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Digital twin – Concepts and terminology

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Digital twin – Concepts and terminology

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DIGITAL TWIN – CONCEPTS AND TERMINOLOGY

FOREWORD

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Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1, available at www.iec.ch/members_experts/refdocs and www.iso.org/directives.

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INTRODUCTION

Digital transformation continues to reshape the world at multiple scales, from a city to a building, a factory, an automobile, a process and so on. The concept of a digital twin (DTw) is not new. The concept of twinning in aerospace has been in use for over 50 years. Advances in digitalization, for example those related to the industrial Internet of Things, have enabled the concept to develop and spread outside of capital-intensive industries.

Digital twin has the potential to be widely used in multiple domains such as smart manufacturing, smart cities, smart agriculture, smart energy, smart buildings, smart health care, smart mining and many other fields. However, different fields have developed in isolation, leading to different concepts and terminology. The benefits that can be derived from the use of a digital twin will depend on the use case or cases that it has been conceived to satisfy. The degree to which the benefits are realized is dependent on the implementation of the digital twin and the degree to which it can be trusted to represent the behaviour of the target entity it represents. For example, it can help:

a) simulate and predict products or production lines, resulting in production cycle reduction and cost reduction for manufacturing companies;

b) optimize city construction based on simulation models, and realize visualization, convenience and intelligent city management for city planners;

c) monitor and optimize production operations, and perform predictive diagnosis on machinery and equipment for agricultural producers;

d) achieve visual monitoring management of energy production and transmission processes, as well as fault analysis and remote operation and maintenance for energy managers;

e) monitor patients' real-time conditions, provide personalized medical solutions, dynamically optimize medical resources for doctors, and so on.

The essence of digital twin is a pairing of two things:

– something that provides a functional purpose in reality, for example, an automobile or a petrochemical platform, designated as a target entity in this document;

– a representation of that target entity as a digital entity for the purpose of connection, integration, analysis, simulation, visualization, optimization, collaboration or, when necessary, providing external management for that target entity.

In view of the increased interest in and potential applications of the digital twin technologies, there is a need to establish a common basis and terminology to enable collaboration and cooperation, and to promote a common understanding of the concept.

The purpose of this document is to:

1) provide a common basis for understanding the concept and composition of a digital twin through definitions of digital twin-related concepts;

2) provide an overview of the life cycle of a digital twin in relation to the target entity it represents;

3) provide a basis for the development of standards, specifications and use of digital twins.

This document provides generic digital twin concepts and terminology that can be applied in any domain or across domains.

DIGITAL TWIN – CONCEPTS AND TERMINOLOGY

1 Scope

This document establishes terminology for digital twin (DTw) and describes concepts in the field of digital twin, including the terms and definitions of digital twin, concepts of digital twin (e.g. digital twin system context, life cycle process for digital twin, types of digital twin), functional view of digital twin, and digital twin stakeholders.

This document can be used in the development of other standards and in support of communications among diverse, interested parties or stakeholders.

This document is applicable to all types of organizations (e.g., commercial enterprises, government agencies, and not-for-profit organizations).

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1 General terms

3.1.1
digital twin
DTw
digital representation (3.1.8) of a *target entity* (3.1.3) with data connections that enable convergence between the physical and digital states at an appropriate rate of synchronization

Note 1 to entry: Digital twin has some or all of the capabilities of connection, integration, analysis, simulation, visualization, optimization, collaboration, etc.

Note 2 to entry: Digital twin can provide an integrated view throughout the life cycle of the target entity.

3.1.2
entity
<digital twin> thing (physical or non-physical) having a distinct existence

EXAMPLE Person, object, event, idea, process, etc.

[SOURCE: ISO/IEC 20924:2021, 3.1.18, modified – The example has been added.]

3.1.3
target entity
entity (3.1.2) providing a functional purpose in reality which is the subject of *digital representation* (3.1.8)

Note 1 to entry: The target entity, which provides some functional purpose in reality, can be either physical or digital under consideration.

