Re-classifying Digital Twin from The Perspective of Implementation Purpose

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Abstract

Digital Twin is one of the many components in Industry 4.0. Unfortunately, the meaning of digital twin could be differed from one to another. It is very confusing when someone is asking for a "Digital Twin" solution, what does the person really want? IBM has defined digital twin as virtual representation of component or assembly of components that interact with one another limited for the purpose of product life management. Siemens defined it in three areas namely Product, Production and Performance twins. The name suggested limit the definition to its application and there is no relationship with another. Lastly Jones characterized the term to 19 areas which is too much for one to remember and to know how they are related to one another. The purpose of the paper is to re-classify digital twin from the perspective of its purpose of implementation. By knowing the need, we could recommend the level of digital twin to be adopted.

Keywords
1. Digital twin, 2. Virtual-entity, 3. Physical-Entity, 4. ML/AI, 5. Optimization

1. Introduction
The term Industrial 4.0 was introduced at the Hannover Fair, Germany in 2011 (Schwab 2017) and later this was proposed by Kiaus Schwab, founder and executive chairman of the Entity Economic Forum (VDI nachrichten 2011). In short, Industry 4.0 is a label that was given to the integration of technology and the use of data that reflects a new direction. It is a terminology for the confluence of many innovations that are coming to fruition and now being integrated (using high speed data sharing) (Thorsten and Sink 2022). Industrial 4.0 is the industrial revolution from Industrial 3.0 where the industry adopted automation using high speed supercomputer to reduce or eliminate the dependency on manpower in the operation. With the enhancement of high-speed internet and clouds computing at the back end, data hunger technology such as AI/ML, simulation, Augmented Reality, Big Data, and data analytic, Cybersecurity and others which could not be accomplished by technologists effectively and timely in the past, could now achieve through the digitalization of such information in the clouds. Operation data such as operation performance, quality information, equipment performance could be upload and access through such an ecosystem. Both the flexibility and the ability to access this information timely and even before the event has taken place has enabled quick actions in the decision making or interruption to the wrongdoing in the day-to-day operation. The result of such intervention has greatly improved the quality and the efficiency of the operation even at the absent of manpower. This facilitates the concept of "smart factories" where an entity of virtual and physical systems of manufacturing globally cooperates with each other in a flexible way. Among the technologies that are possible now, Digital Twin is one of which. Through the different enablers such as IoT devices, high speed data sharing capability, digital twin has been applied at product lifecycle management, building design affirmation, operation performance monitoring and optimization, predictive operation control and management and others; solving different problems at different level, but all of them are still known as digital twin. In 2022, Mendonca and the team has provided a summary of the application of the digital twin into several areas (da Silva Mendonça et al. 2022).

- Test of the concept and its definition with different application.
- Support digital twin through applications and management system.
- In a interlink network environment to adopt cybersecurity for digital twin and to monitor shopfloor activities through a virtual space.
- Support the entire Product Lifecycle Management for customized product and manufacturing system.
- Simulate, evaluate, and analyse of the physical system through the virtual system.

One common example is Volvo, in the case study released by Unity; has taken their car design design/development process onto digital twin. The result is that Volvo has claimed to have improved the design-engineering communication and collaboration between the different stages and modules of the processes, they are able to achieve faster iteration (Unity Technologies 2023). Hence the terminology "Digital Twin" means entire different thing in the different application and creates confusion to people who are exploring digital twin as a solution. It is the purpose of this paper to suggest and to provide an appropriate classification of the terminology of "Digital Twin" based on its purpose of the implementation. This approach is clear to the industrialists who are adopting digital twin to solve the current problem.

