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An analysis of the available virtual engineering tools for building manufacturing systems digital twin

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Abstract

A variety of virtual engineering and commissioning tools are available in the market. However, the considerations of the manufacturing system's life cycle and the development of the digital twin vary. Thus, there is no guidance for manufacturing systems developers on links between the lifecycle and the recommended approaches to be followed when building the digital twin. This paper evaluates and compares the current approaches and tools which support Lifecycle to develop a Digital Twin. To do so, a set of criteria is derived from the IIC (Industrial Internet Consortium) industrial standard, and the corresponding tools that fulfil these criteria are presented. The software tools are evaluated based on an industrial case study conducted at WMG, the University of Warwick.

Keywords: Digital twin; digital shadow; virtual engineering; virtual commissioning; comparison

1. Introduction

With the movement towards manufacturing digitalisation, digital twins of manufacturing systems, components and processes are a game changer. The development of the digital twin (DT) of the automation system consists of three main phases: virtual simulation creation, virtual commissioning (VC) and operation of the developed virtual system. VC nowadays is considered as one of the key technologies in the fourth industrial revolution (Industry 4.0), which assists manufacturing systems developers in the early design phases [1]. The main benefit of using virtual simulation and virtual commissioning is to shorten the lifecycle and save costs during the system development by testing and verification of processes before the physical system has been built or even ordered. However, the development of the virtual system and further the Programmable Logical Controller (PLC) code verification requires significant efforts, time, costs, and engineering skills, which may make the benefits questionable.

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As an appropriate prerequisite for the digital twin of the manufacturing process, the virtual system has to realistically represent the physical system at a certain level to verify the processes precisely according to the requirements with as less effort as possible. Therefore, the software solution developers aim to satisfy the industrial customer requirements and provide a tool which requires as less effort as possible to develop a virtual system, with the most realistic representation of the physical counterpart. Moreover, this digital twin is to be useful to be implemented further at the operation and reconfiguration stages of the life cycle.

There are different methods and software solutions to develop the digital twin, such as WinMOD®, Emulate3D®, Visual Components®, vueOne® and NX MCD®. Each of the tools has its main procedure of system development such as developing components, creating the static system out of the components, defining behaviour and signals connection, and finally the connection to a PLC to execute the virtual commissioning. In addition, each software solution has a different approach and steps of the general method to develop a digital twin. To this end, machine builders and system developers lack a guide on selecting VC tools in relation to the creation of manufacturing processes' digital twin. Therefore, the paper presents an anal-

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ysis and comparison of the existing virtual engineering (VE) software tools using a virtual automation system as a case study. The work aims to compare the current approaches to creating a digital twin based on features from the DT standard from the Industrial Internet Consortium. The remainder of the paper is structured as follows: Section 2 reviews the literature on VC and DT development taking into account the coverage of the system's lifecycle. An evaluation of the VE tools depending on the features needed to build a DT is introduced in Section 3. Finally, Section 4 concludes the paper.

2. Literature Review

The following literature review aims to identify the relationship between VC and DT, then the challenges faced whilst building DTs. Afterwards, the perspective of researchers on VC tools is explored so that the research gaps can be defined.

2.1. The relationship between DT and VC, and DT building challenges

A joint whitepaper shared between the Industrial Internet Consortium (IIC) and the Plattform Industrie 4.0 refers to DTs as means of the assets' data collection and management across the stages of the lifecycle including design, engineering and commissioning. In this context, VC is regarded as an advanced application of field devices and real-time simulations [2]. Lechler et al. [3] consider VC as the cornerstone for building DT, where DT here can be of the machine, logistics, products and their intersections. Also, they exemplify the use of some tools for these purposes. According to Barbieri et al [4], by completing a VC process, the architecture of a DT is defined and verified through a virtual environment.

