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Conceptional Design and Prototypical Implementation of a Digital Twin for a Modular Manufacturing System

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Abstract

Digital twins of manufacturing systems have become increasingly relevant for use cases such as virtual commissioning and AI related process optimizations such as predictive maintenance or condition monitoring. However, the lack of standardization with regard to implementation tools and the ambiguous use of the term prevent digital twins from widespread industrial application of digital twins. This paper presents a conceptual approach and a successful implementation guide for a digital twin of a modular manufacturing system. First, different notions of the term digital twin from the vast literature are summarized and a unifying definition is presented. Turning to the application example, the modular design of the manufacturing system considered in this paper is outlined as well as the workflow of the industrial assembly process. In the main section a detailed architectural concept for a digital twin of manufacturing systems is presented. Finally, the toolchain that implements this architecture is described emphasizing the functionalities of the components used. The results are discussed and an outlook towards a bidirectionally interdependent digital twin is given.

Keywords
Digital Twin, Automation, Smart Manufacturing, Digitization, Industry 4.0

1. Introduction
In order to meet the increasingly complex requirements of modern manufacturing processes, new transformative concepts are needed, such as the digital twin. Digital twins are often not clearly defined and therefore offer a wide range of applications. Whether for virtual commissioning, AI applications such as preventive maintenance or development purposes, digital twins can support decision-making, operational control tasks and design decisions. In order to fully unlock this potential, the individual use case must be correctly identified and the digital twin correctly defined according to the requirements. The appropriated choice of a software toolchain that connects real and virtual entities is also essential for correct implementation.

As a future technology the digital twin serves as a bridge between the physical and digital realms, enabling manufacturers to gain unprecedented insights into their operations. With this knowledge, processes can be adapted and optimized accordingly towards more growth, resilience and sustainability. Using suitable software solutions, digital twins can be set up as closely as possible to the real counterparts and processes. This allows software solutions of varying complexity to be selected depending on the level of detail required. For example, entire processes can be simulated in real time. Dynamic in-loop adjustments in the manufacturing process can be adapted to be able to react appropriately to exceptions or to simply minimize downtimes (International Organization for Standardization, 2016). Dynamic in-loop adjustments can be made to the manufacturing process in order to react quickly and appropriately to exceptions or irregularities and thus avoid bottlenecks. Processes can also be tested in advance and different scenarios compared with each other in order to design a process as optimally as possible. This allows manufacturing deadlines to be met dynamically. Processes can also be tracked and visualized through the utilization of digital twins. This means that parts and components can also be traced. This is particularly advantageous in downstream processes.

Despite these considerable advantages, implementations of digital twins for existing manufacturing systems have to overcome challenges, such as the lack of data standards, observability issues, obstacles in creating physical models, and many more (Lyu, 2024). Furthermore, the toolchain required for digital twins can be difficult to realize and implement. This is mainly due to the fact that an overview of available tools and software, as well as their individual advantages and disadvantages, is lacking. However, with the emergence of IoT and cyber-physical systems, the relevance of digital twins continues to grow drastically in the future. Kagermann sees the digital twin as one of the main technologies for the manufacturing development in the next ten years, as manufacturing gets more and more data driven and the digital twin strongly corresponds with the production megatrends of the next years (Kagermann and Wahlster, 2022). Industrial AI, edge computing, 5G in the factory, team robotics, autonomous intra-logistics systems and trustworthy data infrastructure are identified as megatrends of future manufacturing, see Figure 1. For instance, a twin can be used as an agent in a multi-agent system and thus be able to make decisions, which are able to decide and coordinate the next steps for workers and robots.

This suggests the relevance of the digital twin will not be lost in the future. This paper presents therefore, a feasible implementation of a digital twin for a modular manufacturing system. For this purpose, the current definition of the digital twin is first examined in a literature review. Afterwards an exemplary manufacturing use case will be shown, on which the methodology covered in this work will be applied. A general architecture model is created for this realization, from which a requirement list for the corresponding simulation toolchain is derived. Appropriate software is then selected from this and combined into a toolchain with suitable interfaces. A conclusion is then presented and possibilities for further research and development are presented.