• Literature Review

2.1 Digital Twin

Digital twin is the digital representation of a real-world entity or system (Gartner 2022). IBM has defined Digital Twin as a virtual model designed to accurately reflect a physical object (IBM 2022). Greives defined digital twin as a digital representation of an intended or actual real-entity physical product, system, or process (a physical twin) that serves as the effectively indistinguishable digital counterpart of it for practical purposes, such as simulation, integration, testing, monitoring, and maintenance. The digital twin has been intended from its initial introduction to be the underlying premise for Product Lifecycle Management (Greives 2002). Siemens in their website, they have further explained that digital twins are used throughout the product lifecycle to simulate, predict, and optimize the product and production system before investing in physical prototypes and assets. (Siemens 2022) By incorporating multi-physics simulation, data analytics, and machine learning capabilities, digital twins are able to demonstrate the impact of design changes, usage scenarios, environmental conditions, and other endless variables – eliminating the need for physical prototypes, reducing development time, and improving quality of the finalized product or process. A simple example of a digital twin is the 3D model of a bicycle that is drafted in a 3D CAD drawing. Depending on the level of the application, the 3D model will have levels of detail. For example, the sufficiency of the visual information such as the respective shade of colour, the texture of the different components, and the animation that shows the different dynamic features of the bicycle is enough to meet the requirement of the sales and marketing people to promote the new product. On the other hand, a product engineer will require to 3D model to inherit the different material and mechanical properties, so that they could find out the product is able to meet the product specification and beyond during the extreme conditions. Using the model, they could even find out the when, where, what and how the product could buckle under the different operation conditions. At time a dynamic and animated model of the bicycle under the different operating condition will even provide a better understanding of the experiment. At the same time, a manufacturing engineer could use the model to identify the optimum manufacturing operation, the way that the components could be best assembled, to determine the optimum approach and the optimum number of resources that are needed to manufacturing bicycle. After the product has been delivered, product/manufacturing engineer might need to further enhance the product and the manufacturing process by real time monitor and gathering the data from the product and the manufacturing operation without physically with the product or manufacturing process. At this point, using Internet of Thing (IoT) devices, product and manufacturing operation could connect and synchronize with the 3D model to reflect exactly what happen to the physical entity both the bicycle and the manufacturing operation. The data collected from the real time monitoring will provide product/manufacturing insight of the product and manufacturing operation. Such valuable information will help them to make better decisions in the current product life cycle and manufacturing operations. They could further conduct what-if scenarios on the 3D model of the bicycle or the manufacturing operation to decide and define the future strategy of the product and manufacturing operation. For each level of application, the information needed for the 3D model of the bicycle and the manufacturing operation is totally different. Therefore, the terminology of Digital Twin alone is inadequate to effectively communicate the type of information needed for that application level of digital twin.

2.2 Classification of Digital Twin

IBM classified as digital twin as Components Twins/Part Twin, Assets Twins, System or unit twins and Process Twins. The classification defined the different twins based on the structure of the twin beginning with a component, a few interacting components which is called an asset, a few assets that interacts with one another to form a system. Components Twins/Part Twins are the basic unit of digital twin, the smallest example of a functioning component and with less importance components. When two or more components interact together, they form what is known as an Asset Twins. The interaction generates performance data that can be processed and analysed and to gather insights of the interaction. Different Assets work together to form an entire system or System Twins. The Asset Twin provides visibility of the system and suggest performance improvement (IBM 2022).

Siemens classified Digital Twin into Product, Production and Performance Digital Twin. Product Digital Twin explains the use of digital twin for product design and development. Product Digital Twin explains the use of digital for validating the manufacturing operation and product plan before going life. Performance Digital Twin explain the use of the digital twin to capture the operation information and analyse it to provide actionable insight for informed decision making (Siemens 2022). Jones reviewed through 92 literatures has summarized 19 core themes to characterize digital twin (Jones & Snider 2020). Some of which are physical entity which characterize digital twin as an artefact of something already pre-existed in the real entity regardless of it has been twinned such as car, part, product and other. Virtual entity characterizes digital twin as computer generated representation of the artefact such as Mathematical representation, CAD model or simulation model. Parameter is the information that are required by the digital twin based on the various applications. Under which there is Form is the geometric information of the object. Functionality is the operation information such as machine parameters.