Many of the challenges that are associated with the Digital Twin can be traced back to its enabling technologies such as the Internet of Things (IoT) and Industrial IoT (IIoT). These technologies facilitate significant data collection, which makes it difficult to control the data flow in a digital twin setup with a bidirectional flow of data unless it is appropriately managed. The flow of data should be consistent, noise-free and uninterrupted meanwhile ensuring that the right data is collected to ensure efficient usage of the digital twin [5]. In addition to the challenges connected to gathering and processing the data, there are also difficulties associated with the prediction of complex systems with many parameters and more complex functionalities [6]. Besides, there are also connectivity challenges related to the development of IoT solutions, primarily associated with the real-time monitoring of the digital twin [6]. Another enabling technology for the digital twin is simulation which has its own challenges. Here it is argued that there are missing high-fidelity models for the simulation, and virtual commissioning at different stages, which also lack uncertainty quantification [6]. On the conceptual level, there are challenges associated with standard approaches for the digital twin in industry and a lack of unified models and approaches to modelling ([5]). On a larger scale Tao & Zhang [7], implemented the digital twin on the entire shopfloor and identified three additional challenges for the digital twin: the uncertainty and fuzziness of the high-fidelity of virtual models, the consistency and synchronisation between the physical and virtual parts, and the time scale difference of the data coming from the physical to the virtual world.

2.2. Virtual engineering tools

The current available VC tools do not allow full automation of the process [8]. According to Pellicciari et al. [9], the important challenge to be faced with VC is to embed the knowledge of the product and the process into the control system, due to the fact the knowledge stems from mechanical engineers whereas the logic of the process is inputted by control engineers. Thus, the success of a VC tool is attributed to its capability to facilitate the engagement of both. Another challenge recognised by Stecken et al. [10] is the heterogeneity of the involved systems, and the use of multiple software tools to create virtual models, and these tools usually cannot exchange information because of the interoperability absence. Ugarte et al. [11] highlighted the fact that despite the common use of simulation technology to develop systems, there is no holistic multi-domain simulation platform exists. This fact discourages companies from investing in VC simulation technologies. To address the needs of machining in relation to VC, a group of VC tools are explored and compared against a set of criteria.

Although most of the VC tools are commercial, some academic institutions started to develop their own tools. For example, Chalmers University of Technology developed their Sequence Planner (SP) in 2016 which aims to support DT creation [12], and the University of Warwick that developed the vueOne toolset which supports VC and DT [13].

2.3. Research gap and paper contribution

To create digital twins for manufacturing systems, simulation tools must be able to handle field and control level communication. Currently, as shown in the literature review, most simulation programmes can be coupled with external IOs to facilitate either virtual commissioning or a digital twin setup. The pace at which this communication happens between the simulation and the emulation (virtual commissioning) or the physical system (Digital Twin), adds natural limitations to such a setup. Therefore, the cyber-physical aspects of a given system must be managed to ensure the correct commissioning of the system. This aspect is in most cases handled through a control software which can act as a control cabinet for the electrical signals, being the baton of the orchestra. Currently, there is no precise evaluation of tools which can compare performance, reliability and usability for VC and DT tools. In this work, a number of tools and their functionalities are looked into in regard to a simplified machine setup, to understand when and where we need additional functionalities, and to which degree these specific tools support this process according to the DT standard. Most of the simulation tools were optimised towards the development of the models and the dynamic simulation hereof, with relatively few exceptions. The basis of the VC tools comparison is laid out in the next section.

3. A comparison of the existing VE tools to support a lifecycle of manufacturing system

	Plan	Build	Operate	Maintain
Document management	PLM	PLM	Operation Instructions	Service record
Model	Physical properties predict		Optimisation	Diagnostics
Simulation	Design Simulation	Virtual Commissioning		
3D representation	Design drawings	Manufacturing instructions		Service instructions
Data model	Engineering data	Production data	Operational data	Service data
Visualisation			Operational state display	Health status display
Model synchronisation			Real-time movement	Model inversion
Connected analytics			Operational KPIs	Asset health KPIs

