



Digital Twin Ecosystem Built with PLM Software for Smart Factory

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Abstract. The article points to a new trend in the digital twins creation. It is the use of Product Lifecycle Management (PLM) software to create online twins, which are supported by simulation. Some definitions state that a digital twin is a virtual copy of a real object, but the digital twin ecosystem presented by us combines a virtual twin, simulation, Programmable Logic Controller (PLC), Industrial Internet of Thing (IIoT) and sensors. In the article, we gradually offer an overview of the digital twins development with the proposal of the Digital Twin Ecosystem, which we presented on a practical example in a case study. We describe the step-by-step process from component selection, gradual construction, assembly to final inspection and packaging. This entire technological procedure is transferred to the simulation tool Tecnomatix Plant Simulation and the steps for connecting the simulation with the digital twin created according to the experimental workplace are described step by step. The hardware and software requirements for the design of a complex interactive ecosystem are described in detail in the individual steps. In the conclusion, the benefits of the digital twin are highlighted and potential issues that need attention are outlined. In the article, we wanted to show the process of creating the Digital Twin Ecosystem and that it is becoming a promising tool for optimizing testing in smart companies

Keywords: Digital Twin · PLM software · IIoT gateway · ecosystem

1 Introduction

The term digital twin was first mentioned in the mid-90s of the 20th century. More than 30 years have passed since then, and the digital twin is once again remembered as a pioneer in the engineering-focused manufacturing industry [1]. At the beginning,

the digital twin was aimed at creating a virtual twin of the production product and the production system, then the digital twin was applied to create a physical twin of the entire production line, and last but not least, entire production twins of complete production halls are created. However, the spectrum of use of the digital twin has not yet reached an end, and therefore another goal of the application of the digital twin is its application in the design of production and logistics systems [2]. The emergence of the digital pairs concept was related to the growth of production processes digitization, during which physical or analogue sources were replaced by informational or digital ones. Organizations follow the latest trends and try to identify how digital solutions can help them gain operational and strategic advantages. Until the second half of 2010, due to technical limitations, it was not possible to create computer systems that would replicate the properties of physical objects in almost real time [3]. And only a significant breakthrough in the digital technologies development, which made it possible to increase computing power and reduce the price of their use, allowed leading companies to combine information technology with operational processes and create digital duplicates of enterprises [4].

1.1 Literature Review

By some definitions, a digital twin is an integrated product model that is intended to reflect any manufacturing defects and it is constantly updated to include wear and tear over the life of its use [5]. Other definitions describe a digital twin as a sensor-based digital model of a physical object that simulates the object in an active setting. The digital twin is based on massive, cumulative measurement data in real time, in the real world, and across a range of dimensions. These measurements can create an evolving process or object profile of an in the digital world that can provide important insights into system performance, leading to actions in the physical world, such as changing the product design or manufacturing process [6]. As mentioned at the beginning of this article, the digital twin was created in the mid-1990s. But the evolution of the digital twin continued and gradually went through digital simulation, the Internet of Things, and today it is influenced by mixed reality and artificial intelligence, as you can see in Fig. 1 [7].

The digital twin will form an integral part of the production process in the future companies. In Fig. 2 we can see how production enterprises should change in terms of production enterprises time and strategies [8].

Manufacturing companies can be divided into four strategies types. In the past, the production company operated on a reactive strategy [9]. This strategy dealt with different types of problems only after something happened. The second type of strategy followed, namely the real-time strategy, which was able to solve problems in real-time production. The future of manufacturing companies is a predictive strategy, which is influenced by the Digital Twin and Big Data [10]. In addition to the digital twin, artificial intelligence has already been mentioned in the proactive strategy.

→ R & D and engineering			
→ Production operations, new services, models			
Mirror model of information	Digital simulation, 3D printing	Internet of Things services	Mixed reality and artificial intelligence
Digital twin as a concept R & D and engineering Dedicated workstations and servers	Collaboration, simulation and workflow in a global enterprise Browser and web access	Unification of data between the physical and virtual worlds IoT, Big Data, Cloud	Holography, virtual and augmented reality Artificial intelligence
1985 -2002 (18 years)	2003-2014 (12 years)	2014 – 2016 (3 years)	2017 - presentness
Powerful 3D modeling and analysis Programming of CNC machines and robots	Digital design, virtual assembly and simulation before physical deployment 3D printing	Fast feedback in design, production and operation products Expanded with digital services	Accompanying Interactions mixed human-machine collaboration Autonomy and self-healing