3.1.4
physical entity
entity (3.1.2) in the physical world that can be the subject of sensing and/or actuating

[SOURCE: ISO/IEC 20924:2021, 3.1.27]

3.1.5
digital entity
computational entitiy comprising data elements and procedural elements

3.1.6
physical domain
classification of physical entities under consideration

3.1.7
digital domain
classification of digital entities under consideration

Note 1 to entry: Entities in the digital domain can be embedded in a physical domain.

3.1.8
digital representation
digital entity representing either a set of properties or behaviours or both of one or more observable elements

3.1.9
modelling
using symbolic paradigms or formal languages to create an abstract representation of a thing

3.1.10
ecosystem
infrastructure and services based on a network of organizations and stakeholders

Note 1 to entry: Organizations can include public bodies.

[SOURCE: ISO/IEC TS 27570:2021, 3.8]

3.1.11
life cycle
evolution of a system, product, service, project or other human-made entity from conception through retirement

[SOURCE: ISO/IEC/IEEE 15288:2023, 3.21]

3.1.12
semantics
rules that provide the intended meaning of entities or things to construct, deploy and use

3.1.13
semiotics
study of signs and their properties including the relationships between the domains of symbols, concepts and cyber-physical phenomena

3.1.14
control loop
<digital twin> feedback link between digital entities and target entities whereby the digital entity receives data from the *target entity* (3.1.3) and issues back to the target entity data that are used to modify the behaviour of the target entity

Note 1 to entry: Control loops use engineering control methods for the purpose of automation, e.g. to keep the temperature on an engine under control of a certain limit.

3.1.15
concept
<semiotics> semantic artifact that represents meaning of a symbol, a thing or a phenomenon

3.1.16
symbol
<semiotics> ontological artifact that denotes a certain meaning, a thing or a phenomenon

3.1.17
phenomenon
<semiotics> thing artifact that is symbolized by an ontological symbol and has implemented certain concepts

3.1.18
asset
entity (3.1.2) that has potential or actual value to an organization

[SOURCE: ISO 6707-4:2021, 3.1.2, modified- In the definition, "item, thing or" has been deleted.]

3.1.19
object
concept or a physical thing existing in the real world

[SOURCE: ISO 15531-31:2004 3.5.7, modified – In the definition, "which may" has been deleted.]

3.1.20
synchronization
<digital twin> action of making the states of target entity and digital entity synchronized, using network for real time system

3.1.21
digital twin system
system providing functionalities for the digital twin composed of inter-operating target entities, digital entities, data connections, and models, data and interfaces involved in the data connection process

3.2 Data-related terms

3.2.1
data
reinterpretable representation of information in a formalized manner suitable for communication, interpretation, or processing

[SOURCE: ISO/IEC 2382:2015, 2121272, modified – Notes have been deleted.]

3.2.2
asset data
facts, concepts or instructions pertaining to an *asset* (3.1.18)

3.2.3
big data
data set(s) with characteristics (e.g. volume, velocity, variety, variability, veracity, etc.) that for a particular problem domain at a given point in time cannot be efficiently processed using traditional technologies and techniques in order to extract value

Note 1 to entry: The term Big Data is commonly used in many different ways, for example as the name of the scalable technology used to handle big data extensive datasets.

[SOURCE: ISO/IEC 38505-1:2017, 3.2, modified – In the definition, "current/existing/established/" has been deleted.]

3.3 Model-related terms

3.3.1
statistics model
model that uses mathematical analysis tools to build a representation of the data for the purpose of conducting analysis to infer any relationships between variables or discover insights

3.3.2
engineering model
model that includes geometry, materials, components and behaviour relevant throughout the entity life cycle

3.3.3
information model
model of a set of facts, concepts or instructions to meet a specific requirement

[SOURCE: ISO 6707-2:2017, 3.2.35]

3.4 Performance-related terms

3.4.1
verification
confirmation, through the provision of objective evidence, that specified requirements have been fulfilled

[SOURCE: ISO 9000:2015, 3.8.12, modified – The notes to entry have been deleted.]

