1. Digital Twin Definitions in the Literature

Author	Year	Definition
Shafto et al.	2010	An integrated multi-physics, multi-scale, probabilistic simulation of a vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its flying twin. The digital twin is ultra-realistic and may consider one or more important and interdependent vehicle systems. [1]
Tuegel	2012	A cradle-to-grave model of an aircraft structure's ability to meet mission requirements, including submodels of the electronics, the flight controls, the propulsion system, and other subsystems. [2]
Glaessgen and Stargel	2012	A Digital Twin is an integrated multiphysics, multiscale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin. The Digital Twin is ultra-realistic and may consider one or more important and interdependent vehicle systems, including airframe, propulsion and energy storage, life support, avionics, thermal protection, etc.[sic] [3]
Lee et al.	2013	Coupled model of the real machine that operates in the cloud platform and simulates the health condition with an integrated knowledge from both data-driven analytical algorithms and other available physical knowledge [4]
Reifsnider and Majumdar	2013	Ultra-high fidelity physical models of the materials and structures that control the life of a vehicle [5]
Majumdar et al.	2013	Structural model which will include quantitative data of material-level characteristics with high sensitivity [6]
USAF	2013	A virtual representation of the system as an integrated system of data, models, and analysis tools applied over the entire life cycle on a tail-number unique and operator–by-name basis [7]
Grieves	2014	The Digital Twin concept model […] contains three main parts: a) physical products in Real Space, b) virtual products in Virtual Space, and c) the connections of data and information that ties the virtual and real products together [8]
Rosen et al.	2015	Very realistic models of the process current state and its behavior in interaction with the environment in the real world [9]
Rios et al.	2015	Product digital counterpart of a physical product [10]
Bielefeldt et al.	2015	Ultra-realistic multi-physical computational models associated with each unique aircraft and combined with known flight histories [11]
Bazilevs et al.	2015	High-fidelity structural model that incorporates fatigue damage and presents a fairly complete digital counterpart of the actual structural system of interest [12]
Schluse, Rossman	2016	Virtual substitutes of real-world objects consisting of virtual representations and communication capabilities making up smart objects acting as intelligent nodes inside the Internet of things and services [13]

Canedo	2016	Digital representation of a real-world object with focus on the object itself [14]
Gabor et al.	2016	The simulation of the physical object itself to predict future states of the system [15]
Schroeder et al.	2016	Virtual representation of a real product in the context of cyber-physical systems [16]
Kraft	2016	An integrated multi-physics, multi-scale, probabilistic simulation of an as-built system, enabled by digital thread, which uses the best available models, sensor information, and input data to mirror and predict activities/performance over the life of its corresponding physical twin [17]
Bajaj et al.	2016	A unified system model that can coordinate architecture, mechanical, electrical, software, verification, and other discipline-specific models across the system life cycle, federating models in multiple vendor tools and configuration-controlled repositories [18]
Boschert and Rosen	2016	The vision of the Digital Twin itself refers to a comprehensive physical and functional description of a component, product or system, which includes more or less all information which could be useful in all—the current and subsequent— lifecycle phases [19]
Abramovici et al.	2017	A virtual twin is a model that integrates interdisciplinary (mechanics, electronics, software, and services) virtual product models and related real-time data of a product instance (physical twin). A virtual twin can be dynamically generated from a model and data space to fulfill a specific task (e.g., dynamic reconfiguration of a smart product during its use phase) [20]
Stark et al.	2017	A digital twin is the digital representation of a unique asset (product, machine, service, product-service system, or other intangible asset) that compromises its properties, condition, and behavior by means of models, information, and data. [21]
Schleich et al.	2017	In synthesis, the vision of the digital twin describes the vision of a bi-directional relation between a physical artifact and the set of its virtual models. In this context, the virtual "twinning," i.e., the establishment of such relations between physical parts and their virtual models, enables the efficient execution of product design, manufacturing, servicing, and various other activities throughout the product life cycle [22]
Grieves and Vickers	2017	Digital Twin (DT)—the Digital Twin is a set of virtual information constructs that fully describes a potential or actual physical manufactured product from the micro atomic level to the macro geometrical level. At its optimum, any information that could be obtained from inspecting a physical manufactured product can be obtained from its Digital Twin. [23]
Negri et al.	2017	The DT [Digital Twin] consists of a virtual representation of a production system that is able to run on different simulation disciplines that is characterized by the synchronization between the virtual and real system, thanks to sensed data and connected smart devices, mathematical models and real time data elaboration. [24]
Chen	2017	A digital twin is a computerized model of a physical device or system that represents all functional features and links with the working elements. [25]
Banerjee et al.	2017	Computerized clones of physical assets that can be used for in-depth analysis [26]