Fig. 1. The digital twin evolution

→ Time			
Past	Presence	Future	
First level	Second level	Third level	Fourth level
Reactive strategy	Real-time strategy	Predictive strategy	Proactive strategy
	Internet of things	Digital Twin Big Data	Artificial intelligence
			Digital Twin
			
→ Difficulty and uncertainty			

Fig. 2. Development of management of the production company

The basic tasks of digital twin implementing include:

- Creation of 2D or 3D objects of the production product, system or production hall,
- Collecting real data from real production operations,
- Implementation of collected data into simulation software,
- Starting a simulation with continuous data evaluation,
- Verification of results and their implementation in a real production environment

When processing the first step of the digital twin implementation itself, we have to create 3D objects of the real operation in CAD software (AutoCAD, Process Designer, CEIT Table, etc.). The method of 3D the production operation scanning can also be used for an extensive type of objects [11]. After creating a physical twin in CAD software, we need to collect data from real production. At the beginning of the data processing cycle, the first step is the selection of the real part from which we want to create a digital twin. The following is data collection, which we can implement using various types of sensors, detectors and intelligent production systems. Intelligent production systems include e.g. RTLS system, which serves as monitoring of the movement of objects in a

defined space in real time [12]. Wireless technologies are used for information transfer, be it Bluetooth, Wi-fi, Ultra-Wide-Band, Lora, Sigfox, etc. methods. The collected data are stored on a server (Cloud), which all production company employees have access to, where they can view and edit the data [13]. All data located in the Cloud is referred to as Big Data. These Big Data are finally transformed into simulation software, where they are then connected to physical objects that were created in 3D software. After the input data implementation, the simulation of the production process can be started, which will evaluate the required information about the production process state. The goal of the digital twin is actually to constantly evaluate the collected data, which are interconnected by simulation software and optimize them, so that they could then be converted back into the production process of real operation. This is a system for implementing a digital twin in a manufacturing enterprise [14].

2 Methodology

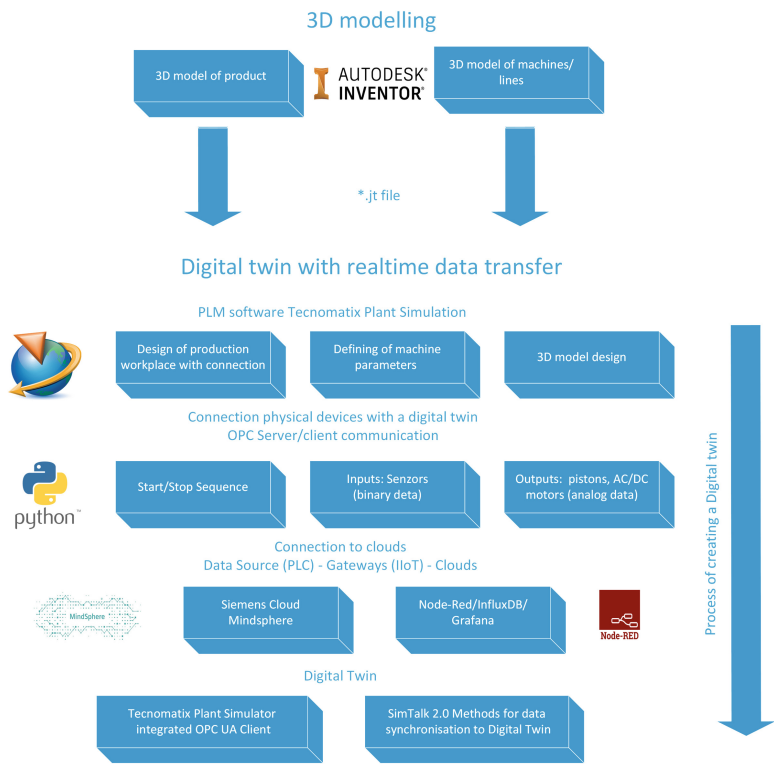


Fig. 3. The process of Digital twin ecosystem creating

The digital twin was initially created as a concept of creating a physical twin of a production product and a production system. In our article, we focused on the individual stages of creating a digital twin. The proposal consists of a model solution that we can

apply to any smart enterprise. In the following figure, we have described the process of creating a digital twin in the PLM program Tecnomatix Plant Simulation [15] (Fig. 3).