2. Conceptual Understanding of Digital Twins

The term digital twin was first coined by Grieves in 2002 (Grieves and Vickers, 2017): "It is based on the idea that a digital informational construct about a physical system could be created as an entity on its own. This digital information would be a 'twin' of the information that was embedded within the physical system itself and be linked with that physical system through the entire lifecycle of the system." A different interpretation of the term by Shafto sees the digital twin as a comprehensive simulation of a vehicle or system, encompassing multiple physics, scales, and probabilistic aspects (Shafto et al., 2010). It utilizes the most accurate physical models, sensor data updates, fleet history, and other relevant information to replicate the real-world counterpart. A more detailed and widely recognized definition in research is given by Glaessgen, Stargel in 2012: The digital twin is a comprehensive simulation of a complex product, integrating multi-physics, multi-scale, and probabilistic models, using the best physical models and sensor updates to replicate the life of its real-world counterpart (Glaessgen and Stargel, 2012). Further attempts at definition have been made in recent years. In 2019, Rosen therefore stated that the digital twin is understood differently from user to user depending on their perspective, interests and system type (Rosen et al., 2019). The wide-ranging application scenarios, use cases and life cycle phases complicate matters further. A clear definition of the digital twin is therefore currently not possible. It can only be stated that a digital twin is a realistic virtual representative of a real system. According to him, the life cycle phase in which the digital twin is used plays a decisive role. Another modern approach for the definition of the digital twin in manufacturing was introduced by Stark and Damerau in 2019. By this definition a digital twin is a virtual model of a distinct product, whether it be a real device, object, machine, service, or intangible asset, or a unique product-service system, which integrates a product and its related service (Stark and Damerau, 2019). This virtual representation includes the selected characteristics, properties, conditions, and behaviors of the real product or system, captured through models, information, and data. This can encompass various phases of the product's or system's lifecycle. In 2021 Wilking added new dimensions to enhance the current concepts. The Digital Twin concept involves linking a real-world physical object to its virtual counterpart. This virtual counterpart is made up of various models that describe the physical object, including system models, simulations, and mathematical models created during the product development phase. During this lifecycle stage, these models collectively form what is known as a virtual prototype (Wilking et al., 2021). It is clear from these numerous attempts at definitions that the digital twin is a complex technology that cannot be clearly defined due to its wide range of applications, which means that there is still a lack of clarity.

In principle, a distinction must be made for each application as to which digital twin is involved, as not every digital twin has the same functionalities, the same area of application and information flow is not identical for every digital twin. The right use case is therefore crucial for successful exploitation and categorization of digital twins. As an example, digital twins can be used to monitor and visualize processes. This allows abnormalities, irregularities and optimization potential to be highlighted and exploited in real time. The advantage of this is that a digital twin makes it possible to simulate certain scenarios before they occur and predict how the real entity would behave. Digital twins can also be used to determine the remaining useful life of components. This makes it possible to determine the downtimes of systems in advance and thus reduce or completely avoid downtimes by arranging repairs in advance. Machine learning tools are proving to be extremely promising as a complement in this area, but the accuracy of these applications is still limited, as they are only estimations that can vary considerably from individual to individual (Jiang et al., 2021). Shao has therefore created a framework based on Hedberg's elaboration in which digital twins are defined differently depending on the use case (Shao and Helu, 2020). For this purpose, the relationship between the real and virtual entity is defined more precisely. The relationship is analyzed in terms of the methods and tools used, the physical target system, the digital system and the implementation of the real system or digitalization of the virtual system. Examples used in this framework are the minimization of equipment downtime, optimization of production planning and the enabling of virtual commissioning.

Inspired by the reference architecture model of Industry 4.0 (RAMI 4.0), the multi-level model depicted in Figure 1 has been developed to unify the different notions in a multi-faceted model (Deutsches Institut für Normung, 2016). The cross-domain characteristic of a Digital Twin is the complete virtual representation of a real entity. Analogously to the Reference Architectural Model of Industry 4.0 (RAMI 4.0), the lifecycle, hierarchy, and interdependence between the real and virtual systems represent three dimensions to characterize options of digital twins. The spatial-temporal dimension spans the entire lifecycle of the entity. It can be differentiated in the prototype phase which includes in particular the conceptional design and specification until the commissioning of the entity.

During this phase the virtual representation has to model the behavior of the prototype in its intended operational environment to foster development and verification tasks. Following successful commissioning, instances of the entity can be used productively. During this operational phase, individual instances adapt to changing environmental conditions, implement efficiency gains from real-world experience, or accommodate modifications, maintenance or repair. The system's lifecycle ends with decommissioning and dismantling. Concurrent with the physical entity's lifecycle, the digital twin evolves to meet the needs of each phase: During the prototype phase, it provides the capabilities of a model-based development paradigm. During the operational phase, data-driven analyses from operational use continuously refine the digital model, which in turn can be used to optimize the real-world instances.

The second dimension describes the hierarchical structure of the digital twin. The fundamentally modular structure of the virtual representation starts with the design specification of the entity, further extending through material properties and manufacturing processes to the material flow, and may include the value-added network. The level of detail of the digital twin can be adjusted to suit the specific application. For a comprehensive digital twin, however, the behavior of each component should be replicated as accurately as possible, with multiphysics or co-simulations being suitable methods to model the behavior in detail.

