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# A BRIEF SURVEY OF CREATING A DIGITAL TWIN ARCHITECTURE FOR VIRTUAL COMMISSIONING ON THE MACHINE LEVEL

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**Abstract**

*Digitalization is a hot topic today in every business, affecting the whole life cycle of a process or a product. This paper focuses on the design phase of automation systems, especially creating a digital twin of a machine to support the software development of the control system and its virtual commissioning. Different simulation model architectures are introduced, as well as specific use-case. The main objective of this paper is to present three basic types of digital twin architectures for virtual commissioning of production devices and systems. These architectures were investigated and built based on predefined requirements. Collaborative project work for the development of the digital twin and efficiency was defined as one of the requirements. Efficiency is required due to the software and hardware used for the digital twin. Architectures such as centralized, basic distributed and completely distributed were introduced in the paper. Based on the results from observation and testing, the authors recommend using the concept of completely distributed architecture of the digital twin based on the defined requirements. This digital twin architecture separates mechanical engineering and automation engineering with respect to PC stations. Nevertheless, it interconnects them using the standard machine-to-machine software and communication interfaces.*

**Keywords**

*Simulation, digital twin, virtual commissioning*

## INTRODUCTION

The conservative world of industry has faced a big challenge in the last few years, which is transformation through digitalization. Gartner's glossary defines: "Digitalization is the use of digital technologies to change a business model and provide new revenue and value-producing opportunities; it is the process of moving to a digital business."

From the perspective of the life cycle of automated machines and equipment, we can understand this as moving to a virtual environment by creating simulation models suitable for its separate phases. This approach brings many opportunities and advantages especially in prototype production. The machine CAD model is tested and optimized before it has been produced and assembled, and the machine control system could be optimized as well, while decreasing the development costs. In this way, the traditional machine commissioning is shifted from reality into a digital world and changes into a virtual commissioning, which uses instead of real machine its simulation model, so called digital twin.

With the focus on the initial stages of the life-cycle, the market currently offers a wide portfolio of software tools for creating a graphical 3D model of the device, testing its physical properties, its behavioural simulation and simulation respectively emulation of the control system, while having interfaces for their interconnection. These include CATIA, SOLID EDGE, MATLAB, MAPLE, ANSYS, Process Simulate, Witness and many, many others.

## OBJECTIVE AND METHODS

The main objective of the research described in this paper was to provide a basic overview of digital twin architecture in the design phase of a product life cycle. Fundamental definitions, as well as different simulation system architectures, were summarized. Based on the basic analysis, a simple use case in particular simulation software environment was introduced to show some undercover pitfalls and of course possible solutions.

## CREATING A DIGITAL TWIN

Let’s find some answers to the questions like what digital twin is, what it is good for etc.

### Definitions

#### *Digital twin*

Answering the question ‘What is digital twin?” is not as easy as it might seem at a first glance. Many different definitions of this term could be found in the literature depending on the author’s focus. The twin concept was used for the first time and is historically known since the NASA Apollo project in 1970. The technology had gone a long way until the real-world twin transformed into a digital representation of reality. Simply, the digital twin is a simulation model of a real system serving for different purposes according to a various point of view on a system life-cycle, e.g. optimization, monitoring, maintenance, etc.

An exhaustive explanation with a review of commonly used definitions offers [1] and defines the archetypes of a digital twin according to its independence from user intervention. Another point of view is brought up [2], where the conceptual framework of the digital twin is introduced, which divides the digital twin according to its application and defines different system architectures.

From the commercial point of view, the SIEMENS Company compared to competitors offers software products covering the complete system life cycle. Theirs holistic portfolio comprises solutions from product design through commissioning to services, using hardware and physical simulation platforms, edge computing, IoT, cloud, etc. as could be seen in Fig. 1. Thanks to this approach, it is possible to create digital twins tailored to the needs of a given phase of the life cycle, with advantage of their interconnectivity and interoperability.