2.1 Case Study

When we want to start creating an ecosystem, it is necessary to choose the object of our interest. The first step in creating a digital twin was the selection of an automated workplace and a product. We chose a cam switch as a product. It is intended for multiple switching in the main and auxiliary circuits. As motor switches, they are intended for direct on-line switching on and off of single-phase and three-phase motors. They can also be used as star-delta switches, reverse switches, motor switch pole switching, switches in auxiliary and measuring circuits. The advantages of cam switches are: good ability to switch on and off, electrical and mechanical endurance, small dimensions. Specifically, it is a cam switch S 16 16A/3P. It is a simple part consisting of 42 parts, of which 23 components are different [16] (Fig. 4).

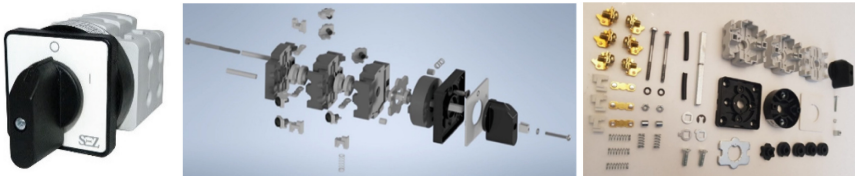


Fig. 4. Cam switch S 16 16A/3P 0–1 level

After the product is defined, the next step is to define the automated workplace. In our case, it is a conveyor system with production equipment and an assembly workplace. This system is located on the grounds of the Technical University in Košice, Faculty of Production Technologies with headquarters in Prešov, and is a SmartTechLab laboratory for Industry 4.0 [17] (Fig. 5).

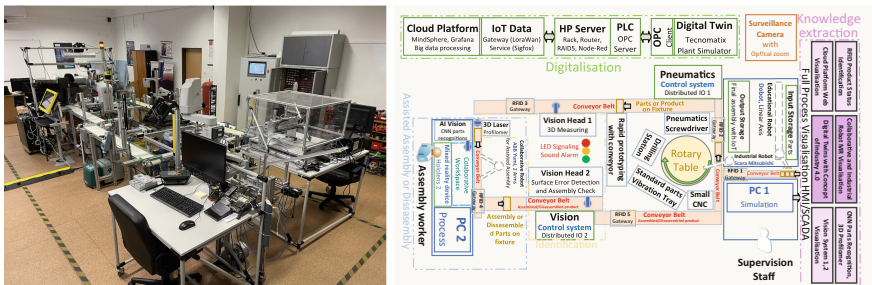


Fig. 5. Experimental automated workplace SmarTechLab for Industry 4.0

It is a partially automated line with integrated control systems. It is equipped with a robotic workplace and an assembly workplace with a collaborative robot. A partially

automated assembly line is cost-effective and can later be integrated into a fully automated line. The next step is to build a model of the given workplace and product. The cam switch can be seen in Fig. 6 on the left and on the right is a 3D model of the line constructed in Autodesk Inventor Professional version 2021 [18].

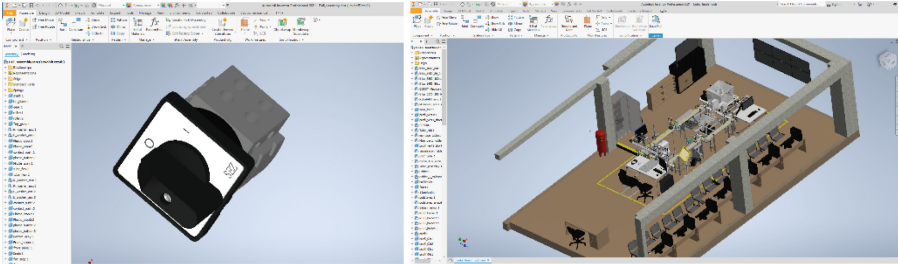


Fig. 6. 3D component model and experimental workplace

We will then transfer the 3D models to PLM (Product Lifecycle Management) software, which is used to manage and control the product life cycle. It is an integrated system that includes various functions such as product design, development, manufacturing, delivery and maintenance. PLM software enables organizations to streamline and automate their product processes and improve their results in terms of quality, availability and efficiency. PLM software can be used in conjunction with digital twins to improve product design and manufacturing. Digital twins can be integrated into PLM software and used to simulate and optimize product design and manufacturing processes. In this way, organizations can get a better idea of how the product will work in a real environment and what its features and performance will be [19]. The Tecnomatix Plant Simulation application (developed by Siemens PLM Software) will be used for our digital twin design. It is a simulation tool for a wide range of systems and processes [20]. First, we propose an informative model. Subsequently, we define the machines and equipment layout, we define the technological sequence of operations and times and assign methods and rules [21] (Fig. 7).