The connections between the real system and the digital representation determine the third dimension. When the digital model is viewed in isolation, it combines design data such as 3D Computer-Aided Design (CAD) models, bills of materials, electrical CAD, simulation models, and other design documents, accurately reflecting the behavior of the real entity. Encompassing cross-domain and domain-specific models universal interfaces such as sub models of the Asset Administration Shell have to be employed to access and interconnect the behavioral models. While data exchange can be implemented unidirectionally, the full digital twin requires automated and bidirectional interconnection between the digital and physical entity, setting it apart from the digital shadow, which only has a unidirectional flow of data or information from the physical to the digital entity (Kritzinger et al., 2018).

With its three dimensions, the multi-layer concept spans the entire model space of digital twins thus reducing ambiguities surrounding the term. In the following, the concept will be further detailed to obtain an implementation strategy for one particular layer. The example concerns the process automation at the life cycle stages beginning with virtual commissioning. Communication will be established in a unidirectionally automated manner This classification is explained in more detail after the toolchain for the digital twin is set up.

Although this layered model still does not provide a definition for the digital twin, it unites the core aspects of the definition approaches in a standardized model. For example, the model adopts Grieves approach that the twin must be mapped with the real system over the life cycle (Grieves and Vickers, 2017). In this model, this is done over the life cycle axis. Another example is the view of Stark and Damerau. They emphasize that the digital twin can also originate from or belong to a service (Stark and Damerau, 2019). This differentiation is reflected in the multi-layer model developed here through the hierarchical dimension. Overall this multi layered model has greatly simplified the differentiation that the diversity of the term digital twin entails, as previously mentioned by Rosen (Rosen et al., 2019). This multi-layered model therefore provides a good basis for further detailing and is used within this paper on the digital twin use case to narrow it down.

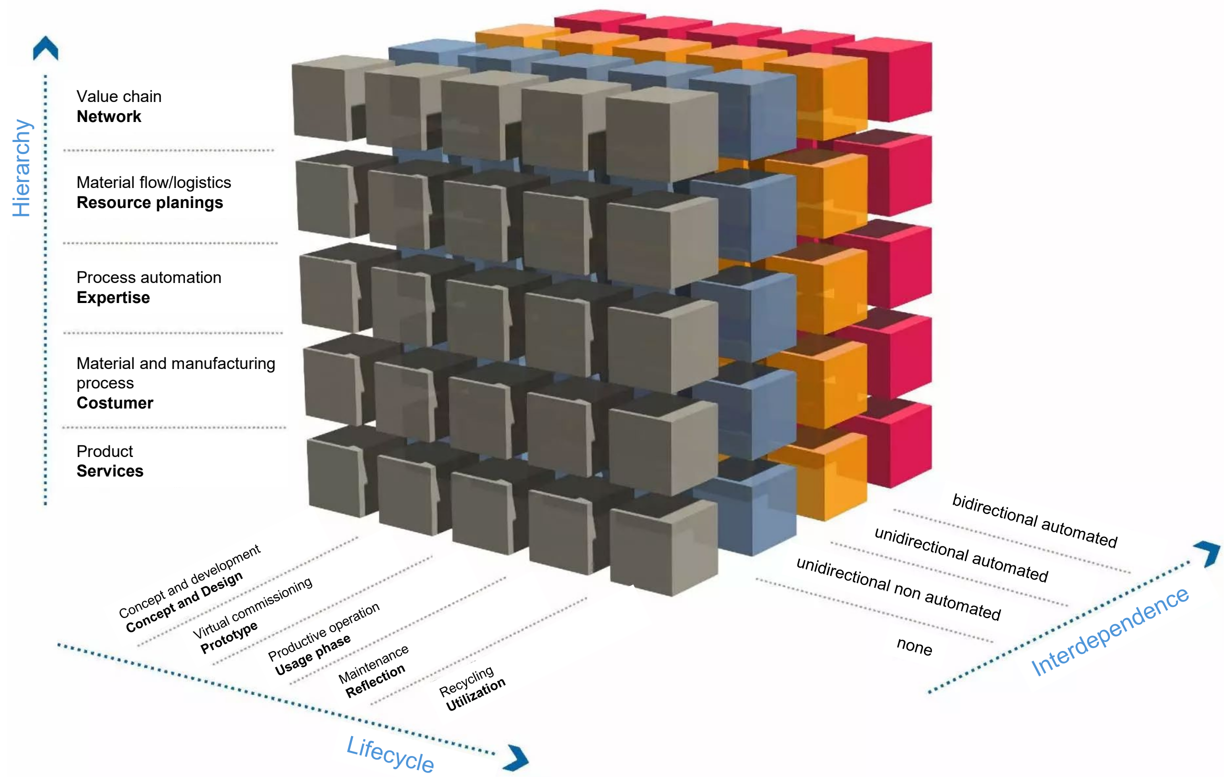

Figure 1. Digital Twin definition based on RAMI (Deutsches Institut für Normung, 2016)