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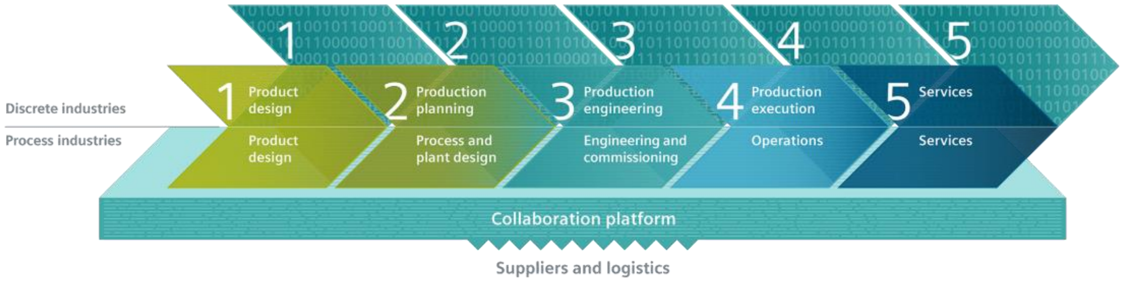


***Fig. 1*** *Digitalizing of the entire value chain. Reprinted from [3]*

For a system integrator who standardly implements control systems based on PLCs from SIEMENS, the software tools from the "The Digital enterprise" portfolio means unequivocal choice.

Accordingly, to the above-stated facts, a digital twin suitable for virtual commissioning is considered further in the paper. The digital twin could be thus defined as a data-interconnected complex of physical system and its virtual representation. This includes the graphical 3D model with the physics simulation capability, the system behavioural model, and real or emulated control system. This type of digital twin is suitable for the optimization of construction and application software development.

### *Commissioning*

Commissioning is a process of bringing the device or equipment into a productive state, which means assuring that all systems and components are developed, designed, assembled, tested, operated and maintained in compliance with user requirement specifications.

Commissioning is a very time-consuming but obligatory part of automation project, which could introduce higher costs especially in prototype production depending mainly on the effectiveness of the factory acceptance test. Fortunately, the development of computer technologies makes it possible to create increasingly sophisticated simulation models, which has enabled the emergence of virtual commissioning. Considering the virtualization level, four different commissioning configurations [4], [5], [6], [7] are identified, as shown in Fig. 2.

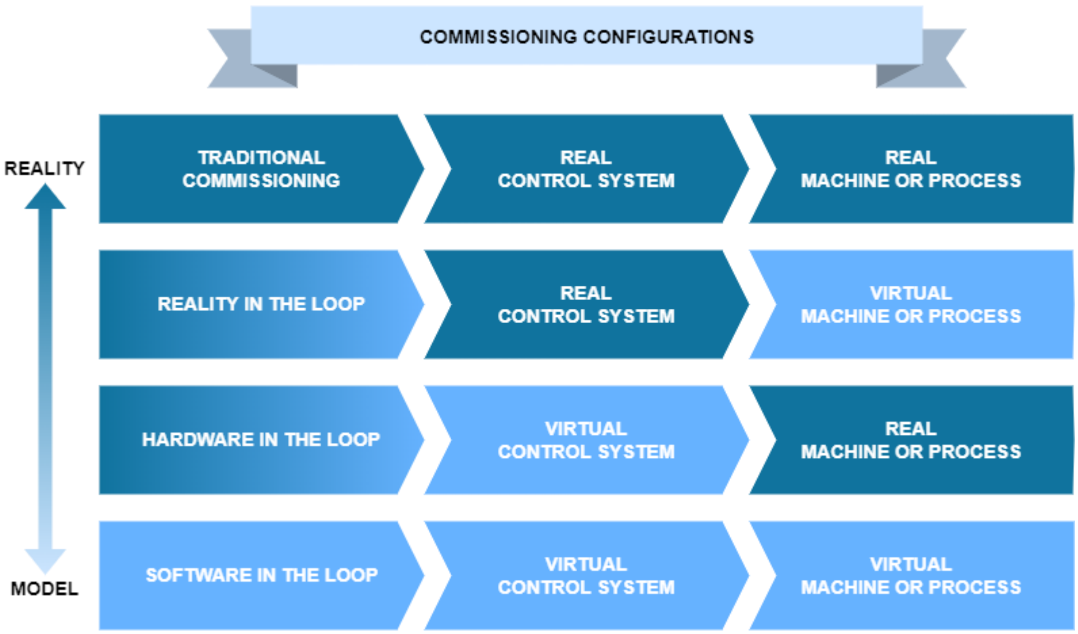


***Fig. 2*** *Overview of commissioning configurations*

In the context of the design phase of the automation system life cycle, virtual commissioning undoubtedly brings advantages over traditional commissioning such as:

- decreasing time to market and increasing software development time due to parallelization of development processes,
- optimization of the mechanical design, without building a physical prototype,
- faster test execution and increased number of test scenarios owing to altering the real time,
- executing targeted failure tests scenarios without system damage or safety risks,
- execution of virtual factory acceptance tests, so-called vFAT,
- and finally decreasing the time of physical commissioning.

On the other hand, also the resources and effort for virtual commissioning implementation must be taken into account. Apart from the cost of simulation software, there are some added activities and challenging tasks which must be done, like the behavioural model implementation or increasing the 3D model complexity to be able to simulate its physical behaviour. However, the standardisation goes a long way also in these processes, e.g. through repeatable software components.

**Use case**

If we consider the digital twin from different perspectives based on a state-of-the-art analysis, the purpose and goal of creating such a digital copy are important. From the point of view of Siemens and its software products, this can be seen from three sides; see Fig. 3.

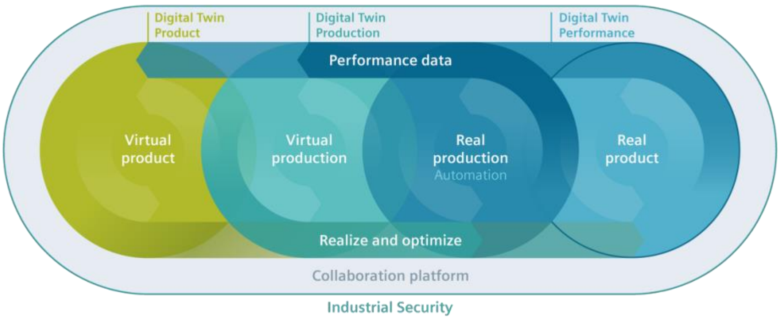


***Fig. 3*** *A comprehensive concept of the digital twin by Siemens [8]*

Their goal is to provide software solutions to the design of the Digital Twin of Product, Production and Performance. This view can also be applied to consumer products as well as production line solutions. With the created digital twin, we can create various "what if?" simulation scenarios, and predict the actual performance of the production line through the digital twin created by ourselves. According to the author [8], the goal of building a digital twin is to establish a closed loop between the virtual model and the actual physical product/production line. For our case study, we chose the model of creating a digital twin for a production line. If we look at it analytically, the production line and its digital twin can be useful on all three of these levels. From a product lifecycle perspective, PLM is a useful digital twin at various levels:

- Level 1: Digital twin of the production line for design and commissioning,
- Level 2: Digital twin of the production line for real-time production traceability,
- Level 3: Digital twin of the production line for optimization of behaviour and operation.

In the first case, we find simulation solutions for the design of the production line and machine parts, to what extent and in detail; the digital twin needs to be processed. In this case, we could take it to the level of sensors and actuation, mechatronics, and I/O level control. Then, it is appropriate to use the solutions for virtual commissioning, testing and debugging of the PLC code on the digital twin of the machine with its created behaviour model and 3D simulation

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model of the machine. We can design, simulate, and validate multi-physics simulations, automation elements and control software without the need for physical prototyping.

