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Stepping into the Industry 4.0: The Digital Twin Approach

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ABSTRACT

The digital manufacturing process based on the Digital Twin is a new approach that will forever shape the future of the Industry 4.0. This innovative concept is based on well-known technologies that already power the cloud-based economy: Big Data, Machine Learning and Data Science techniques. We present a Digital Twin model for manufacturing and the stages involved to build it. Currently, many Digital Twin solutions are available on the IT market, which contribute to the successful implementation of the technology in different industries. Our study presents the features and benefits of several dedicated Digital Twin software applications for the current-day business environment. Our case study involves the trial version of the ARIS software platform, that allows the construction of a DT model and we are emphasizing the possibilities offered by this new approach for the manufacturing future.

1. Introduction

Digital Twin (DT) is not a new concept, it was originally proposed in 2002, but it became popular in recent years, due to the development of Internet-of-Things (IoT), Big Data and Cloud computing.

DT is a technology that combines a system simulation model with data obtained from the functioning of the real, physical system and provides a reliable method for monitoring and an efficient way to guide the evolution of the system.

This approach has gained traction due to its precious ability to create a reliable digital model of the real objects, with all features described in detail, a virtual clone that can be used to improve the future operation of the real equipment (Pettey, 2017).

Given these clear strong points, it should not surprise anyone that this technology has attracted the attention of the major creators of physical goods, as it could be a way to optimize their manufacturing processes and offer them a significant competitive advantage in the near future.

By involving the DT in their design and production strategies, companies will be better prepared for the Industry 4.0 wave of ground-breaking evolutions in the tech business.

DT will solve many of the society's demands for The Fourth Industrial Revolution, the so-called Industry 4.0 or Industrial Internet of Things (IIoT), primarily aiming to combine interconnected "things" with smart digital technology, artificial intelligence and big data into holistic ecosystems for manufacturing and supply chain management.

Due to the deep anticipated impact on the industry, this technology was ranked the 4-th on Top 10 Technology Strategies Trends 2019 by Gartner, an important leading research and advisory company (Panetta, 2018).

The paper is organized as follows. The concept of Digital Twins and the technologies that are powering the actual generation are reviewed in section 2 (State-of-the-Art). In section 3 – Methodology, the phases of building a Digital Twin model and several dedicated software applications are presented. Section 4 contains the case study, realized with ARIS Cloud trial software, and Conclusions are drawn in section 5.

2. State-of-the-Art

This section will focus on introducing the Digital Twin philosophy, describe its nature in detail and on reviewing the state-of-the-art of the research in the field, as well as the applications successfully implemented in various industries.

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In the domain-specific literature, there are many definitions of the concept, that converge to common understanding of the Digital Twin: "A Digital Twin is a virtual model of a real product, process or service that can monitor, analyse and improve its performance." (Tao et al., 2019a)

Madni et al. distinguish between a digital twin and a virtual prototype, meaning that DT is a virtual instance of a physical system, continuously updated with feedback data, and system life cycle status (Madni et al., 2019).

As indicated by the definition, there are three types of Digital Twins, on successive levels, according to their importance (Tao et al., 2019a):

Product Twin – this is a virtual prototype of a product used before starting its production line, in order to analyse its behaviour and make adjustments should the need arise. Thus, product twin decreases costs of control and validation phases and can be used to improve the functional performances and the quality of physical product.

Process Twin – the next level is represented by the model for a virtual manufacturing process, which allows the company's management to make the best decision in terms of manufactured products, operations to accomplish and test them. *Process Twin* could use *Product Twin* for each component of the manufacturing line, establishing its opportunity and efficiency.

System Twin – this is the higher level, representing the virtual model of an entire system, based on *Product Twin* for each device and *Process Twin* to optimize the manufacturing processes of these components.

Virtual models are continuously updated by collecting device status information from online IoT sensors and offering solutions to adjust their behaviour or fix errors in a timely manner (Banica et al., 2018).

Digital Twins technology is based on other latest generation research fields, such as AI & ML, the aforementioned Big Data and its associates, and use the intelligence gathered in order to create a realistic and as-close-to-reality-as-possible model (Fig. 1).

According to Tiwari, Machine Learning (ML) is a field of Artificial Intelligence and represents the ability of systems "to automatically learn and improve from experience without being explicitly programmed" (Tiwari, 2017).

Digital Twins is achievable using Big Data, due to the huge amounts of information collected and processed.

