehicle on the road.
- Aerospace: Commercial plane’s thousands of sensors stream asset data to better system servicing and operational status.
- Healthcare: Connected medical systems and tools ensure product integrity and measure patient outcomes.
- Manufacturing: Digital factory equipment and machinery increase uptime and production yield, while reducing repair and maintenance rates.
- Oil and Gas: Remote rig sends health data limiting routine inspections and servicing.

- Rail: View of deployed locomotives and assets health better optimize scheduling and reducing servicing time.
- Utilities: Digital representation of systems on the power grid improve demand response functions and energy efficiency.

Of course, the value of the data is an indispensable condition in every smart manufacturing project, since without the Digital Twin it is impossible to identify the KPIs and identify the areas in which to intervene, it is equally true that its implementation requires method. It is important too that the entire value chain is involved so that all aspects and all processes are examined in a holistic and structured manner.

The big companies, like GE, Siemens, have developed some platforms for the utilisation of DT, that was able to meet the expectations of the industrial world by producing forecasts and results that could be valid for any type of market a company was involved with.

In particular developing the “Edge devices”.

The ”Edge devices” considers remote devices as intelligent devices able to operate directly on the data or on the resources to which it is close. For this reason the devices that are used include the use of machine, which is able to guarantee them the use and organization of communication and authentication protocols. Being smart devices, they have the ability to make forecasts directly without having to communicate with the cloud; thanks to this they are able to independently detect anomalies and act directly on the environment. Supported by the possibility of communicating with the cloud to obtain data on past history, they are able to improve their forecasts over time. Each item can also be combined with a position. This is because in certain work areas it is normal to suppose that products are in motion and they want to keep track of them. As mentioned before, the great advantage of Digital Twin concerns the optimization at process level and also at operational costs level through the division between various infrastructures, achieved important investment by worldwide companies.

3.2 Leverage of DT at Management Level

With the growing importance of devices utilized in the smart industry, especially for Digital Twin, it is becoming increasingly important, within a company, the opportunity for employees, who are now able to perform more tasks using their help.

The employees are more connected than ever, able to improve his own efficiency, reduce costs for the company and increase customer satisfaction.

The digital technology also needs high-level experts that have a “suited” knowledge regarding this new methodology about the control and productivity of the company.

It’s recognize a global level that specific investments needs the use of specific expertise in a view of a more dynamic and flexible organisation’s strategy (Moeuf et al., 2018).

(Moeuf et al., 2018) have adapted the works of (Porter and Heppelmann, 2014), initially proposed for measuring the capacity of new smart connected products and services, to establish a list of four distinct managerial capacities aligned with the concept of Industry 4.0.

Summarizing, in this list 4 main aspects are considered:

- Monitoring: the role of decision- making (Velandia et al., 2016)is based on the analysis of historical data provided by various connected objects (Wang et al., 2015) in smart manufacturing. In this way any change occurred during the production process is reported as warming and the analysis of these data allows a further elaboration to improve the production performance,
- Control: all data that have a different behavior respect to the planned performance, allows to define algorithms with the specific role of detection of alert situation (Aruväli et al., 2014),
- Optimisation: it’s possible to optimise in real time the production process, (Saenz de Ugarte et al., 2011) combining the analysis of data and the utilization of specific algorithm for detection of alert situation,
- Autonomy: Thanks to the above mentioned operations, it’s possible to reach a new levels of autonomy in production system (Khalid et al., 2016) with a great advantage – with AI - to develop systems capable of learning autonomously and adapting themselves from their own behaviour (Bagheri et al., 2015)

In this way, a better level of production process is offered by the utilization of DT through data acquired by sensors in real time, and the consequently modelisation, reached often by AI, fostering the entire value chain of Industry4.0 also a knowledge management level.

In fact, Digital twin focus on three key assets: the technological asset, represented for example by all the initiatives of Industrial Internet of Things, the product life cycle, the management of the value chain. The latter is probably the aspect on which attention is less often concentrated. And yet, it is precisely in optimizing the entire value chain that the potential of smart manufacturing projects emerges. In particular, the DT leverage the needs of ”digital skilled” employees:

- professions related to the processing and analysis of information (big data, business intelligence);
- professionalism in Artificial intelligent field (machine learning, deep learning);
- professionals specialized in the automation of productive and automated processes.

Dealing with a smart manufacturing project with a keen eye on the impact on the entire value chain means breaking away from a short-term approach and acquiring a strategic and long-term vision thanks to new levels of collaboration with partners and suppliers. A well managed value chain trough Digital Twin makes it possible to integrate processes, reduce inventories, improve service levels, with an overall improvement in both products and customer satisfaction levels.

4 CONCLUSIONS

Considering the role of the Digital Twin in the context of Industry 4.0, it seems clear that any strategy that leads the company to move in a logic of smart manufacturing cannot be limited to a reflection on cost savings on improving productivity, also in terms of Return on Investment (ROI). In particular it’s possible to define three main aspect. The first aspect is the role of the digital twin of the product. It is created as early as the definition and design stage of a planned product, allowing the engineers to simulate and validate product properties depending in advance. The second aspect is the digital twin of production. It involves every aspect, from the machines and plant controllers to entire production lines in the virtual environment using real time data. This simulation process, as mentioned in the previous sections, can be used to optimize production in advance - with PLC code or AI. As a result, sources of error or failure can be identified and prevented before actual operation begins. This saves time and lays the groundwork for customized mass production, because even highly complex production routes can be calculated, tested, and programmed with minimal cost and effort in a very short time.

Last but no list, the aspect related to the digital twin of performance. It is constantly fed with operational data from products or the production plant. This allows information like status data from machines and energy consumption data from manufacturing systems to be constantly monitored. In turn, this makes it possible to perform predictive maintenance to prevent downtime and optimize energy consumption. This generates a completely closed decision-making loop for the continuous optimization process. The conclusion is that the Digital twins are not only a trend, but play important role in industrial innovation. They allow simulation based not only on collected data but also exploring existing knowledge and know-how to understand, improve, take into consideration the ”weak signals” and contextual knowledge as well.

Renewing industry is not only about introducing trendy technology, but also about understanding the related ecosystems including people, business and environment.

Digital twins are useful for training and simulation but final goal is to create a sustainable synergy between technology and humans allowing to explore the best the both capacities. Enabling this transparency across the organizational value chain through digital and physical world convergence is becoming increasingly necessary as products shift to ‘as-a-service’ models. This digital transformation and final link of the digital thread is capable through the advent and adoption of the digital twin.

It’ also true that some recent disasters demonstrated that fully automated systems are not 100% reliable, especially in case of missing data during the operation and when the device is commercialised with undiscovered bugs during prototyping phase. The main challenge of this work is to study the 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. We focus first on digital twins considered as a component of the whole I4 and eco-innovation systems. Other components of I4 will be added in the future work, applying incremental approach.

Our future research will focus on this collaboration.

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