In the second case, we look at the digital twin from a different perspective within PLM. The production line can be built, delivered, and it serves the intended function, namely the production itself. At the same time, future production can be planned during continuous discrete or process production. The digital twin supports production planning itself. The interconnected simulation of mechanical and automation components depicts the final behaviour of the machines and forms the backbone for virtual commissioning; it can also be used for training of new employees or training of maintenance work on the production line or for testing of various changes without the need to stop the production itself. In this case, it is not necessary to create a digital twin as in the first case. Firstly, it is not important to observe the behaviour of individual elements at the level of detail, and secondly, it is an unnecessarily complex simulation and can put a huge strain on the hardware on which the simulation is running in this case.

In this case, the digital twin for the production operation is at the third level. In this case, the digital model of the production line is constantly fed various data that is processed by the digital model itself and directed from the line itself. Alternatively, vice versa, the digital twin can send certain data backward after optimization. In this way, a closed loop is created for decision-making and optimization processes. In this case, the graphical representation of the digital twin is in most cases in a simplified form, and only the most important facts affecting the decision-making process itself are highlighted. This principle also applies to the behavioural model and the amount of data being processed.

***Selection of parameters and software requirements for the development of a digital twin***

As mentioned above, it is possible to create a digital twin of the production line at many different levels. Since our goal is to use the digital twin in the design of single-purpose machines, automated equipment and production cells or lines, virtual commissioning technology is important to us. For this reason, we will make use of the Digital Twin at Level 1. The goal is to find solutions that are suitable for the needs mentioned above. The requirements are as follows: collaborative project work between the different departments (mechanical design, electrical and automation design, PLC programming), simplicity, flexibility, efficiency, possibility to test the PLC control program on a virtual model, reduced on-site testing, improving the software quality, improved productivity.

Siemens Digital Industries Software NX software platform has modelling software and an electromechanical design tool, including logic control models and the ability to connect to control systems. For this reason, we chose this particular solution for modelling and testing the digital twin. STEP 7 and the Totally Integrated Automation Portal (TIA Portal) allow you to create scenario in order to simulate and validate your user program.

Our prerequisite is to do the research and development of our customised digital twin for an automated system with a conveyor and semi-automated stations with manual operation. Thus, the subject of the research is to identify an appropriate solution in terms of the software support to be provided, the size of the digital model of the digital twin, the number of individual instances of the control system, the number of inputs, outputs, data types of individual variables, and to establish specific conclusions for optimal cooperation in the engineering work on the development of the digital twin. For our research, we chose the following configuration. The digital twin would be implemented using the SiL (Software-in-the-Loop) method, as it is a solution without the need for the required hardware on the control systems side. Based on our experience and also on the analysis from the literature review, we concluded that the digital twin will be applied and developed according to the following configuration.

- 3D visualization model by Siemens NX Mechatronics Concept Designer NX 2007 Series,
- Behaviour simulation model by Siemens SIMIT V10.3+Update1,
- PLC emulation model by means of PLCSIM Advanced V3.0,
- Control program model by Siemens TIA Portal V16.

The TIA portal (Total Integrated Automation) is the software used to program the PLC code, the so-called user program. The TIA portal project also includes the hardware configuration: drivers, screens, peripherals, drivers and communications. Once the TIA Portal project is complete, it can be tested and verified using PLCSIM Advanced, which simulates a controller (PLC). PLCSIM Advanced also handles communication and synchronization with external applications such as MCD or SIMIT. NX Mechatronics Concept Designer (MCD) is the tool used to build the physical and kinematic model. The user can introduce the physics and kinematics of the machine components over a previously existing 3D model (CAD) of the machine. That includes defining the mass and inertia of the rigid bodies, the collision bodies, the kinematic joints and constraints, the sensors, and the actuators. With this model, an engineer can generate and validate the operation sequence and motion of the machine or the load curves of the actuators. It can also be used to detect collisions and mechanical interference that occur during the machine operation [9].

***Proposed architectures for the digital twin***

In our case, we proposed three possible architectural configurations for the design of the digital twin according to our requirements defined above. At the same time, we defined the peripheral conditions, namely the software used by us. Thus, the overall proposed architecture was limited to the use of this available software and was intended for the design of a digital twin for automated manufacturing equipment and systems of small to medium configurations. Our proposed architectures were three, namely:

- Centralized architecture of the digital twin.
- Basic distributed architecture of the digital twin.
- Completely distributed architecture of the digital twin.