3.4.2
validation
confirmation, through the provision of objective evidence, that the requirements for a specific intended use or application have been fulfilled

[SOURCE: ISO 9000:2015, 3.8.13, modified – The notes to entry have been deleted.]

3.4.3
interoperability
ability of two or more different systems to exchange information and to use the information that has been exchanged

[SOURCE: ISO/TS 27790:2009, 3.39, modified – In the definition, "or components" has been deleted.]

3.5 Application-related terms

3.5.1
visualization
use of computer graphics and image processing to present models or characteristics of processes or objects

Note 1 to entry: Visualization tools are provided to support human understanding.

[SOURCE: ISO 23247-4:2021, 3.4, modified – "for supporting human understanding" has been moved from the definition to a new Note 1 to entry.]

3.5.2
optimization
design and operation of a system or process to improve its efficiency or effectiveness

3.5.3
prediction
process of computation used to obtain the predicted value(s) of a quantity

Note 1 to entry: The term “prediction” can also be used to denote the predicted value(s) of a quantity.

[SOURCE: IEC 62059-31-1:2008, 3.27]

3.5.4
simulation
use of a similar or equivalent system to imitate a real system, so that it behaves like or appears to be the real system

Note 1 to entry: Simulation serves the purpose of analysing the future behaviour of a system, i.e. making predictions, or the purpose of reasoning on the past behaviour in order to analyse failures. For performing simulations, a model is needed together with actualized sets of data and a platform able to execute the simulation.

[SOURCE: ISO 16781:2021, 3.1.9, modified – Note 1 to entry has been added.]

3.5.5
monitoring
means of providing automatic or manual performance supervision and alarming of the status of the *target entity* (3.1.3)

[SOURCE: IEC 62270:2013, 2.34, modified – In the definition, the words "process to personnel and control programs" have been replaced with "target entity", and the words "or manual" have been added.]

3.5.6
augmented reality
AR
virtual objects superimposed upon or composited with the real world

Note 1 to entry: Virtual and real-world objects co-exist in augmented reality systems.

[SOURCE: ISO/IEC TR 23843:2020, 3.3]

3.5.7
virtual reality
VR
artificial environment presented in the computer

[SOURCE: ISO/IEC TR 18121:2015, 3.6]

3.5.8
analytics
predicting, reasoning, and controlling the behaviour (current and future) of an asset or process via both physics and artificial intelligence or machine learning models

3.5.9
Internet of Things
IoT
infrastructure of interconnected entities, people, systems and information resources together with services which processes and reacts to information from the physical world and digital world

[SOURCE: ISO/IEC 20924:2021, 3.2.4, modified – In the definition, "virtual" has been replaced by "digital".]

3.5.10
cyber-physical system
smart system that includes engineered interacting networks of physical and computational components

[SOURCE: ISO/IEC TR 15067-3-8:2020, 3.8]

3.5.11
infrastructure
system of facilities, equipment and services needed for the operation of an *entity* (3.1.2)

[SOURCE: ISO 9000:2015, 3.5.2, modified – In the definition, "organization" has been replaced by "entity".]

4 Symbols and abbreviated terms

AAS	asset administration shell
AI	artificial intelligence
API	application programming interface
CPS	cyber-physical system
DTw	digital twin
ML	machine learning
IT	information technology
OT	operational technology

5 Concepts

5.1 General

In a typical physical scenario, the entity being studied – for example, a wind turbine – is fitted with various sensors related to vital areas of functionality. These sensors produce data relating to the target entity, such as energy output, nearby temperature, and weather conditions. This data is then relayed to a processing system and applied to the corresponding entity. As for the non-physical scenario, the digital entity of IT network is established, and the control of the original target entity is realized to achieve remote management.

When provided with data, the digital entity can be used to run simulations, study performance issues, and generate possible actionable recommendations for improvements, all with the goal of generating valuable hindsight, insights, and foresight – which may then be applied back to the target entity.