The definition of Digital Twin by IBM provides the different level or depth of the use of digital twin, but it is limited to product development level. Though IBM explained that that the original ideal as said of the digital twin is for product life cycle development, we are aware that manufacturing digital twin (simulation and modelling) existed and ranked one of three most important technique in “Operation Research” (Law 2007). Siemens explained digital twin based on the three different field of applications, but without showing the different level or depth of the application. Furthermore, the application of digital twin is not only limited to product life cycle management and manufacturing operation, but also in supply chain, construction (Jones and Snider 2020), healthcare (Y. Liu et al., 2019), transportation (Y. Gao 2021), retail (Shrivatava 2022) and others where there are increasingly need and more and more industries want to ride on this wave of revolution. The characterization of digital twin by Jones has provide in-depth study in the many fields of application at his point of time, the field of study and application has never stopped since then. More fields of application have started its pilot study and more industrial application is expected soon. In my own opinion, such classification on one hand will be superseded in due time and on the other hand, though it is beneficial to the academic study, it is too much for the industrialists to have a quick understanding of the concept digital twin.

3. Re-Classification of Digital Twin

The classification of digital twin should be simple enough for the industrialists to remember and to understand how it is being implemented easily. It should classify based on the purpose of the implementation. That is the problem statement. Lastly, the classification should be able to tell the impact of the implementation. Three factors we should considered. Firstly, the ownership of the data. Does the data is only used within the virtual entity, or it is shared between both entities through a physical connection? Secondly, the type of data. Does implementation of the digital twin require only historical data as the input parameter, or it requires real time (or close to current) data as input parameters? Lastly, the length of the impact. Does informed decision from the implementation of the digital twin changes the current state of the physical entity or it goes beyond? Table 1 shows a summary of the classification based on the three factors.

- Level 1 Digital Twin
- Level 2 Digital Twin
- Level 3 Digital Twin

Table 1 Classification of the Digital Twin

	Level 1	Level 2	Level 3
Data ownership	Withing the Virtual entity	Transacted between Virtual and Physical Entity	Transacted between Virtual and Physical Entity
Type of input parameter	Past historical data	Close to current or real time	Close to current
Impact of the implementation	Future or long run	Current	Close to current or long run

3.1 Level 1 Digital Twin

Level 1 Digital Twin is where the data ownership of the digital twin is within the *virtual entity* (the representation) of the physical entity components or system. The digital twin inherits the necessary *virtual processes* (static or dynamic behaviour) that from the historical data that represents the *Physical Processes* of the physical entity, and it has self-sufficient *fidelity* (or validated) and without the need of physically connecting to the physical entity (see Figure 1). The existence of the visualization and animation of the model could be an added advantage based on the need of the application. The result from the data analysis is implemented through offline to the real-entity and the impact (perceived benefit) is generally long term.