Artificial Intelligence contains multiple type of applications, and many of them could be used successfully in deployment of DT, especially Business Intelligence and Analytics tools.

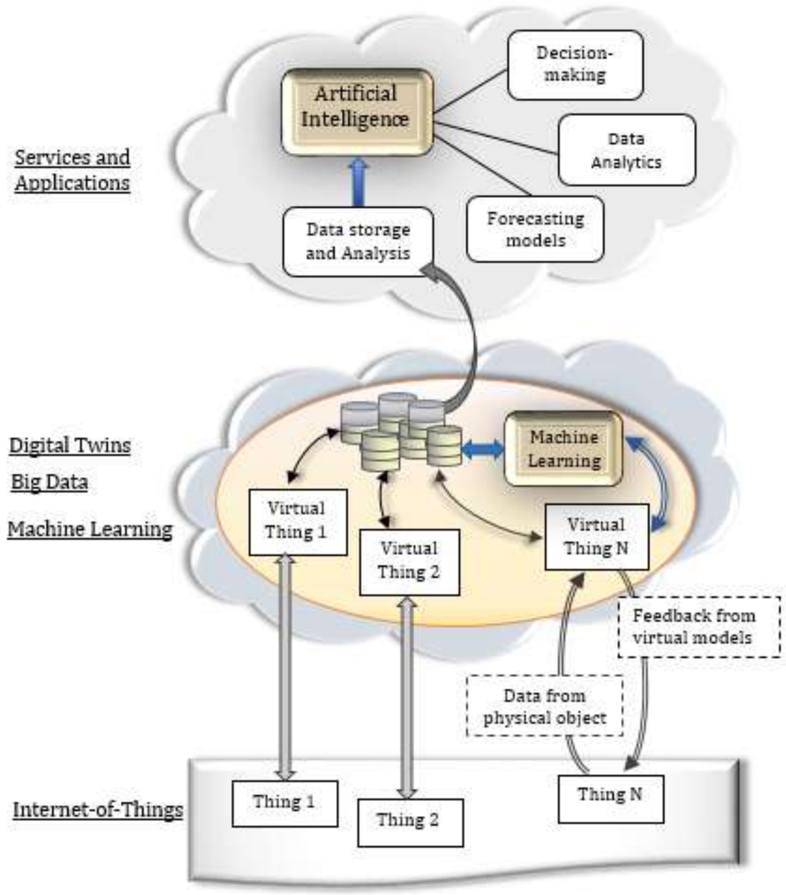

Figure 1. The model of Digital Twin

Due to the large volume of acquired data, a professional Big Data solution is required, as the information needs to be processed in parallel, and this way we could be able to detect trends and patterns, and thus improve the Digital Twin Model. As mentioned by Qi and Tao, these tools are a key component of the DT (Qi & Tao, 2018).

At the forefront of the DT adoption process are the biggest players in the high-tech industry (such as SAP, GE, Siemens or even Royal Dutch Shell), and they rely on it for improving the real-life systems performance and apply optimization strategies (Weippl & Sanderse, 2018). The years to come will bring an extension of this approach to other economic sectors, such as the energy industry or the construction companies.

3. Methodology

Being a digital representation of a real system, DT modelling has the advantage of always being related to the functional requirements of physical assets.

From the authors point of view, building a Digital Twin model involves 5 stages (Figure 2):

1. Model building by extracting the physical characteristics and behaviour of the real product as input for the appropriate Machine Learning algorithm;
2. Simulation of the model behaviour in the virtual environment;
3. Creating DT capabilities to collect data from sensors, devices and actuators, in order to adapt the model functions and processes to the real-time state of the reality; at this level the IoT (Internet-of-Things) connections can be used, especially cloud computing infrastructures that are able to offer two-way secure connections between the physical and the virtual object;
4. Leveraging the Big Data infrastructure in order to capture data flows from the experiment;