3. Exemplary Manufacturing Use Case

The manufacturing system considered in this use case consists of four mobile modular manufacturing cells, see Figure 3. The individual cells have the same design and component structure which makes them suitable for assembly processes of workpieces up to dimension 0,15 x 0,15 x 0,15 m. The production cells can be dynamically arranged to accommodate for new product variants or order fluctuations. They therefore provide an excellent basis for enabling a fluid manufacturing system (Fries et al., 2021). A Manufacturing Execution System (MES) collects customer orders and defines the workflow for each product variant. Each cell performs one assembly step as part of the total process. An industrial robot system with a gripper is therefore installed. A conveyor belt driven by an electric motor and frequency converter transports the workpieces from cell to cell. At each cell, the workpiece carrier is stopped to determine which assembly step has to be performed. The order information stored in the MES is compared to the workpiece data contained in a Radio-Frequency Identification (RFID) chip. A Programmable Logic Controller (PLC) serves as controller for the cell through which all the components and external communication are managed. It also monitors the safety functionalities like safety stops. An Human Machine Interface (HMI) continuously reads data from the PLC to display the current status of the system. The HMI allows the user to select the operating mode and sends corresponding commands to the PLC. The hierarchical structure of the manufacturing cells is outlined in Figure 2 using the automation pyramid specified in IEC 62264 (International Organization for Standardization, 2020). Profinet is used as the field bus system, as it offers real-time capability. Each participant in the system owns an assigned IP - address and can therefore be identified the whole time. Order and other process-related information is obtained from the management and planning level by interfacing Enterprise Resource Planning (ERP) and MES systems. The HMI allows operators to manually set up the manufacturing system, e.g. choosing the operation mode. A master controller serves as interface both to the higher and lower levels controlling in particular the sensor and actor systems needed for process automation.

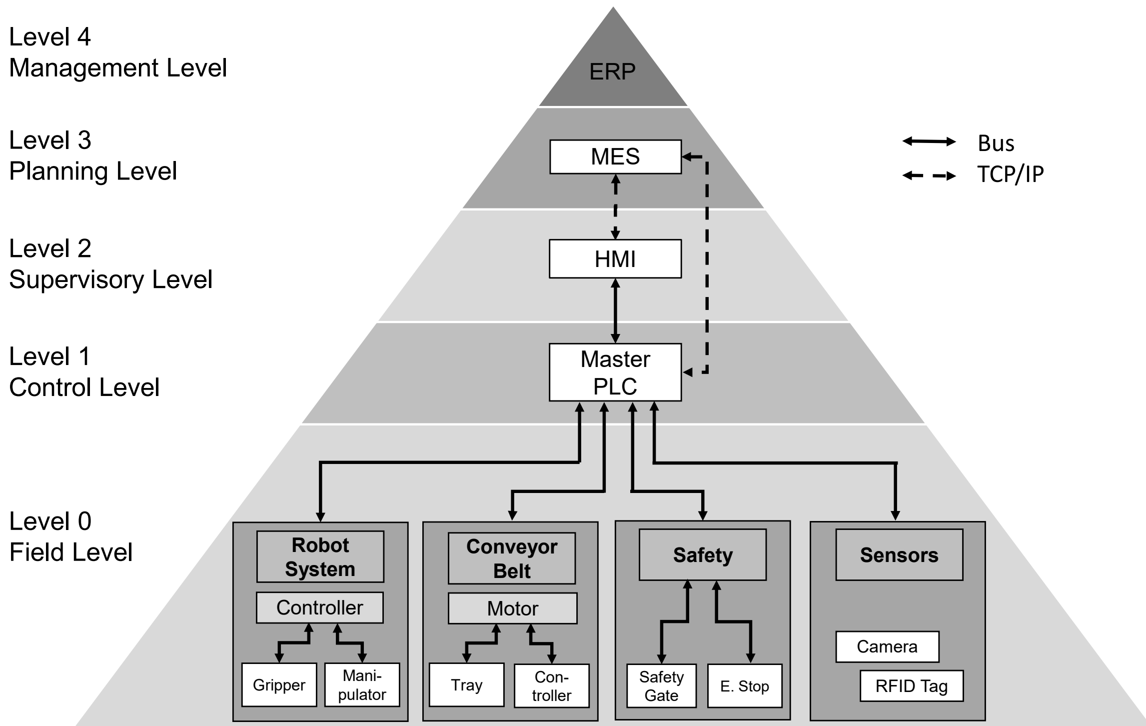

Figure 2. Modular Manufacturing System Architecture based on IEC 622646 (International Organization for Standardization, 2020)

As an exemplary product, the system packages chocolate bars into a container, closes the container with a lid and hands back the filled container to the customer. In this setup, the first cell detects and measures the supplied container and lid. The data is propagated to the next cells that use KUKA Agilus and KUKA iiwa robots, respectively, for the assembly process. Figure 3 shows the Computer-Aided Design (CAD) model of the physical manufacturing system on the right side and the real physical system on the left side. On the conveyor belt of the third cell the carrier with the container into which the product is to be filled, can be seen.