In the next stage of creating a digital twin, we will modify the model in the 2D interface, according to the real distribution of operations. We import 3D models for individual operations and create a faithful experimental workplace copy. See Fig. 8.

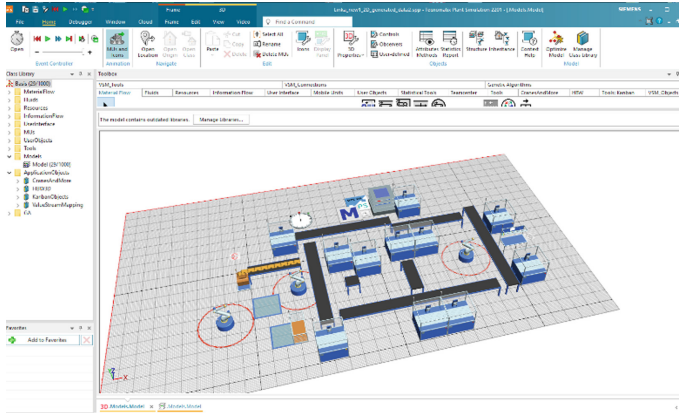


Fig. 7. Informative model in PLM tool

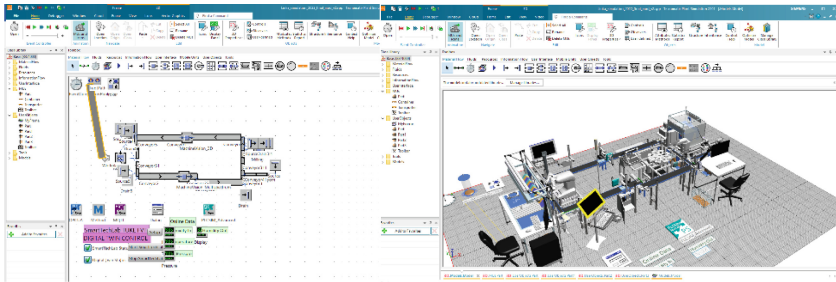


Fig. 8. 2D and 3D display of a digital twin

Following the creation of the model, the simulation will be set up and the individual steps necessary for the assembly of the cam switch will be defined. For easier assembly at the experimental workplace, we divided the individual activities into stages [22]. The first is the preparation of components from the incoming warehouse. An empty handling pallet arrives at the entrance, then it is fitted with a preparation in which all the plastic components necessary for assembly are placed. Next, the pallet with the preparation moves along the conveyor system and goes through the inspection process under the camera system [23]. It identifies the presence of individual components. After the inspection, the fitted pallet is moved to the assembly workplace. Manual assembly will take place here according to the Table 1.

Table 1. Cam switch assembly procedure

№	Procedure
1	Two nuts are already inserted in parallel in the arresting chamber under the press, and two set screws are inserted in parallel in the other two holes
2	The arresting chamber is placed on the rear attachment
3	The arresting star is placed in the centre of the arresting chamber
4	A square rod (on which there is already a locking ring) is inserted into the centre of the chamber through the arresting star
5	Next to the locking star, two locking rollers are inserted parallel to each other
6	Two detent springs are inserted into the chamber and each of them is placed perpendicular to the detent rollers
7	A stop plate is placed on top
8	Two stops and a washer are placed in the middle
9	The switching chamber is placed
10	Two cams are placed one on top of the other on the shaft
11	Two left and two right terminals are inserted in the corners of the switching chamber
12	The connector is inserted into the guide and the contact spring is placed in the centre of the connector
13	The lead with the connector and the contact spring is placed in the upper part of the switching chamber between the right and left terminals
14	The connector is inserted into the guide and the contact spring is placed in the centre of the connector
15	A lead with a connector and a contact spring is placed in the lower part of the switching chamber between the right and left terminals
16	The switching chamber is placed
17	Two cams are placed one on top of the other on the shaft
18	The right and left terminals are inserted into the upper part of the switching chamber
19	Two insulating tubes are placed on the set screws (through the holes in the switching chamber)
20	The connector is inserted into the guide and the contact spring is placed in the centre of the connector
21	A guide with a connector and a contact spring is inserted between the terminals
22	The switching chamber is closed by the plastic lid of the cam switch
23	Nut washers and two nuts are inserted
24	Nuts are screwed in
25	A type label is affixed to the arrester chamber
26	The contacts are tight

This entire assembly process takes about 4 min. By using assisted assembly using the ABB YUMI collaborative robot, we can shorten this process to 3 min. After the final assembly, the transfer of the cam switch to the pallet for output inspection is ensured. After the functionality is tested, the product is moved to the packaging and to the output warehouse [24] (Fig. 9).