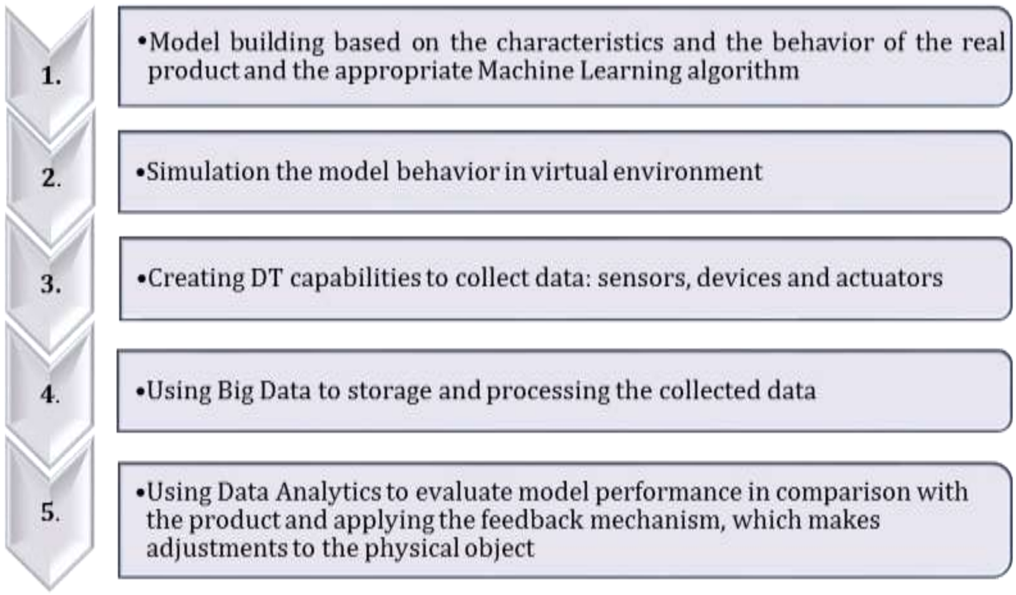

Figure 2. The stages that a Digital Twin model requires

5. Analysis of the data obtained from the physical process, evaluated in comparison with the virtual object, and the application of the recursive feedback mechanism, which continuously makes adjustments in a loop.

Grieves defined a three-component model, consisting of physical layer, virtual layer, and connections between physical and virtual products (Grieves, 2014).

For high-fidelity modeling, Tao et al. propose an extension to a five-dimension model (Tao et al., 2019b):

$$M_{DT} = (PE, VE, SS, DD, CN),$$

where PE - Physical Entity, VE - Virtual Entity, SS - services for physical and virtual layers, DD – data from both layers and CN - the connections.

Advanced artificial intelligence techniques can be embedded into DT model to increase its capacity of reasoning and decision-making.

Big Data technologies are necessary because of the large volume of structured data and also, for unstructured data, mainly consisting of environmental information from Social media.

Thus, inside a Digital Twin model is recommended to use Big Data processing, Machine Learning and Data analytics, according to the developer's point of view (Tao et al., 2019b).

3.1 Digital Twins software

Digital Twins software builds a virtual representation or simulation model of an object, obtains real-time information to update the model and manage the behavior of the physical asset in order to optimize its functionality and performance.

Objects can be IoT devices, and in this case tracking and monitoring them can be achieved with IoT ecosystems that are able to manage large fleets of devices with ease – like the Amazon, Microsoft and Google ad-hoc infrastructures.

We will present the features of several Digital Twin software launched on the IT market and considered the most commonly used in 2019 by the peer-to-peer review site G2 (G2 official site, 2019):

- *Akselos* company is the world leader in Digital Twin technology, focused on large and critical engineering systems, such as: Offshore structures for oil and gas, Rotating machinery, Wind farms, Mining machinery, Civil infrastructure. David Knezevic defined Akselos Digital Twin as a "physics-based model of an entire asset which incorporates the current condition (e.g. based on inspection data), and enables fast high-fidelity structural integrity analysis, optionally linked to sensor data (IIoT)" (Knezevic, 2018). The physics-based Digital Twin represents the standard approach of the simulation by finite element analysis (FEA). But, as FEA has some limitations (for example the speed in decision-making, or to link to sensors), Akselos's software changed the model. The new approach is called Reduced Order Model and is based on numerical methods for reducing the computational complexity of mathematical models in simulations.
- *Oracle IoT Production Monitoring Cloud* is a software for collecting data at the manufacturing machine level, continuous tracking and forecasting of production performance across factory, products, and machines (Oracle official site, 2019).
- *ScaleOut Digital Twin Builder* - The main objective of this software is to receive and analyze event messages from data sources or other digital twins, also command messages from applications or other digital twins, and to generate alert messages to applications and feedback to data sources. Digital Twin Builder will lead to faster decision-making than previously and it was implemented in the rental car application, avoiding network bottlenecks, data parallel analytics in real-time to assess aggregate trends across the customers (ScaleOut official site, 2019).
- *Seebo Digital Twin* software operates on meaningful insights from machines, equipment, and manufacturing processes. It includes code-free graphical modeling, simulation, and deployment tools to virtualize the assets and manufacturing processes for remote monitoring, process control, and increased production yield (Seebo official site, 2019). Seebo Digital Twin includes a visual modeling tool, enabling to visually design the digital replica of the production line processes and assets. First models of objects could be designed with 3D CAD software and then completed with the required digital twin components from built-in software libraries.
- *ABACUS* is a software platform that allows users to create a dynamic model for an organization, model called a "digital twin". This virtual model will track the company's evolution in real time, will continually collect data, and ABACUS will use this information to compute performance indicators and perform forecasting analyses, offering the organization a chance to adopt the best strategy (Avolution official site, 2019)