Figure 3. (left) physical manufacturing system (right) digital manufacturing system

4. Architectural Model and Implementation of a Digital Twin for the Manufacturing System

Virtual commissioning and process simulations during operational use are of great significance for special purpose machinery manufacturers as well as for the manufacturing industry itself. In the following, an architectural model for digital twins applicable to these domains (compare with Figure 1) will be developed. Based on this model, an exemplary implementation for the industrial use case presented in Chapter 3 is presented. Software solutions with the the corresponding network interfaces and interconnections are outlined to obtain a complete simulation toolchain for automated unidirectional interdependece between the real and virtual production system.

4.1 Architectural Model of Digital Twins for Process Automation

The modular manufacturing architecture of Figure 4 represents a current standard for process automation. In this, the individual modelling levels are linked together according to the necessary requirements. It connects the simulation layers of the Design Suite, the behavior simulation and the controller emulations. It also shows where signals or models need to be transferred to the other levels. The architecture model then serves as the basis on which the toolchain can be built.

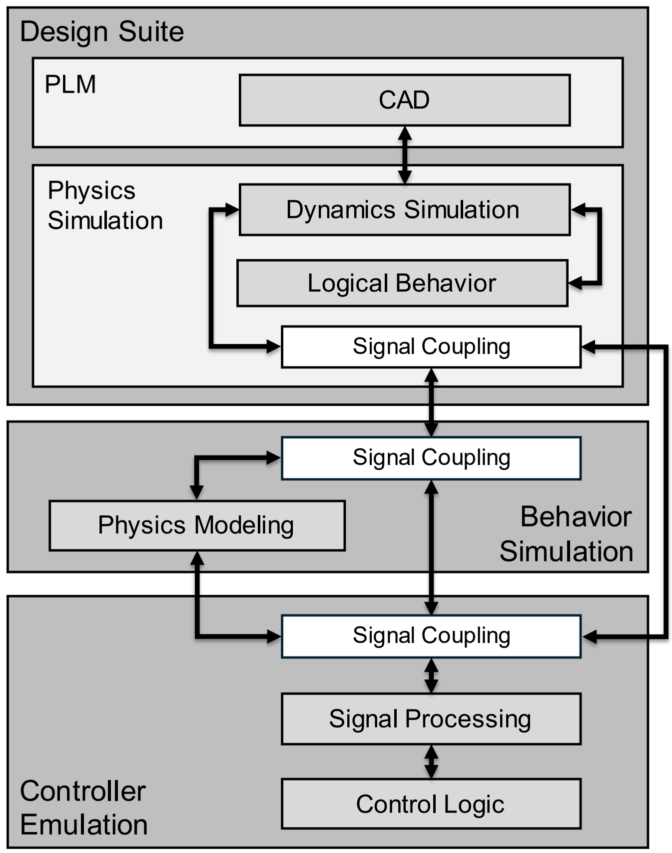

Figure 4. Architectural Model of Digital Twin for the for Process Automation

A virtual model of such a manufacturing system should replicate the physical behavior of the real entity accurate enough to fulfill the process automation use case requirements. This requires real time physics engine to simulate and visualize the behavior of all components. For the scope of this work, only solid multibody simulation is considered. However, fluid dynamics, soft body and other physical properties can be simulated with suitable toolchains as well. The physics simulation should implement interfaces to design suites to obtain CAD models for each component. Ideally, product data or product lifecycle management suites are integrated as repositories for CAD models during the whole lifecycle. In order to dynamically simulate CAD models, they have to be annotated, in particular by assigning movable joints and their inertial, stiffness, friction or other physical properties. Moreover, the behavior of each component, especially sensors and actuators, has to be modeled. Different levels of abstraction can be used for this purpose:

Hardware **Emulations** replicate the behavior of components by executing the functionality of the real entity, i.e. their control logic, data communication and processing routines etc. by means of software (McGregor, 2002). Hence, the emulation represents the most detailed and realistic abstraction. However, only few hardware component manufacturers provide emulations of their devices to be utilized in digital twins.