All these architectures are shown in Fig. 4.

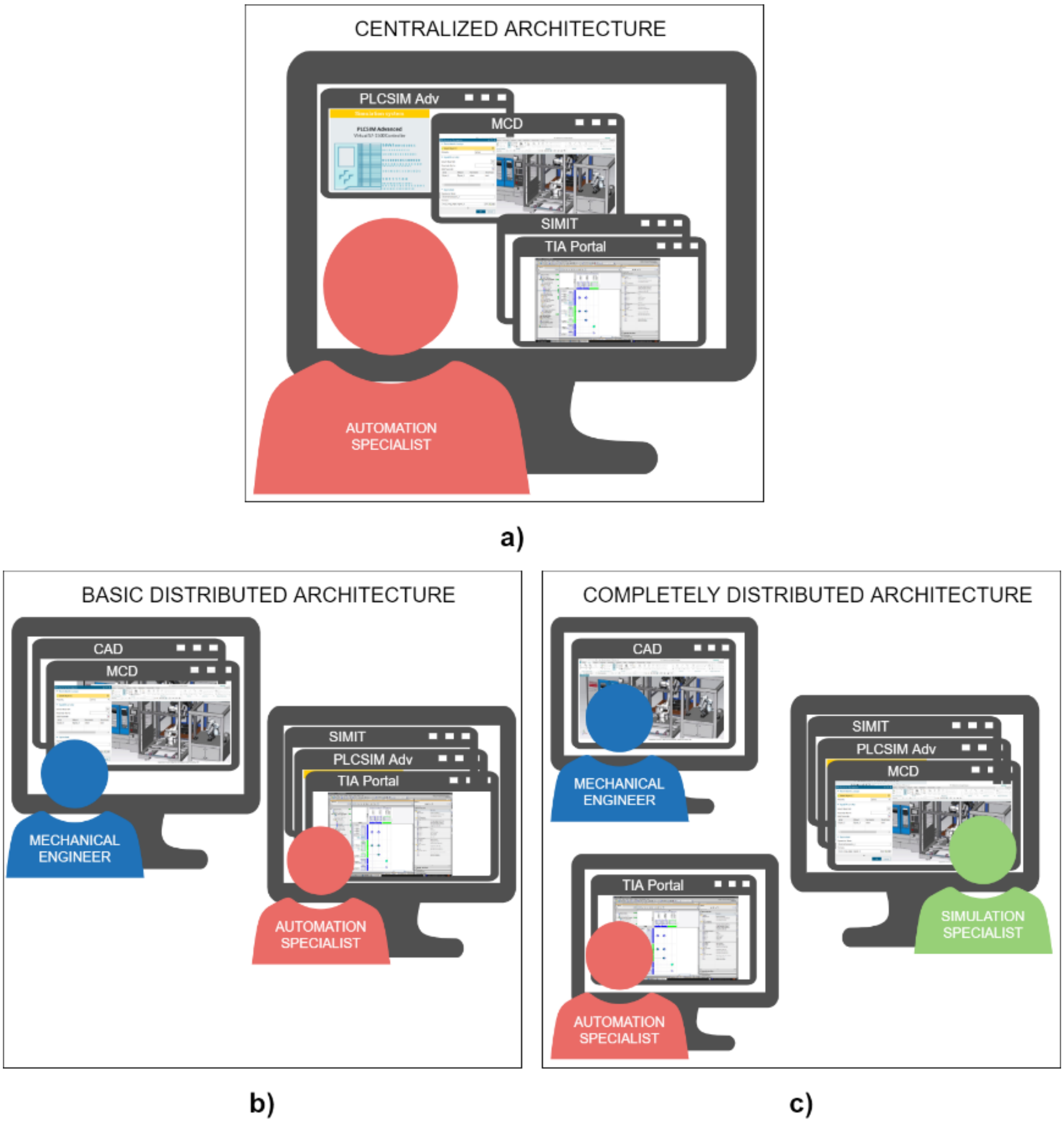


***Fig. 4*** *Overview of the Digital Twins architecture types*

As mentioned above, these architectures were subjected to analysis and testing themselves. Based on the empirical findings, we came to some conclusions such as the advantages and disadvantages of each architecture. The advantages and disadvantages were defined based on empirical investigation, where we gained some knowledge from testing of the different architectures.