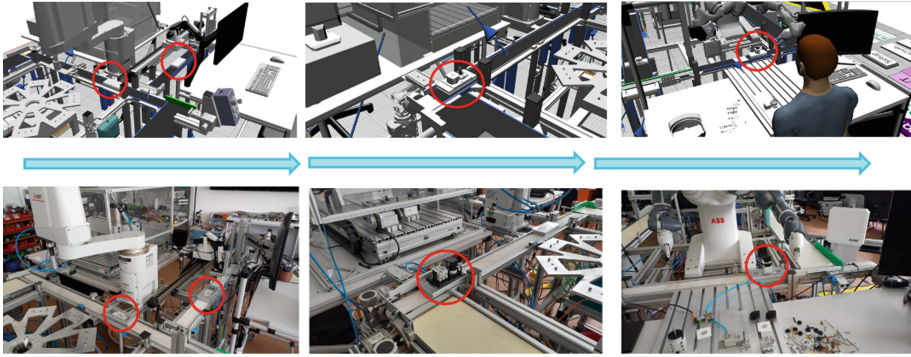


Fig. 9. Digital and physical model

3 Results

An improvement of the proposed approach is online optimization within the digital twin and synchronization with the real system. In the setup, the Python OPC UA server is responsible for transferring data from the digital twin to the PLC system. Thus, we can synchronize the simulation with the experimental workplace control system with online data recording (Fig. 10).

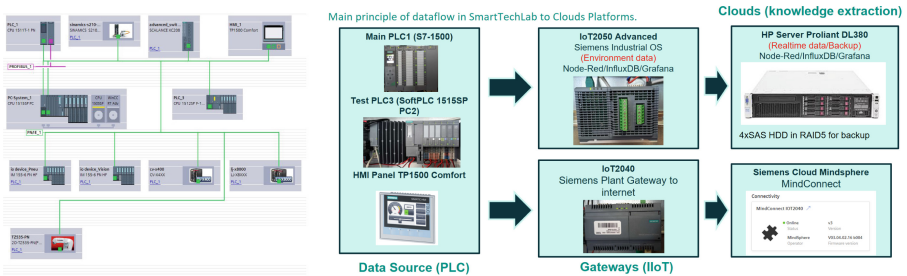


Fig. 10. TIA portal Software with OPC Server and Communication scheme of Data Storage

Data transfer to the cloud is ensured using IIoT gateways Siemens 2040 and 2050s with OPC server network interfaces. We use 2 communication gateways sending data to 2 clouds. One connection is freely available and works on the principle of connecting Node-Red/InfluxDb/Grafana with its own cloud storage on its own server storage. The second

connection uses the cloud as service (CaaS) cloud platform through the MindConnect Mindsphere network unit. Any sensors can be connected to the proposed ecosystem if they are compatible with digital and analogue inputs/outputs from PLC/IIoT.

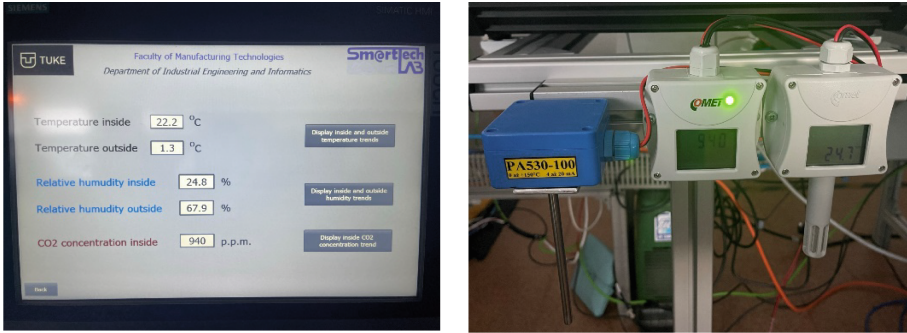


Fig. 11. Measured data and sensors

An example of measured data can be seen in Fig. 11. The OPC server must secure three communications: the first with the digital twin model, the second with cloud platforms and the third with the PLC system. For this reason, a customized OPC server written in the Python programming language was designed and implemented. To transfer data to the PLM system, we use:

- Tecnomatix Plant Simulator integrated OPC UA Client,
- SimTalk 2.0 Methods for data synchronisation to Digital Twin.