A case study of a Digital Twin model for supply chain management will be presented in the following section, built using the trial version of the ARIS Cloud software.

4. Digital Twins in Industry 4.0

The International Data Corporation (IDC), leader in Digital Transformation Market Research forecasts, published in November 2018, 10 predictions in digital transformation, the 5th referring to Digital Twins: "By 2020, 30% of G2000 companies will have implemented advanced digital twins of their operational processes, which will enable flatter organizations and one-third fewer knowledge workers" (IDC, 2018).
Gartner also forecasts that by 2021, about 50% of all large industrial companies will adopt the Digital Twin technology *(*Bharathy, 2019).

4.1 Digital Twins in manufacturing

Digital Twins is very useful especially for optimizing the manufacturing industry. Thus, any piece of a machinery that involves high production costs or is underperforming and must to be replaced, can be simulated as a Digital Twin. The virtual component can be digitally created, tested and optimized without interrupting the production line.

Thus, by installing IoT-enabled sensors across the entire production line, sensors that are able to provide real-time information, a continuous monitoring by Digital Twins software is performed. The model itself will update as new processed data becomes relevant and leads to an improved system component, with qualitative and effective benefits.

After obtaining optimal results in terms of costs, efficiency and precision, the component can be manufactured and integrated into the real system.

As an extension approach, the whole manufacturing process can be defined in the digital version of an entire factory, with every component included in Digital Twin model (Bushnell, 2018).

By operating the virtual twin system in parallel with the physical system, the continuous updating of the digital model with real world data will lead to an advanced optimization of the machine operation, the ability to predict issues, and the safe replacement of outdated components, and to the decrease of the operational costs, thus offering the best solutions.

The Digital Twin concept can be successfully extended in other areas adjacent to product manufacturing, such as (Rosik, 2019):

- optimization of supply chains through digital modelling of product distribution, storage and distribution networks;
- managing customer relationships, for tracking and predicting the customer's needs.
- training the factory staff without interrupting production, by simulating critical situations.

4.2 ARIS Cloud to build a Digital Twin model for supply chain

DT is evolving towards approaching the enterprise as a whole, in order to achieve faster adaptation to the changes in the business environment and consumer demands, and to test the impact of some changes before they are implemented.

A supply chain model focuses on three main areas: real-time transmission of manufacturing updates, tracking and updating warehouse inventory and controlling the distribution networks.

Data is collected using IoT platforms, stored and processed in a scalable manner using Big Data applications. After this first level of use, the selected data is sent to the Digital Twins layer, where artificial intelligence technology is used to determine the differences between the physical and the virtual product and to make the necessary adjustments that are to be applied to the products.

Enterprise Digital Twin is the business operation model launched by Software AG, defined as "a virtual replica of all processes, information and outputs" for the supply chain network (SoftwareAG official site, 2019a).

The ARIS Cloud application from Software AG provides users with a trial version that allows the creation of a digital twin for an enterprise's operational model.

Figure 3 presents an example of a business model built in ARIS Cloud application.