Table 1. Digital twin features and use cases (Adapted from IIC [14])

3.1. The objective and approach

There is a wide range of different software tools which provide virtual engineering and commissioning of the manufacturing system. In principle, they allow the development of the manufacturing system 3D simulation with the following emulations or virtual commissioning of the machine with its PLC software code and system's functionality. Some of the tools offer a wide range of features to cover the entire lifecycle of a system or a product. Nevertheless, the current VC tools are still primitive in terms of the lack of toolchains and model exchange standards, which necessitates the creation of model integration interfaces [15]. Moreover, the heterogeneity of the tools makes it difficult to build robust and complete models of the system [12].

This section evaluates the current VE/VC software tools and their availability to support the entire system's lifecycle and to build a DT. The performance of each of the selected simulation tools is addressed in a simple setup in which we address the 'plan', 'build', 'operate' and 'maintain' phases according to the digital twin standard from IIC (Table 1). In the following, the assessment criteria are explained and the case study is introduced.

3.2. Assessment criteria: Features needed to build a DT

Building a digital twin of a discrete manufacturing system differs according to the requirements and the stage at which the development is happening. In the concept phases, the ease of testing a potential solution is of high importance while the precision of accuracy is of greater importance during the later phases. In its essence, this is mirrored in the many types of software tools currently available. Some suppliers use several types of tools during this process while others try to integrate everything into one tool. Learning several tools means a higher learning curve but also means a higher level of precision can be applied to the specific tools. On the other hand, a broader-ranging tool which covers everything will be quicker to learn but less specific/precise. Therefore, evaluating/benchmarking different tools must take its offset depending on the status in the development phase (new product/legacy), and what type of machine/system is being dealt with. The assessment criteria are adapted from the IIC as follows [14, 13]:

- Document management: the documents related to equipment throughout its lifecycle.
- Model: Digital form of the equipment that can simulate properties and behaviours of a physical system.
- 3D representation: Properties of a physical system (measured or simulated) mapped to its 3D digital form.
- Simulation: Representation of a physical system in a simulation environment to analyse its behaviour.
- Data model: Standardised data model for analytics, connectivity, and/or visualisation.
- Visualisation: Graphical representation of the asset either on a supervisory screen or personal device.
- Model: Alignment of a model with real-world parameters (possibly in real-time).
- Connected analytics: Algorithms and computational results based on measured properties of a physical system.

The assessment criteria for the VE tools capability comparison are based on the availability of the aforementioned features. To evaluate if the current commercially available tools provide the necessary features the case study is presented in the next section.

3.3. Case study

For the case study, six commercial VE tools were chosen to evaluate the DT features. The tools were chosen according to their VE and VC capabilities, possibilities for DT integration, and current use in the manufacturing industry:

- Visual Components (4.3)
- Emulate 3D (Demo 3D 2018)
- Unity with Real Virtual Asset (Unity 2021.3.5f1; Real Virtual 2021.06.1637)
- Siemens NX toolset (NX MCD 12)
- vueOne (V2020.8)
- WinMOD and Winmod Simline toolset (WinMOD V7.2.0.26; WinMOD-SIMLINE V8.0.0.20.)

The case study is based on the Festo Rig Station virtual modelling in each tool (Figure 1). The rig consists of the following components: part hopper, pusher, swivel arm with vacuum gripper and conveyor. The rig functions as follows: a part is loaded to hopper and pusher moves the part to the pick position. The