We set up a connection to the server and display the monitored data in a simulation environment (Fig. 12).

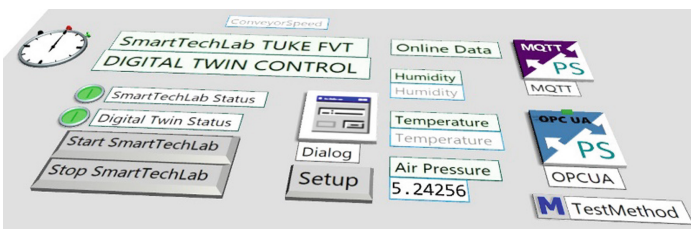


Fig. 12. Online Digital twin

This interface provides us data monitoring in the simulation tool. In our design, we observe:

- Start/Stop Sequence synchronization,
- Digital Twin Status,
- Inputs: sensors (Binary data, humidity, temperature, air pressure),
- Outputs: pneumatics pistons (Binary data), AC/DC motors (Analog data),

- 2D image/3D model data transfer: in development.

All these data are presented in online 3D models and also on cloud platforms. See Fig. 13.

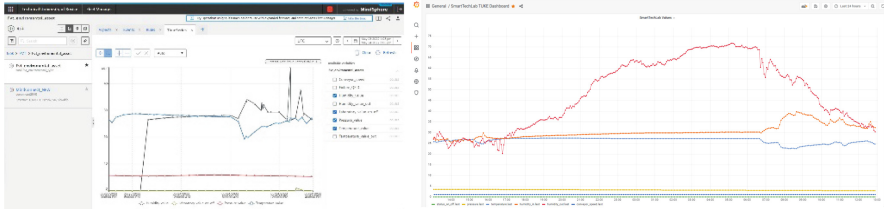


Fig. 13. Measured data v prostředí Siemens MindSphere a Grafana SmartTechLab

The number of monitored data is unlimited depending only on the number of sensors connected to the experimental ecosystem. The presented article provides an insight into the complex system.

4 Conclusion

The proposed digital twin experimental system will serve for further research and also for educational purposes. The use of advanced technologies based on the concept of Industry 4.0/5.0 can help the development of new Smart enterprises. The designed and tested digital twin ecosystem using a PLM program with full data digitization provides a universal digital model that can be used as a template for real production of small and medium enterprises. In general, our proposal brings several benefits for the smart industry:

- Improvement of efficiency: Digital twins make it possible to simulate and analyze the operation of equipment and processes and find out where savings and efficiency improvements are possible.
- Cost reduction: Digital twins can help organizations reduce the cost of manufacturing and operating equipment, for example by helping to identify and eliminate unnecessary or inefficient processes.
- Quality improvement: Digital twins can help organizations improve the quality of their products and services by allowing them to simulate and test different scenarios to see how they will affect quality
- Improving security: Digital twins can help organizations improve the security of their devices and processes by allowing them to simulate and test different scenarios to see how they will affect security.
- Environmental improvement: Digital twins can help organizations improve their environmental impact by allowing them to simulate and test different scenarios to see what their environmental impact will be.

The implementation of digital twins in production is a necessary condition of product life cycle management (PLM) to ensure sustainable production. There are several trends in digital twins that could improve in the future:

- Integration with artificial intelligence: Digital twins can be integrated with artificial intelligence and machine learning, which would enable them to better predict and solve problems
- Uses in various industries: Digital twins can be used in various industries such as manufacturing, transportation, energy and healthcare, helping to improve efficiency and reduce costs.
- Greater integration with IoT: Digital twins can integrate with IoT devices, allowing them to better collect and process data about the devices and processes operation.
- Real-time use: Digital twins can be used for real-time monitoring and control of equipment and processes, helping to improve their efficiency and reduce costs
- Greater availability: Digital twins are becoming more accessible and affordable for smaller organizations, enabling them to improve their processes and reduce costs.

Our ecosystem was created in the Tecnomatix Plant Simulation environment and we applied it to the experimental workplace. It brings a lot of knowledge from IIoT issues, digitization and simulation. In the future, we want to focus on the emerging trend of industry 5.0 and connect our proposed ecosystem with collaborative robotics, artificial intelligence and product sustainability.

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