When looking at the basic structure, the centralized architecture of the Digital Twin (Fig. 4a), we could observe a simple solution where the whole architecture ran on a single PC workstation. Therefore, all software platforms (NX MCD, SIMIT, PLC Sim Advanced, TIA Portal) ran on one common PC. If we look at this solution in terms of inter-platform communication, inter-platform information exchange and time response, this solution is possible as the NX MCD allows Signal Mapping and external connection of signals via Shared Memory or the MCD SIMIT Add-in, where there is a direct connection to and from the SIMIT platforms. Communication between SIMIT and PLCSIM Advanced was solved through Emulation Coupling, where data and symbol variables are imported from the imported created TIA Portal project. With integrated behavioural models, SIMIT is the interface between the 3D CAD system and automation technology. SIMIT emulates the behaviour of devices such as sensors or drives. Once connected, the SIMIT Simulation platform communicates with

PLCSIM Advanced via a Localhost connection. PLCSIM Advanced emulates the PLC control program, and if the TIA Portal is running online, it is possible to directly monitor the read values towards the NX MCD or control the outputs towards the NX MCD. This communication is also traceable on the SIMIT platform. This configuration is advantageous in the following points: simplicity - simple configuration on one computer and efficiency - you can directly respond to the digital model, behavioural model and individual signals. In addition, this in all software that is running. For basic testing of the digital twin, such a configuration is advantageous on these points. In addition, the MCD communicates directly with SIMIT and SIMIT directly with the SIM Advanced PLC. It is not necessary to create channels to link the above software. On the contrary, this configuration has disadvantages in terms of hardware performance requirements; all software must run on one PC and most importantly. Very disadvantageous for a collaborative project, the Completely Digital Twin has to be managed by one person. Probably a separate engineer has to be hired for the projects. This is inefficient and, from our point of view, may not save time on the project.

The second type of architecture is the basic distributed architecture of the Digital Twin, Fig. 4b. When compared with the previous one, a noticeable difference can be seen. The simulation part, representing a graphical representation of the 3D model of the digital twin at the level of the mechanical, kinematic, and dynamic model, runs on one PC workstation, and the behaviour model, including automation, runs on the other. The computing power for the control system side is decoupled from the graphics power of the PC station on the other side. In this case, communication between the two platforms has to be ensured. The solutions for the simple model do not completely apply to this architecture model. The communication between SIMIT, PLCSIM Advanced TIA Portal runs in the standard way as in the previous version. However, it is necessary to provide a solution between NX MCD and SIMIT. Here, two solutions are possible. If we are on a local network, data exchange via OPC DA or OPC UA. This can also be used if we secure it by encrypted transmission between Server and clients. Both platforms, SIMIT or MCD have the possibility to create either a server or a client. This method of configuration has the advantage that it can perform work on the digital model and work on the automation project. These works can be separated and, from an efficiency point of view, this is advantageous, as it can save time. From the efficiency point of view, we find the work to be realistic, two people in the team can coordinate their work, and signals are sent between the two stations. In terms of simplicity, the system is more complex, there is no direct link between MCD and SIMIT, but this was solved via OPC UA and the system appeared to be stable, it was only necessary to forward the names of the individual Tags to each other as the communication is via Signal Name. As for the cost, two engineers, two PC stations are needed, but the project still needs to have such stations regardless of whether the machine being developed uses Digital Twin or not. However, these persons can work independently, saving time on the project and thus reducing costs. This is also related to increased productivity.