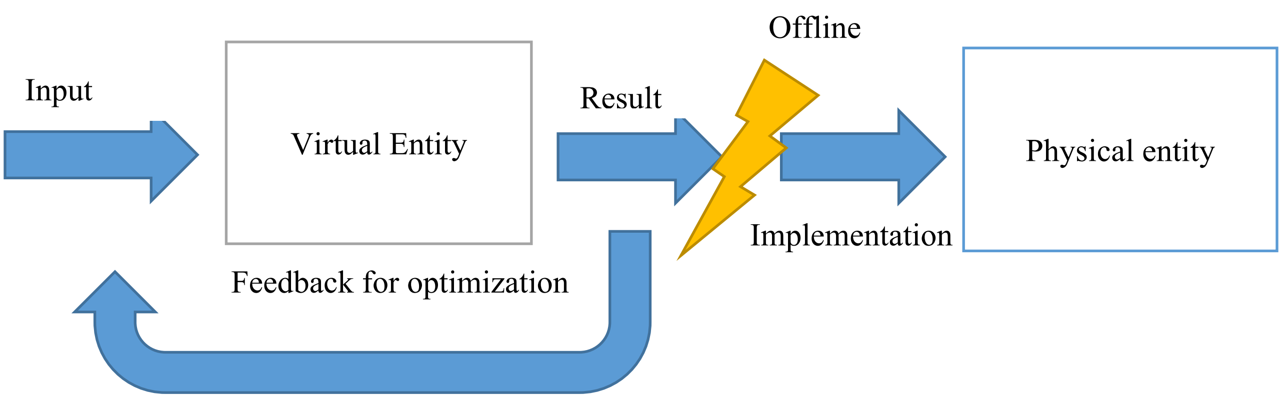


Figure 1 Illustration of Digital Twin Level 1

In the prior example of the bicycle, its 3D model is a virtual entity of the new design where the real entity is not existed. The virtual entity should contain the details requirement from the past project, design and research or reference manuals for the different applications. For example, the previous *form* and *functionality* of the design, customer and expert opinion will act as the input to the virtual entity. The result from the analysis is implemented to the new product/manufacturing system design, determine product/manufacturing cost, product life cycle management, production planning, and others. In the case of evaluating an existing operation system, such as an operating COVID 19 vaccination centre (See Figure 2) (Cueva 2022). The virtual entity contains different parts of the operation system with the respective operational data, workflow, operating conditions, resources, and randomness needed as input parameters (Law 2007). The result from such evaluation will help management to make informed decision to improve the operation of the centre in long run. With this requirement, it is not necessary to connect the virtual entity to the physical entity.

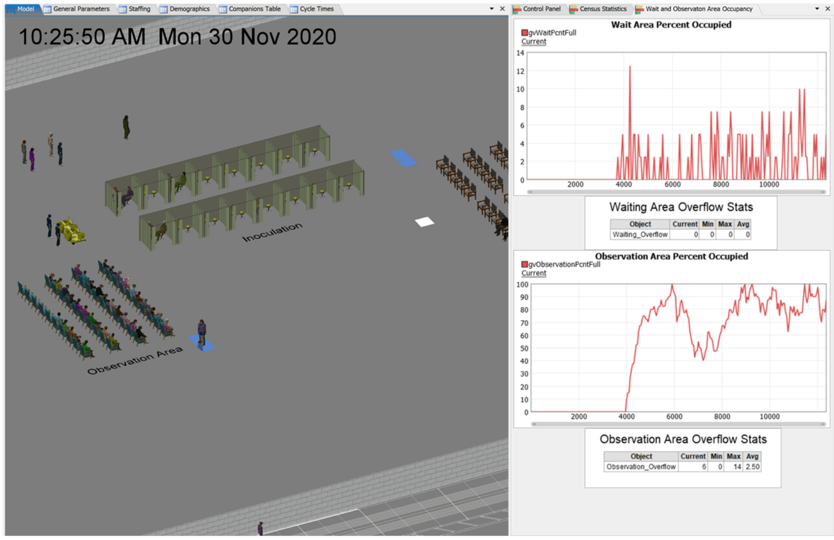


Figure 2 Model of a Mass Vaccination Centre

3.2 Digital Twin Level 2 Digital Twin

Level 2 Digital Twin is where the ownership of the data comes from both the virtual and real entity and the data are shared through the *enablers*. Through the data sharing, the virtual entity is synchronized or mirror with the current behaviour of the physical entity which is known as *twinning* (Jones and Snider 2020). The state of the virtual entity is changed in real time (or close to current) based on the input from the physical entity. In additional, the result from the virtual entity to support the decision maker to make immediate decision that affects the real-entity immediately or near to current (See Figure 2) Jones characterised the sharing of data to change the virtual entity as Physical-to-virtual and the immediate action taken in the virtual entity to change the state of the physical entity as Virtual-to-physical connection (Jones and Snider 2020). And enablers are IoT devices such as sensors, web-based services, 5G and databases (Jones and Snider 2020) that facilitates data sharing. Figure 4 shows an example of the physical conveyor and connected to the virtual conveyor via sensors and Programmable Logic Controller.