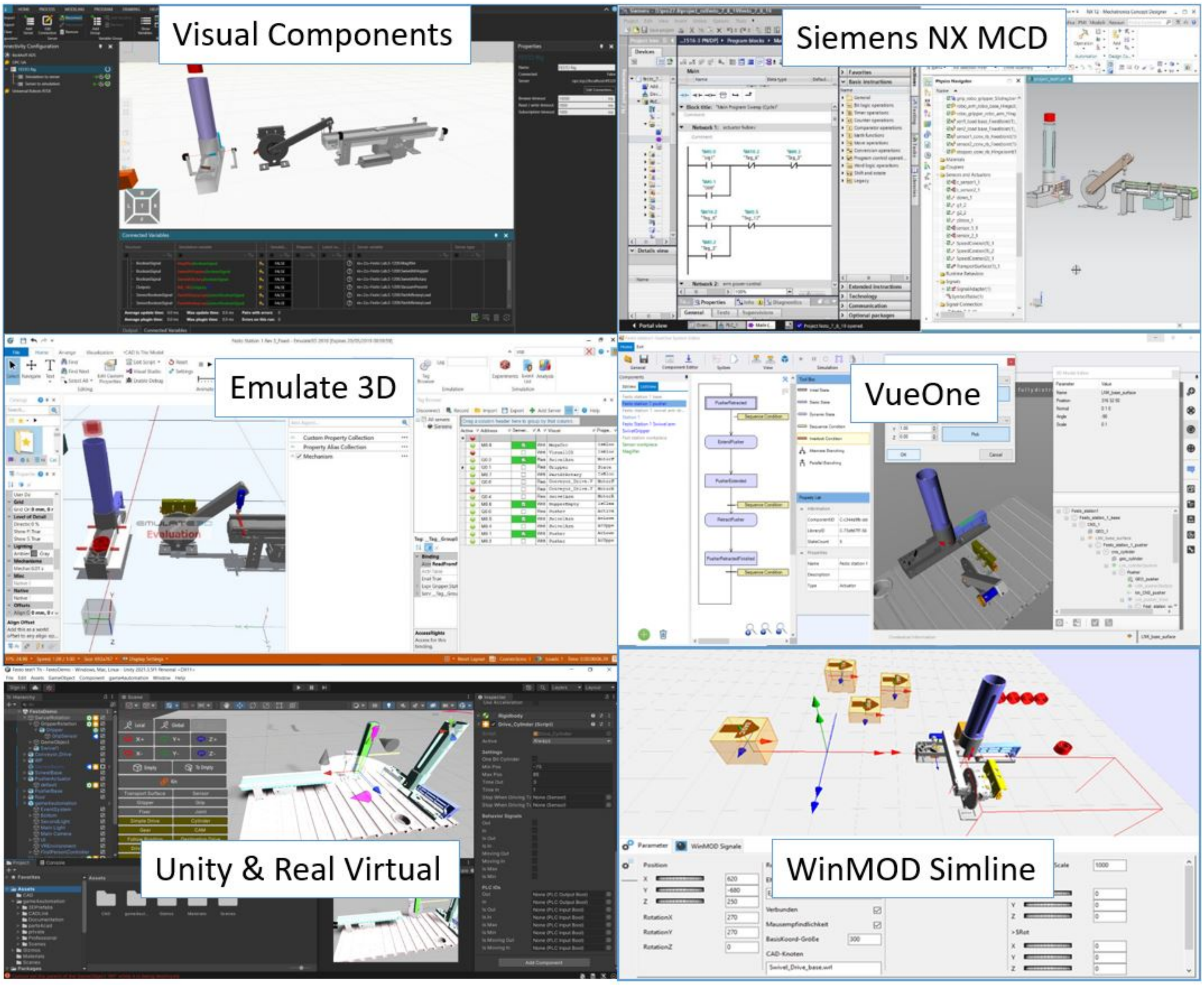

Fig. 1. Station 1 of FESTO rig modelled in VE tools

swivel arm picks the part with the gripper and moves it to the conveyor for the next operations at the next stations of the Festo Rig.

The virtual model was connected to a Siemens S1200 PLC for Virtual Commissioning and further to the Festo Rig for model inversion and Digital Shadow capabilities tests. The PLC code had KPI (Key Performance Indicators) monitoring function blocks which are connected to an SQL database and maintenance software for monitoring and analytics of the processes during the operation phase of the system development lifecycle. Thus, the case study aimed to test the lifecycle phases proposed in [14]: "plan" phase with VE modelling and simulation, "build" with Virtual Commissioning, "operate" and "maintenance" with KPI monitoring and data analytics.