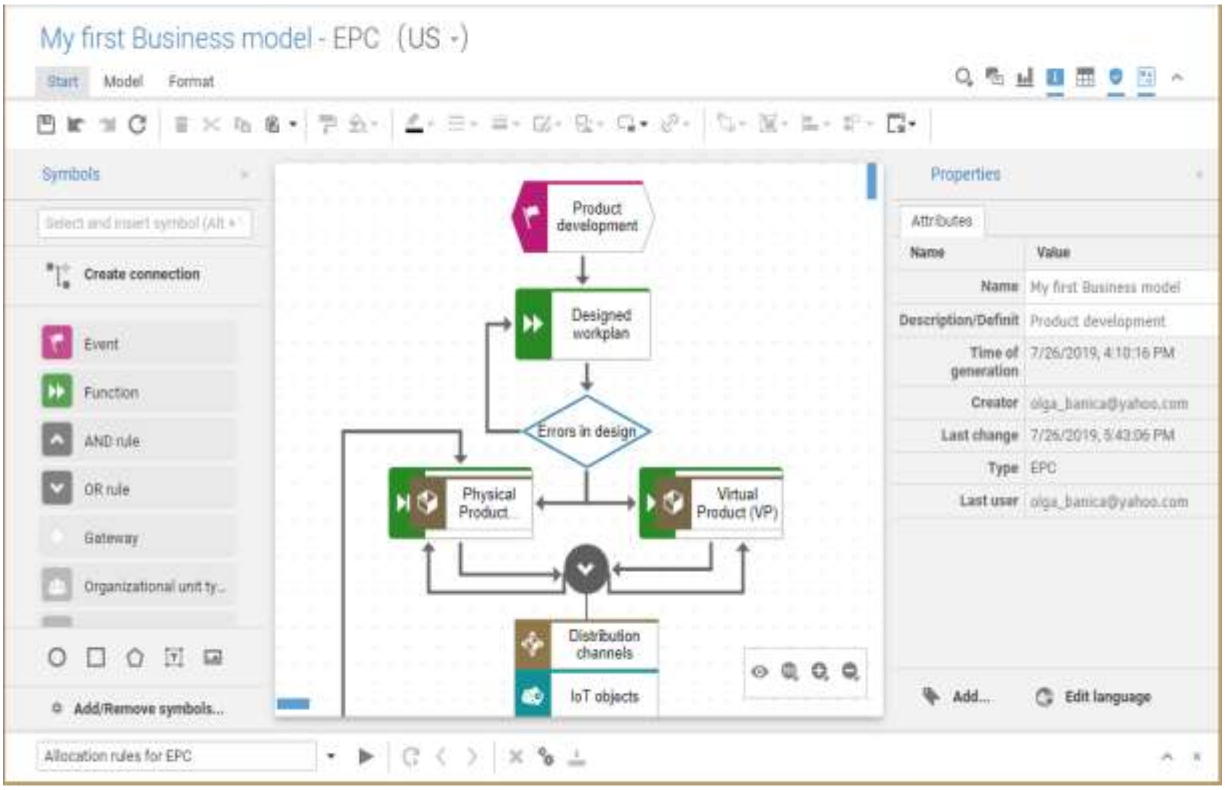

Figure 3. Business model in ARIS Cloud application

The ARIS platform is a specialized application for modelling and analyzing business processes in commercial organizations. All the components of the model (organizational units, processes, application systems and data) are stored in a central database, accessible to users via ARIS Business Server (Davis, 2012).

ARIS software contains four specialized applications (SoftwareAG official site B, 2019b):

- Strategy Platform, that focuses on the company's plans for the future, and their application in practice, based on the internal policies and feedback evaluation
- Design Platform component, for describing and modelling business processes according to the logical structure of the organizational information systems;
- Implementation component, that blends the logical structure from the processes and rules of the virtual business model into the organization's IT systems ((ERP, SCM, CRM etc);
- The Controlling Platform tool provides real-time monitoring of implemented business processes, and their presentation using a graphical frontend.

The Advanced Analysis component is dedicated to finding the anomalies (peak values in data sets) present in the data flow from various parts of the virtual model, anomalies that can be corrected in order to increase the efficiency of the real manufacturing process. The help of the AA component is precious for the user as it significantly accelerates the business optimization process.

5.Conclusions

The most important findings of this paper are:

- The important advances in Digital Twins technology are powered by the evolution of other complementary IT areas, such as: IoT, Big Data, Cloud Computing, Machine learning and Data Analytics.
- DT plays a key role in smart manufacturing, and consequently in Industry 4.0.
- The most important capability of DT is to predict the behaviour of the physical system based on the model and the data-driven analytics, in order to identify malfunctions and make on-the-fly adjustments and optimize its functionality towards the desired goal.

As the IoT elements and 5G networks will become widespread, the role of the Artificial Intelligence in shaping the future manufacturing vision gets even more clear. Large automotive factories are already experimenting with this technological paradigm and are getting promising results. In our opinion, the enterprise of the future will embed the Digital Twin in the process, as the whole system will be guided, monitored and adjusted in real time by a Digital Brain, in order to fulfil the client requirements regarding time-to-market, precision or build quality.

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