Figure 3 Illustration of Digital Twin Level 2

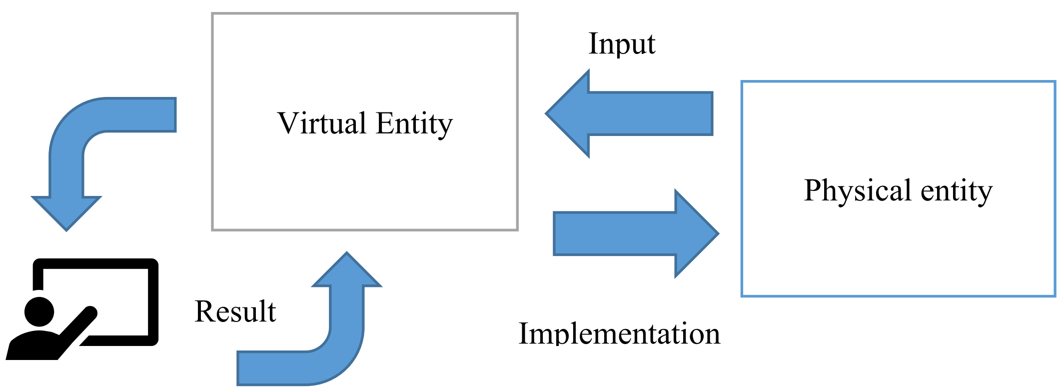


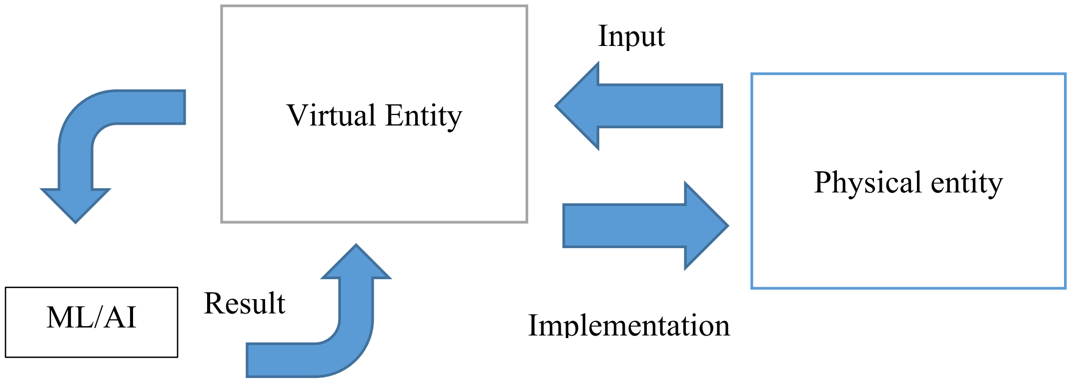
Figure 4 A Connection between the Physical Entity with the Virtual Entity through Enablers

Through the enablers, the physical bicycle (prototype) is put to test under different condition is connected to the virtual entity. Using the virtual entity, the designer monitors the operation condition of the bicycle and vary the test conditions of the bicycle immediately without physically there. The behaviour of the bicycle under the tests are feedback and captured by the virtual entity to validate the design specification and make the necessary changes immediately. In the case of operation management, the management could monitor the operation of the system from the real time data that is shared by the real entity. The management through knowing the current state of the real entity through the virtual entity, strategic decision could be made and implemented through the virtual entity to the real entity. In the case of an aviation part manufacturer, using the current state of the material flow, the state of the workplaces from the shop floor (physical entity) as the data sharing with the virtual entity, they determine the current work schedule, resource allocation for the physical entity in this given period (Pawlewski and Olszewski 2021). On the other hand, the rate of patron arriving at the vaccination centre (physical entity) could be shared with the virtual world, through the virtual world say the waiting time of the patron could be monitored. If it is gone beyond a pre-set threshold, the supervisor could receive a notification. The supervisor could adjust the current manpower allocation with the current available resource and simplify certain procedure to reduce the waiting time and the number of people wait in line. In the case of last miles delivery, with the sharing the physical road condition with the virtual entity, the virtual entity could response with analysis to help the management to make current decision to re-route the delivery route (Belfadel 2021). Given sufficient decision-making rules to the virtual entity, the digital twin level forms the basis for Light Out Manufacturing. "Lights-out Manufacturing" is a form of production, which is characterized by end-to-end automation that allows for a manufacturing process without the need for direct human intervention at the production site (Lengsfeld 2022). Besides process automation, decision making automation is also a key factor in such initiatives. Hence real time feedback from the physical job shop to the virtual job shop with the intelligence to make decision based on the information is a key success factor in this area. Digital Twin level 2 is basically a day-to-day operational tool. It helps the management to adjust the original plan responding to the current situation especially an unplanned event to elevate problem and improve the situation.