The third version of the architecture is at the level of medium or large digital twins. Here, we are talking about a completely distributed architecture; see Fig. 4c. This solution allows total separation between CAD mechanical engineer, simulation specialist, and automation engineer. The PC workstation for simulation specialist is equipped with PLCSIM Advanced emulation software, SIMIT for the behaviour model, and NX MCD for the virtual model of the digital twin. In this way, the computing power is transferred to the PC workstation for PLC programming, such as the SIEMENS simatic field PG. Graphics performance is again provided on a PC workstation simulator. Communication between CAD and simulation is ensured e.g. via the Teamcenter platform, via import and translation of CAD data to NX MCD. The communication between TIA Portal and PLCSIM Advanced is provided in the local network via the PLCSIM Virtual Ethernet Adapter. The third way of configuration is complex. It appears to be the most advantageous from the point of view of efficiency, also from the point of view of effectiveness. However, it has the disadvantage of just needing an extra person, technique and simulation specialist compared to the previous ones, which increases the cost. This person develops both, the MCD and the behavioural model in SIMIT, and it appears to be less efficient work.

## RESULTS

All three of these architectural configurations for the digital twin were subjected to fundamental testing and the following basic results were obtained. The requirements were as follows: collaborative project work between the different departments (mechanical design, electrical and automation design, PLC programming), simplicity, flexibility, efficiency, possibility to test the PLC control program on a virtual model, reduced on-site testing, improving the software quality, improved productivity. All configurations were evaluated based on our experience, and evaluated according to our own discretion. We scored from a value of 1 to a value of 3 for each individual category. As a result, the Digital Twin - Basic Distributed Architecture configuration and architecture appears to be the most suitable, as seen in Table 1.

**Table 1** Basic evaluation of architectures according to requirements

| | CENTRALIZED ARCHITECTURE | BASIC DISTRIBUTED ARCHITECTURE | COMPLETELY DISTRIBUTED ARCHITECTURE |
|---|---|---|---|
| SIMPLICITY | 3 | 2 | 1 |
| EFFECIENCY | 1 | 3 | 2 |
| COLLABORATIVE WORK | 1 | 3 | 3 |
| MINIMAL COSTS | 2 | 3 | 1 |
| PRODUCTIVITY | 1 | 2 | 3 |
| **TOTAL** | **8** | **13** | **10** |

From a collaborative perspective, the Completely distributed architecture is the preferred one. It is very difficult to find a person who can deal with CAD design, simulation in SIMIT, programming behaviour models, or PLC programming. It provides flexibility as in the Basic distributed architecture. Also, in terms of project development, this model is the most interesting. However, this model is the most complicated in terms of simplicity; it is necessary to provide individual PC stations. This configuration is also important in terms of the performance distribution of the computers. In our testing, we also experienced graphical system failures on the MCD side due to the fact that PLCSIM Advanced takes power from the CPU (each core represents an instance) and thus the SIMIT platform memory. For simple testing of small models of Digital Twins, the configuration of Centralized architecture is a good solution.

## CONCLUSION

As can be seen, the creation of digital twins of automated devices and machines has a future in design and development. Depending on the relevant results, it has its benefits, it can reduce the project time, and the automation engineer can evolve their control code and test it ahead of time. It is possible to improve the quality of the project itself, verify the mechanical part through the simulation, and also to verify and improve the PLC code itself. Since this was an empirical finding of the above facts regarding the advantages and disadvantages of the proposed architectures, we propose to compile a comprehensive methodology to investigate the different digital twin architectures in the future. Based on the methodology, we will evaluate the data obtained from testing the different configurations of the digital twin architectures, including photo documentation of the different experiments. They should be assessed on real projects, and their effectiveness evaluated.

The aim of this paper was to introduce the basic architecture of digital twins specifically for Virtual Commissioning, evaluate their advantages and disadvantages based on simple tests and define a preferred setup for our project based on experience. In our case, three possible configurations were proposed. For basic testing of simple Digital Twins, Centralized architecture is sufficient, but based on the results and testing, we recommend Basic distributed architecture. We will subject this model to further tests with respect to the performance of digital twin, setting the configuration of the different software parts, and we will develop a digital twin for a specific automated system project. In the future, we will deal specifically with the methodology of evaluating the data obtained from the experiments.

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