The virtual engineering tools were evaluated according to Table 1 and the definition of the features required to build DT identified in 3.2. The evaluation of the reviewed software tools was classified as [16]:

V - "achieved": means that the software has already integrated the mentioned feature.
O - "ready": means the software has a function to connect another tool needed to function the necessary feature.
X - "achievable": means the software needs to develop a feature or API, communication, etc.

The evaluation and classification are based on the engineering resources available for modelling and the current software versions. Therefore, the new software updates of the tools may include features which are not mentioned in the current work or evaluation is to be redefined. Table 2 represents the lifecycle phases of the manufacturing system development and DT requirements with the features needed to build this DT at each lifecycle step.

Some of the features are already implemented in the reviewed software tools, and other ones are available with integration, e.g., to a PLM (Product Lifecycle Management) system or needed to be developed within the software or with connection

LifeCycle Phases	DT Requirements	DT Features	VueOne	WinMOD Simline	Visual Components	Siemens NX Toolset	Emulate 3D	Unity + RealVirtual
	Document Management	PLM	X	X	O	O	O	X
	Model	Physical properties predict	X	O	O	V	O	X
Plan	Simulation	Design simulation	V	V	V	V	V	V
	3D Representation	Design drawings	V	V	V	V	V	V
	Data Model	Engineering Data	V	V	V	V	V	V
	Document Management	PLM	X	X	O	O	O	X
Build	Simulation	Virtual Commissioning	V	V	V	V	V	V
	3D Representation	Manufacturing instructions	O	X	O	V	O	X
	Data model	Production data	X	X	V	V	V	X
	Document management	Operation instructions	V	X	O	O	O	X
	Model	Optimisation	O	O	V	V	V	O
Operate	Data Model	Operational data	V	O	V	V	V	O
	Visualisation	Operational state display	V	V	V	V	V	V
	Model synchronisation	Real time movement	V	V	V	V	V	V
	Connected analytics	Operational KPIs	O	O	V	V	V	O
	Document Management	Service records	X	X	O	O	O	X
	Model	Diagnostics	X	X	O	O	O	X
	3D Representation	Service instructions	X	X	O	O	O	X
Maintain	Data Model	Service data	X	X	O	O	O	X
	Visualisation	Health status display	O	O	O	O	O	O
	Model synchronisation	Model inversion	V	V	V	V	V	V
	Connected analytics	Asset health KPIs	O	X	O	O	O	X
			V = *achieved*, **O** = *ready*, **X** = *achievable*					

Table 2. Features DT needs to support a life cycle of manufacturing system and the capabilities offered by VE tools

to other tools. The Digital Twin is to predict physical properties as it is mentioned in the table within the planning phase, e.g., for a press, it is necessary to predict the force needed for stroke, material properties and selection. Or, for example for a gravity conveyor - the required angle, for a servo drive - load curve diagrams, etc. The features needed for building DT are classified and reviewed within the software tools as follows:

Document management: document integration is available in some of the tools: e.g., Visual Components can generate pdf documents of the production data and statistics; there is an integration of BOM (Bill of Materials), 2D drawings export, etc. Siemens NX tool set has a connection to a Team Center where documents can be managed; vueOne allows operator instruction and MODAPTS export. However, DT full integration requires an automatic update, generation and management of the documentation - e.g., when a physical component is added/replaced all the documentation is to be updated or generated automatically.

Model: all the reviewed tools allow 3D modelling with physics or/and kinematics describing and mimicking the physical assets. Prediction of the physical properties is defined in some of the software tools, e.g., the physics engine of Siemens NX MCD allows the prediction of forces needed for a given function. This load curve can then be exported to the Siemens selection tool or Siemens sizer from where the correct motor and drive are identified. In NX, there are Press Line hydraulic lifters and forces, NX Simulink for motion control simulation etc.