Physical **Simulations** only replicate remodeled behavior, i.e. the execute white box, grey box, or black box models of real entities obtained from first principles, identification, physics-informed machine learning or other methods. They more coarsely abstract real behavior but can be implemented independently of the device manufacturer.

The highest level of abstraction are **logical Simulation**s that only idealize input and output behavior.
To illustrate the difference, consider the example of the conveyor belt. A hardware emulation would execute the actual program code on the same operating system software yet possibly on different hardware. If an emulation is not available the electromechanical behavior of the DC motor and frequency converter has to be modeled and coupled with the physics simulation. Coupling to both the PLC for motion commands and the Physics logic as a finite state machine only replicating the input-output behavior. Emulations are therefore preferable for realistic digital twin models. A pure logical simulation would abstract the program input and output behavior of the conveyor belt as a finite state machine, eg. a speed command is directly executed in the dynamics simulation. The controller signals can be transmitted directly or over the behavior simulation to the physics simulation. To couple the different simulation blocks with the emulations and simulations, a signal adapter must also be possible by the physics simulation. Signals from the models must be received by the physics environment and these must be given a corresponding logical behavior so that the corresponding process operations can be visualized. The overall concept idea is depicted in Figure 4. This also shows the interaction between the individual simulation and emulation levels.

4.2 Prototypical Implementation

Exemplary software solutions can now be derived from the architectural model. The prerequisites for the design simulation for this use case are the possibility of realistic rendering and sufficient interface options to the physics simulation. As a design system for CAD models, Siemens NX has been chosen. All CAD models were designed using this software. This includes the CAD models of the cells and robots, as well as the workpiece carrier. Siemens NX is used because of its good compatibility with the other software and especially because it has the Siemens NX Mechatronic Concept Designer (MCD) add-in. Siemens NX MCD is used within this paper as the main physics simulation software. This means that the CAD models from Siemens NX are extended by physical properties (e.g., velocities, inertias, etc.). It is possible to do this by creating operations in the software. This software therefore simulates and visualizes the entire process in real time. The requirements for the physics software in this use case are that dynamics simulation is possible, that real-time capability is available and that there are enough interface options for connecting to the behavior simulation. This software is the visual counterpart of the digital twin to the real system. For example, by setting a speed operation the robot kinematics are executed visually within this software or the conveyor belt is started or stopped visually. A particular advantage of this software is that the Siemens NX CAD model does not have to be transferred to a separate process simulation software, but can be used directly, as Siemens NX MCD is part of Siemens NX. Siemens NX MCD also offers numerous interface options for external data couplings. This is particularly important for coupling with other software.

Subsequently, SIMIT should be mentioned as an important coupling and behavior simulation software. This is particularly important for coupling with other software and setting up simulations. For example, coupling with Siemens NX MCD takes place over the SIMIT add-on in Siemens NX MCD. It covers a wide range of possible use cases, from simulating the inputs and outputs of field devices to modelling entire processes. SIMIT is also particularly useful for the simulation of signals and the associated devices. With prefabricated models the behavior of device sensors and actuators can be simulated. In this use case, SIMIT is mainly used as a software coupling method between the Siemens NX MCD and the robot simulation, as well as the simulation of some automation components (like the frequency converter of the conveyor belt). It also helps by transmitting Commands from the PLC emulations, as it also offers support in this regard. KUKA.OfficeLite is used as the controller emulation for the robot controllers in this study. This is a emulation software from KUKA that emulates the behavior of the KUKA Agilus controller. There is currently no known alternative that emulates the robot controllers so accurately. KUKA.OfficeLite also offers the possibility to emulate several robot controllers at the same time. KUKA.OfficeLite is used as the controller emulation for the robot controllers in this study. The KUKA.OfficeLite also has the Y200 interface, which can be used to link to other software solutions. The network options of the counterpart, KUKA.OfficeLite and the virtual machine must be configured correctly for this. The KUKA iiwa has no appropriate emulation software and is therefore connected directly to the toolchain as a hardware in the loop component.

Finally, the software for the automation controller emulation must be selected. For this use case, it is necessary to find an emulation for the HMI and the PLC instances that is as realistic as possible. S7-PLCSIM Advanced can be used to emulate the PLC instances used (s7-1500) and emulate their behavior. The automation software is supplemented by WinCC. This software solution can replace the HMI of the individual cells. The conveyor belt can be considered as an example. This can be controlled by the simulated HMI from the WinCC. As a result, the PLC instance sets the respective variable to the SIMIT and forwards it as a command to the field level (the master-slave relationship). Both WinCC and S7-PLCSIM Advanced are manufactured by Siemens and are therefore quite compatible with other Siemens software. They therefore also offer sufficient interface options to the other software solutions and have good monitoring options.