Clause 5 includes advantages and benefits of the digital twin (5.2), the digital twin and related concepts (5.3), digital twin applications (5.4), digital twin system context (5.5), life cycle process (5.6) and types of digital twin (5.7). Among them, digital twin system context, life cycle process of digital twin and types of digital twin are part of the concept of digital twin that can help users better understand the definition of digital twin. Definitions of digital twin in different published standards are shown in Annex A.

5.2 Advantages and benefits of digital twin

Digital twin technology includes the advantages and benefits for the digital entity and target entity system as follows.

- Test or investigate target entity behaviour in various scenarios: for example, find the cause of the failure of the target entity by tracing the historical state of the target entity.
- Test simulations of system enhancement or configuration schemes: for example, simulation in the product design phase to improve the design in a precise manner.
- Troubleshoot incidents in the operational target entity: that is, through the control of the target entity by the digital entity to eliminate the fault of the target entity in operation.
- Reduce the need for on-site attention: that is, by focusing on the digital entity to reflect the operating state of the target entity, in order to reduce the on-site attention that is not easy to achieve, such as a spacecraft in operation.
- Lower the operating costs of assets and services: for example, remote operation and maintenance can be achieved through digital entities to save costs.
- Build competitive advantage and export potential: for example, simulate and refine products (target entity) to iterate on its design and packaging (digital entity), to shorten production cycles and reduce costs.
- Accelerate productivity dividends: drive digitization and automation of target entities to unlock productivity dividends with technology.
- Unlock value across industries and across supply chains: through data collection, sharing, and upstream and downstream linkages, the digital twin supply chain can realize global optimization and decision-making, realize cross-link and cross-ecological supply chain collaborative optimization, and accelerate the integration and upgrading of the industry.
- Bring different industries, functions, and concepts together: for example, through the digital twin of the city, people, things and their relationships, behaviours and activities are mapped and connected.
- Enhance transparency, accountability, and trust: digital twin can help companies improve transparency and visibility, and strengthen managers' capabilities.
- Reduce risk in project and programme delivery: when creating a digital twin, project teams and asset owners can learn more about the performance of the project and the resulting assets, enabling better-informed decisions and improved predictability of deliverables.

- Foster innovation within and across ecosystems.
- Facilitate more modern methods of digital engagement and experience within the community.
- Enhance community service delivery.
- Facilitate easier transactions between government and the community.
- Provide access to more and better feedback from the community.

5.3 Digital twin and related concepts

5.3.1 Digital twin and the semiotic triangle

5.3.1.1 General

To understand and gain knowledge from the concept of a digital twin, and to utilize that idea in practice, developers and users of systems apply the principle of semiotics, most often without realizing they are doing so.

EXAMPLE For each concept expressed in this document, a description of the associated phenomenon or phenomena, along with a symbol or symbols that identify the concept in practice, are also given. By this mechanism, this document provides the understanding and knowledge that are integral to digital twin.

The practice of design and fabrication, whether physical or logical, includes the assignment of symbols, signs, or other distinguishing labels to each of the phenomena identified as relevant to the target entity or to its digital entity. In most circumstances, these symbols do not refer to exactly the same concept because they exist in different contexts.

One context has a symbol for a target entity artifact, a piece of hardware or software component, while the corresponding symbol in the digital twin partner is most often a logical construct. Sometimes this logical construct is an exact replica of a corresponding target entity construct but most often the correspondence is as a digital representation of the target entity construct – two different phenomena, one in reality and one virtually, using the same symbol and having corresponding but rather different conceptualization.

The explicit expression of concept, phenomenon and symbol are necessary to define structure and behaviour of a target entity by using some sort of 'tools' such as semantics + engineering + ontologies. If these tools are not utilized, the life cycle of the target entity has unavoidable gaps.

The above-mentioned tools which are outlined by means of the semiotic triangle represent a holistic view on system deployment, operation and maintenance throughout the whole system life cycle. The holistic view comprises the concepts to understand, cyber-physical machinery to construct, and formal standards and informal ontologies to describe the characteristic behaviour of the target system respectively entity. Further information about semiotics is given in Annex B.