3D representation: the evaluated tools allow a 3D virtual representation of the physical systems. Manufacturing and service instruction can be exported from some of the tools. These DT features are to have the capability to generate, display, update and store the instructions within the tools themselves, or to be connected to other software and databases where they can be managed online.

Data Model: the tools can manage the engineering data during the 'Plan' phase, such as materials, components properties, behaviour, etc. when the 3D model is being built and simulated. Also, production, operational and service data are to be managed during the further life cycle stages. For DT integration, data is to be acquired, stored and revised during all the life cycle stages, therefore the tools need to have a feature to semi/auto manage the data or have a connection to external software with data management capabilities.

Visualisation: all the tools allow 3D visualisation of manufacturing systems and their processes. For DT, it is necessary to also display the operational and health status of the machines within run-time. For instance, Siemens NX Toolset can be connected to Industrial Edge software for the visualisation of the production data and health status of the devices.

Model synchronisation: all 3D models created in the reviewed software tools can be connected to machines' controllers for synchronisation with the physical manufacturing processes. However, there might be delays depending on the communication protocols. In industrial practice, the rising problems stem from the delay in decision-making due to the communication quality and the utilised decision-making algorithms. For these aspects, the contribution of VE tools is limited as they are not meant to build applications but to operate simulated virtual models and manage signals synchronisation.

Connected analytics: Within the DT concept, the tools can store the data, analyse, predict and control the data. The software tools are to have algorithms for operational and health KPI analytics. Otherwise, the VE software tools need to have communication APIs (application programming interface), where external software tools can function as analytics and control operators to complete this DT feature. The reviewed software either has the interface to the connected analytics tools or needs to develop such an interface.

It should be noted that there has been an interest in DT's adaptability (predictive functions) and intelligence (the use of artificial intelligence). Some of these tools allow utilising algorithms in the created virtual models. For example, in Visual Components, it is possible to describe the behaviour using Python scripts. Thereby, to predict performance features and to instruct certain courses of action in response to certain inputs. The physical manufacturing system during the operation stage can be subject to parameters' imprecision/drifting. The provided tools lack reactive mechanisms to change, so co-simulations are needed (e.g. Edge, Matlab). In the "Operation" phase, i.e., after VC, these conditions can be further analysed, predicted and controlled. Also, more sensors and IoT devices can be installed and connected to keep DT up-to-date.

4. Conclusion

A variety of VE tools exist in the market providing different ways of supporting system developers in building the digital twin of manufacturing systems. Nevertheless, most of them focus on covering the development phases more than the operational phases. On the other hand, digital twins are becoming a vital part of modern manufacturing systems. Therefore, the current work aimed to present a guide on using those tools for the purpose of building digital twins that fulfil the criteria identified by the Industrial Internet Consortium (IIC). A case study was utilised to examine the capabilities of the VE tools against the features required to build the digital twin.

In future work, it is intended to extend the current comparison to include more virtual engineering tools and more industrial standards.