After possible software solutions for the use case have now been chosen, a corresponding toolchain will now be developed in this chapter. This means that the software solutions listed above are now linked together and their interfaces are shown. Figure 5 shows the toolchain of the digital twin for this purpose. In summary, the toolchain with the mentioned software solutions looks as follows and can be divided into the following three areas:

- **Robot emulation** (depicted in orange) includes all programs that contain the behavior of the robot controllers and their variable transfer. These are forwarded to the SIMIT over the Y200 interface and these are forwarded to the visualization software, the Siemens NX MCD, over the SIMIT AddIN.

- The **automation software** (depicted in blue) is summarized in the next section. This includes the simulation of the HMI (with WinCC), as well as the virtual simulation of the PLCs themselves with S7-PLCSIM Advanced. The PLCs can be flashed and configured in the TIA Portal. S7-PLCSIM Advanced can also be selected and configured as an interface via the external interfaces in the Siemens NX MCD.

- **External participants** (depicted in grey) include all participants who operate independently outside the company. These include the license server, which can be reached via the HS WAN, or the Sunrise Controller, which is connected directly to the simulation toolchain, as there is no emulation software for the KUKA iiwa yet.

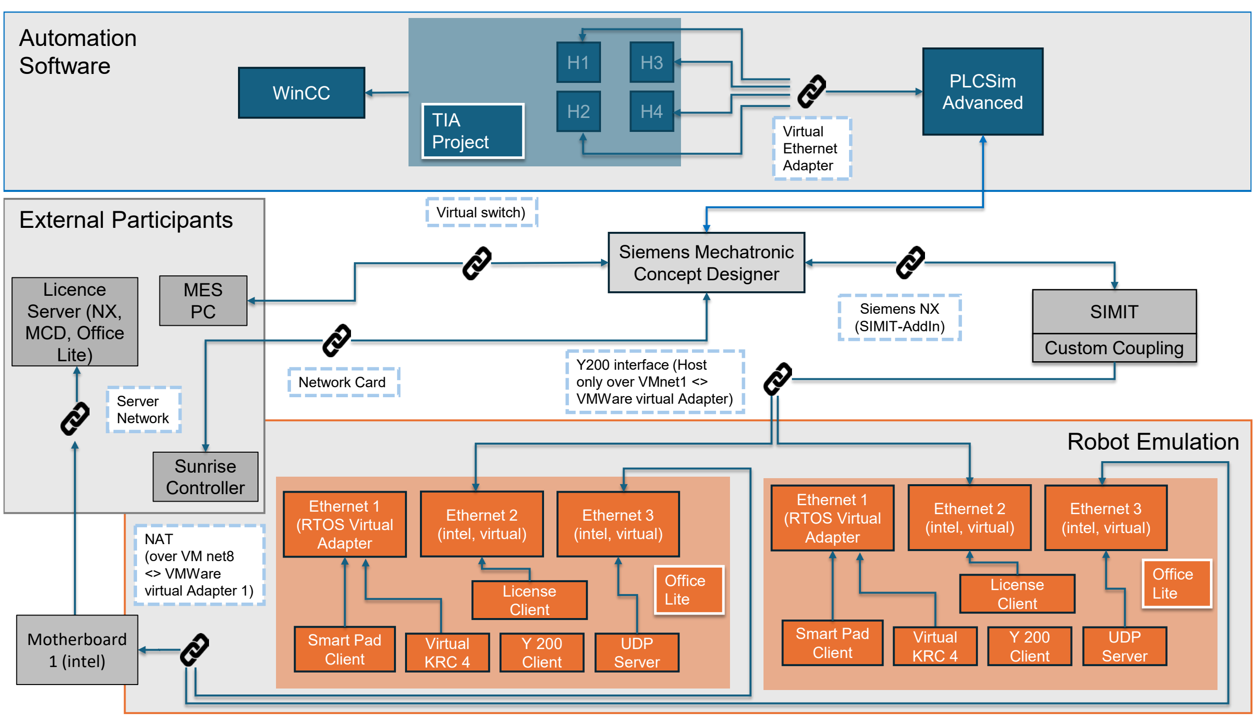

Figure 5. Toolchain of the Prototypical Implementation

The RAMI definition of the digital twin can now be fully described based on the hardware and software composition used. This figure can now also be used to categorize the entire system, which was set. On the one hand, the information flow is unidirectionally automated, as the information flow from the real system only takes place to the virtual one. This is because only the iiwa controller sends data to the digital system. Furthermore, it is a virtual commissioning, as the twin maps the processes of the real system in a virtual environment (the Siemens NX MCD). Also, the twin is used exclusively for process automation. This means that the dimensioning of the RAMI model is now clear and can be classified in accordance with chapter 2.