Vachalek et al.	2017	Functional system of continuous process optimization formed by the cooperation of physical production lines with a digital copy. [27]
Warmefjord et al.	2017	A digital copy of a physical system. [28]
Alam and El Saddik	2017	Digital twin is an exact cyber copy of a physical system that truly represents all of its functionalities [29]
Tao et al.	2018	[…A] complete DT [Digital Twin] should include five parts: physical part, virtual part, connection, data, and service. [30]
Autiosalo	2018	Digital Twin is the cyber part of a Cyber-Physical System. [31]
Demkovich et al.	2018	A Digital Twin of a production system is a multi-level digital layout that describes the product, processes and resources in the environment of their functioning, i.e. allowing to simulate the processes taking place in the real system, as well as collecting and displaying in real time data on the status of objects obtained from the PLC and sensors installed in the production system both on industrial equipment and in its environment. [32]
Kritzinger et al.	2018	Based on the given definitions of a Digital Twin in any context, one might identify a common understanding of Digital Twins, as digital counterparts of physical objects. [33]
Liu et al.	2018	The digital twin is actually a living model of the physical asset or system, which continually adapts to operational changes based on the collected online data and information and can forecast the future of the corresponding physical counterpart. [34]
Zheng el al.	2018	A Digital Twin is a set of virtual information that fully describes a potential or actual physical production from the micro atomic level to the macro geometrical level. [35]
Vrabic et al.	2018	A digital twin is a digital representation of a physical item or assembly using integrated simulations and service data. The digital representation holds information from multiple sources across the product life cycle. This information is continuously updated and is visualized in a variety of ways to predict current and future conditions, in both design and operational environments, to enhance decision making. [36]
Boschert et al.	2018	Comprehensive physical and functional description of a component, product or system together with all available operational data. [37]
Qi and Tao	2018	Virtual models for physical objects to simulate their behaviors. [38]
Guo et al.	2018	Digital mirror of the physical world. [39]
Bruynseels et al.	2018	Digital model that dynamically reflects the status of an artifact. [40]
Talkhestani et al.	2018	Digital Twin is a virtual model of a physical asset capable of fully mirroring its characteristics and functionalities during its entire lifecycle. It is an approach to manage all generated digital data of a component or system along its lifecycle and retrieve them as needed by simulation or optimization functions to address any occurring challenges. [41]
Kahrat et al.	2018	A replication of a real physical production system. [42]
Mabkhot et al.	2018	A virtual model of physical objects are created in a digital world to simulate and monitor their behavior in real environments. The Digital Twin consists of three components, which are the physical entities, the virtual models, and the connected data that tie between them [43]

Madni et al.	2019	A Digital Twin is a virtual instance of a physical system (twin) that is continually updated with the latter's performance, maintenance, and health status data throughout the physical system's life cycle. [44]
ISO/ISO-AWI 23247	2019	A virtual representation of manufacturing elements such as personnel, products, assets and process definitions, a living model that continuously updates and changes as the physical counterpart changes to represent status, working conditions, product geometries and resource states in a synchronous manner [45]
Stark and Damerau	2019	A digital twin is a digital representation of an active unique product (real device, object, machine, service, or intangible asset) or unique product-service system (a system consisting of a product and a related service) that comprises its selected characteristics, properties, conditions, and behaviors by means of models, information, and data within a single or even across multiple life cycle phases. [46]

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