3.3 Level 3 Digital Twin

Level 3 Digital Twin uses the data close to current time own by the physical entity that is shared to the virtual entity, using the ML/AI as an intelligence tool such as reinforcement learning, under a pre-defined objective to predict the course of action and make change to the state of the physical entity in the next few moments or longer run (Jones and Snider 2020) (see Figure 3). An example of such level is the use of a virtual model of a component in the bicycle with the real time data to predict the potential failure time and failure mode. The maintenance schedule of the bicycle could then be made (Jones and Snider 2020). In another prediction of machine maintenance application, the data concerning the condition of the equipment is collected through the enablers. The information is processed to before input to the ML software tool to estimate the Predictive Maintenance time slot (Azab et al. 2021). Similarly, in a high mixed and low volume production environment, the virtual production model using its ML/AI it could determine the optimum production schedule knowing the current production plan (from the ERP system) as the current input parameters. The determined schedule could be implemented to physical entity (Li et al. 2020).

Figure 5 Illustration of Digital Twin Level 3



6. Conclusion

From the perspective of the purpose implementation to classify Digital Twin has responded to the industrialist according to the purpose that one is trying to solve. If the purpose is to identify the bottleneck of an operation system or to define a product design, a Level 1 digital twin which is a virtual entity of the system or design is sufficient to solve the problem. On the other hand, if the purpose is to be able to decide and to make immediate changes to the current state of the system, for example, how many toll lanes to be opened with the immediate influx of car into the toll gates, then a Level 2 digital twin should be implemented. With the use of the virtual system to identify the performance of the physical entity, one solves the problem by intervening the current state of the physical entity manually. Lastly, if the purpose is to predict what will happen to the physical entity from the data trend so as to know what is the best action plan for the next period of time. One should adopt a level 3 digital twin. The approach also simplified the way how the terminology is characterized from nineteen points to three points. Instead of focusing on the industry or the area of application, it emphasizes on how the data come from, the period of the data that is needed and how long is the impact to the physical entity. When someone asks for a digital twin solution, one could then response by clarifying the purpose of the solution. By knowing the purpose, one could know what level of digital twin is necessary to solve the problem.

References

Azab, E., Nafea, M., Shihata, L. A., & Mashaly, M. "A Machine-Learning-Assisted Simulation Approach for Incorporating Predictive Maintenance in Dynamic Flow-Shop Scheduling." *Applied Science* 10 Dec 2021.

Azab, Eman, Mohamed Nafea, Lamia A. Shihata, and Maggie Mashaly. "A Machine-Learning-Assisted Simulation Approach for Incorporating Predictive Maintenance in Dynamic Flow-Shop Scheduling." *Applied Sciences*. 2021.

Belfadel, Abdelhadi & Hörl, Sebastian & Tapia, Rodrigo & Puchinger, Jakob. "Towards a Digital Twin Framework for AdaptiveLast Mile City Logistics." *The 6th International Conference on Smart Sustainable Technologies*. Croatia: IEEE, 2021.