5. Results and Discussion

The main result of this work is that a unidirectionally automated digital twin has been implemented for virtual commissioning in process automation. The twin was created by applying a generally viable architecture model, from which corresponding requirements could be derived, which in turn enabled the creation of a possible toolchain for implementation. At the same time, it shows how the data from the individual simulation levels must be coupled with each other in order to create a suitable tool chain. For the specific use case for which this was carried out, it can be stated that the digital twin was created using only the KUKA iiwa controller as a real component. The digital twin combines the necessary automation functions in a realistic PLC environment with realistic robot emulations, both of which are visualized in a real-time capable process simulation. In accordance with the simulation profile the implemented digital twin enables low latency with realistic behavior and movements, with a negligible offset between the system behavior of the physical and virtual system. Based on this elaboration, real processes can be virtually simulated and thus essential data can be recorded and visualized in advance. Important key performance indicators such as process times or capacity utilization can be determined under realistic conditions and evaluated accordingly. This allows a manufacturing process to be optimally preconfigured. In particular, the combination with the modular manufacturing cells enables a fluid manufacturing system. Here, the modules of the manufacturing system can be reconfigured in short intervals. The digital twin presented enables swift virtual commissioning in this type of dynamic production environment.

6. Conclusion and future Work

Further improvements can be made in regard to complete software-in-the-loop emulation. For instance, the KUKA iiwa controller is yet to be replaced by a suitable emulation, or if not available by a physical Simulation. A suitable interface must also be configured for the simulation or emulation and implemented into the toolchain. Moreover the MES system currently running on another computer can be transferred to the host computer of the digital twin. This would enable centralized control and management of the entire system and the twin. Completing these steps achieves a digital twin further towards bidirectional coupling and a corresponding extension of the RAMI definition. A closed loop control communication between the virtual model data, services and the physical entities is possible by implementing intelligent interconnections (Zhang et al., 2022). This can provide the basis for further research on the existing digital twin and the introduction of corresponding data mining algorithms. As a result, the digital twin can be expanded to include an edge connection, which offers many new possibilities and is a prerequisite for linking the digital twin with IoT technologies (Li et al., 2022). Consequently, the digital twin can also be designed smarter in the future, whereby, for example, it can also make decisions itself by means of an agent system and thus carry out orders autonomously. As a result, it can increasingly become essential for future manufacturing, as described by Kagermann at the beginning, and support the megatrends of manufacturing already mentioned.

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Biographies

Michael Reisig is a student of the Master's program Applied Research at Technical University of Applied Science Augsburg. In addition, he serves as research assistant at the Technology Transfer Center in Nördlingen, Bavaria. Mr. Reisig holds a Bachelor of Engineering degree in Mechanical Engineering from Technical Augsburg University of Applied Science. During his current research master's degree, he is recreating an existing older digital twin and developing a suitable IoT application to go with it. He gained knowledge in the field of manufacturing research and industry through his internships at the Fraunhofer Institute IGCV in Augsburg and Kontron GmbH. His current research focuses on IoT applications, digital twins, data analytics and the associated interfaces.

Jürgen Herbert Lenz is research professor in the field of AI Systems for Manufacturing at Technical University of Applied Science Augsburg. In addition, he serves as Deputy Scientific Manager at the Technology Transfer Center in Nördlingen, Bavaria. Prior to this position, he was Professor of Smart Manufacturing at the Technical University of Applied Sciences Würzburg-Schweinfurt (THWS). He gained Industry Experience as Solution Architect for implementation and consulting of (I)IoT-Applications working for INNEO Solutions GmbH based in Ellwangen, Germany. Previously he served as Postdoctoral Fellow at West Virginia University in Morgantown, WV, USA (2018-2020) and worked for Fraunhofer at the Institute for Manufacturing Engineering and Automation IPA in Stuttgart. He completed his Engineering Doctoral Degree at the University of Stuttgart, Germany (2018), his Master of Science in Industrial Engineering as a Fulbright Scholar at Oregon State University (2012) and the German Engineering Diploma in Manufacturing Engineering at Technical University of Applied Science in Ulm (2009). His research interests are in the field of Smart Manufacturing include Machine Tool Connectivity, IoT-Platforms, Data Analytics and Machine Learning.

Florian Kerber received his diploma in engineering cybernetics from the University of Stuttgart, Germany in 2007 and a Master of Science in engineering science and mechanics from Georgia Institute of Technology in 2006. He obtained his PhD on compositional analysis and control of dynamical systems from the University of Groningen, NL, in 2011. Currently, he is a Professor at the Faculty of Electrical Engineering at the Technical University of Applied Sciences Augsburg, Germany and scientific director of the Center for Technology Transfer at Nördlingen, Germany. His research interests are in modern control theory, robotic systems and formal methods for production automation.