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References

1. Mykoniatis, K., Harris, G.A.. A digital twin emulator of a modular production system using a data-driven hybrid modeling and simulation approach. *Journal of Intelligent Manufacturing* 2021;32(7):1899–1911. doi:10.1007/s10845-020-01724-5.
2. Boss, B., Malakuti, S., Lin, S., Usländer, T., Clauer, E., Hoffmeister, M., Stojanovic, L.. Digital twin and asset administration shell concepts and application in the industrial internet and industrie 4.0. Available https://www.plattform-i40.de/IP/Redaktion/EN/Downloads/Publikation/Digital-Twin-and-Asset-Administration-Shell-Concepts.pdf?__blob=publicationFile&v=9; 2020. Accessed: 10/11/2022.
3. Lechler, T., Fischer, E., Metzner, M., Mayr, A., Franke, J.. Virtual commissioning–scientific review and exploratory use cases in advanced production systems. *Procedia CIRP* 2019;81:1125–1130. doi:10.1016/j.procir.2019.03.278.
4. Barbieri, G., Bertuzzi, A., Capriotti, A., Ragazzini, L., Gutierrez, D., Negri, E., Fumagalli, L.. A virtual commissioning based methodology to integrate digital twins into manufacturing systems. *Production Engineering* 2021;15(3):397–412. doi:10.1007/s11740-021-01037-3.
5. Fuller, A., Fan, Z., Day, C., Barlow, C.. Digital twin: Enabling technologies, challenges and open research. *IEEE Access* 2020;8:108952–108971. doi:10.1109/ACCESS.2020.2998358.
6. Schleich, B., Anwer, N., Mathieu, L., Wartzack, S.. Shaping the digital twin for design and production engineering. *CIRP Annals* 2017;66(1):141–144. doi:https://doi.org/10.1016/j.cirp.2017.04.040.
7. Tao, F., Zhang, M.. Digital twin shop-floor: a new shop-floor paradigm towards smart manufacturing. *Ieee Access* 2017;5:20418–20427. doi:10.1109/ACCESS.2017.2756069.
8. Süß, S., Magnus, S., Thron, M., Zipper, H., Odefey, U., Fäßler, V., Strahilov, A., Kłodowski, A., Bär, T., Diedrich, C.. Test methodology for virtual commissioning based on behaviour simulation of production systems. In: *2016 IEEE 21st International Conference on Emerging Technologies and Factory Automation (ETFA)*. IEEE; 2016:1–9. doi:10.1109/ETFA.2016.7733624.
9. Pellicciari, M., Andrisano, A.O., Leali, F., Vergnano, A.. Engineering method for adaptive manufacturing systems design. *International Journal on Interactive Design and Manufacturing (IJIDeM)* 2009;3(2):81–91. doi:10.1007/s12008-009-0065-9.
10. Stecken, J., Ebel, M., Bartelt, M., Poeppelbuss, J., Kuhlenkötter, B.. Digital shadow platform as an innovative business model. *Procedia CIRP* 2019;83:204–209. doi:10.1016/j.procir.2019.02.130.
11. Ugarte, M., Etxeberria, L., Unamuno, G., Bellanco, J.L., Ugalde, E.. Implementation of digital twin-based virtual commissioning in machine tool manufacturing. *Procedia Computer Science* 2022;200:527–536. doi:10.1016/j.procs.2022.01.250.
12. Khan, A., Dahl, M., Falkman, P., Fabian, M.. Digital twin for legacy systems: Simulation model testing and validation. In: *2018 IEEE 14th International Conference on Automation Science and Engineering (CASE)*. IEEE; 2018:421–426. doi:10.1109/COASE.2018.8560338.
13. Konstantinov, S., Assad, F., Ahmad, B., Vera, D.A., Harrison, R.. Virtual engineering and commissioning to support the lifecycle of a manufacturing assembly system. *Machines* 2022;10(10):939. doi:10.3390/machines10100939.
14. Harper, K.E., Ganz, C., Malakuti, S.. Digital twin architecture and standards. https://www.iiconsortium.org/news-pdf/joi-articles/2019-November-JoI-Digital-Twin-Architecture-and-Standards.pdf; 2019. Accessed: 10/11/2022.
15. Scheifele, C., Verl, A., Riedel, O.. Real-time co-simulation for the virtual commissioning of production systems. *Procedia CIRP* 2019;79:397–402. doi:10.1016/j.procir.2019.02.104.
16. Konstantinov, S., Assad, F., Azam, W., Vera, D., Ahmad, B., Harrison, R.. Developing web-based digital twin of assembly lines for industrial cyber-physical systems. In: *2021 4th IEEE International Conference on Industrial Cyber-Physical Systems (ICPS)*. IEEE; 2021:219–224. doi:10.1109/ICPS49255.2021.9468227.