Cueva, Markus. "Simulation Modeling for COVID-19 Vaccination Sites." 2022. *FlexSim Software Product, Inc.* 7 Feb 2023. <https://www.flexsim.com/healthcare/simulation-modeling-for-covid-19-vaccination-sites/>.

da Silva Mendonça, Rafael, Sidney de Oliveira Lins, Iury Valente de Bessa, Florindo Antônio de Carvalho Ayres Jr., Renan Landau Paiva de Medeiros, and Vicente Ferreira de Lucena Jr. "Digital Twin Applications: A Survey of Recent Advances and Challenges." *Processes* 10.4 (2022): 744.

Gartner. *Gartner Glossary*. 2022. 25 Jan 2023. <https://www.gartner.com/en/information-technology/glossary/digital-twin>.

Greives, Michael. "SME Management Forum Completing the Cycle: Using PLM Information in the Sales and Service Functions." 31 Oct 2002. *Research gate.* 25 Jan 2023. <https://www.researchgate.net/publication/356192963_SME_Management_Forum_Completing_the_Cycle_Using_PLM_Information_in_the_Sales_and_Service_Functions>.

IBM. *What is a Digital Twin*. 2022. 23 Jan 2023. <https://www.ibm.com/sg-en/topics/what-is-a-digital-twin>.

Jones, David and Chris Snider. "Characterising the Digital Twin: A systematic literature review." *CIRP Journal of Manufacturing Science and Technology* 29 (2020): 36-52.

Law, Averill. *Simulation Modeling & Analysis*. Singapore: Magraw Hills, 2007.

Lengsfeld, Dr. oec. HSG Dr. phil. Jörn. *The Future of Automation and Labor: Coboting Versus Lights-Out Manufacturing*. 3rd August 2022. 24 Jan 2023. <https://industrialmachinerydigest.com/industrial-news/columns/business/the-future-of-automation-and-labor-coboting-versus-lights-out-manufacturing/>.

Pawlewski, P. and A. Olszewski. "Integration of Digital Twin with Simulation in Order to Meet Factory Expectations." *Computational Methods In Science and Technology*. 2021. 121-128. <https://cmst.eu/articles/integration-of-digital-twin-with-simulation-in-order-to-meet-factory-expectations/>.

Price, Greg. *How Digital Twins Can Optimize Supply Chain Planning and Efficiency*. 3 May 2022. 25 Jan 2023. <https://www.dataversity.net/how-digital-twins-can-optimize-supply-chain-planning-and-efficiency/>.

Schwab, Klaus. *The Fourth Industrial Revolution*. Great Britain: Pengiun Random House, 2017.

Shrivatava, Rohit. *How Digital Twin Technology Can Help Retail CIOs*. 2022. 24 Jan 2023. <https://www.forbes.com/sites/forbestechcouncil/2022/11/11/how-digital-twin-technology-can-help-retail-cios/?sh=754d99372836>.

Siemens. *Digital Twin*. 2022. 23 Jan 2023. <https://www.plm.automation.siemens.com/global/en/our-story/glossary/digital-twin/24465>.

Thorsten , Wuest and Scott D. Sink. *The Impact of Industry 4.0 on Business Models*. 11 Oct 2022.

Unity Technologies. *How Volvo Cars accelerates collaboration and innovation throughout the automotive lifecycle*. 2023. 7 Feb 2023. <https://unity.com/case-study/volvo>.

VDI nachrichten, Berlin. *Industrie 4.0: Mit dem Internet der Dinge auf dem Weg zur 4. industriellen Revolution*. 1 Apr 2011. 25 Jan 2023. <https://web.archive.org/web/20130304101009/http:/www.vdi-nachrichten.com/artikel/Industrie-4-0-Mit-dem-Internet-der-Dinge-auf-dem-Weg-zur-4-industriellen-Revolution/52570/1>.

Y. Gao, S. Qian, Z. Li, P. Wang, F. Wang and Q. He,. "Digital Twin and Its Application in Transportation Infrastructure." *IEEE, 1st International Conference on Digital Twins and Parallel Intelligence (DTPI*. Beijing, 2021. 298-301.

Y. Liu et al. "A Novel Cloud-Based Framework for the Elderly Healthcare Services Using Digital Twin." *IEEE* 7 (2019): 49088-49101.

Biography

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