5.3.1.2 General introduction to the method of the semiotic triangle

The semiotic triangle is a visualization of the relationships between the phenomenon of interest and the intended semantic concept, that is, the conceptual meaning of that phenomenon, and the intended semantics of the phenomenon of interest. These three semiotic elements and their three relationships should always be considered during the whole life cycle of a thing from conceptualization to its decommissioning.

For that purpose, the digital twin is set up with an abstract model, also called valid type model, by which the dynamic behaviour exhibited by continuous variables either of the wild cat or of the engineered car is modelled. When a new unknown model – that is, a valid labelled proposition – is encountered, it shall be evaluated against the given valid type model. If the proposition "a Jaguar is in your garage" describes a car in the garage, then everything is fine and the "jaguar in your garage" is a valid model of type "car".

5.3.1.3 Semiotic elements domains applied

The three coloured corners of the semiotic triangle of Figure B.1 depict the three-fold basics of the semiotic domains of phenomena described that comprise:

1) the physical phenomenon of an engineered or a living thing;
2) the ontologies describing a car or a cat both labelled Jaguar, and
3) the contextual meanings (semantics) of the contexts of a car or a cat.

These basics are called semiotic domains, which are sets of disjoint artifacts.

Example, if the proposition a "Jaguar in the garage" – the semiotic domains are not sufficient. Each semiotic domain is a set of ordered artifacts. The artifacts from the three semiotic domains must be pairwise related and ordered to derive a possible path through the type model that this semiotic triangle represents. The type representation is achieved by ordering the semiotic relationships of the labelling, analysis and decision-taking. Examples of such artifact pairs are: a) moving car, car labelled with stop sign; b) stop sign identified with 50 % trustworthiness, etc., car type situations alternatives available; c) cause – stop sign recognized, effect – stop car at junction. For a new situation, the labelling, analysis and decision-taking relationship process continues iteratively until sufficient labelling precision occurs.

5.3.1.4 Static and dynamic behaviour of the digital twin

Since all cooperating processes are described by continuous variables, the digital twin gains the semantic concept for a phenomenon from the differential equations that can be transformed to linearized functions for implementing a thing that is explained by ontological propositions.

NOTE In differential equations the continuous variables are equal to differential variables.

When basing the design or use of some phenomenon on variables, the semantic analysis should occur in a stateful mode. The state transition model should be easily operationalized and simulated by a computer. The simulation can be part of the digital twin and the constraints and results of the simulation can be administered by sub-models of the asset administration shell (AAS).

In semiotics, a variable has three kinds of incarnations: first is the variable type related to semantics, that is the nature of the variable; second is the state of the variable related to a situation in a real-world environment, that is the phenomenon like a moving car; and third is the set of valid values related to an ontology, that is the scope of a variable.

The static behaviour of the digital twin is characterized by the structural information resulting from using appropriate reference models like Reference Architecture Model Industrie 4.0 or smart gird reference architecture (SGRA), which is achieved by a state-less representation without the need of a simulation capability.

5.3.2 Digital twin and use of system control elements in the information model

An information model has the purpose to acquire asset data and information about state, quality and performance, etc. to evaluate and to decide upon during all stages of the asset life cycle. Thus, the role of the digital twin is to keep control on all relevant information acquired from the operation technology to be fed into appropriate stages of the asset life cycle that makes a system more safe, more secure, or more performant. To achieve its task the digital twin may use system external tools such as modal logic evaluators, semantic analysers, e.g. based on graph theory, visualizers, augmented reality tools, etc.

A common use for a digital twin takes advantage of system control theory to manage its corresponding target entity. This utilization takes the state of the target entity received by the digital twin as synchronizing data transfer, performs a relevant calculation or analysis, and transfers control signals back to the target entity to modify its behaviour, forming a control loop. Another variety of interaction occurs when the target entity senses that it has reached a set-point or alarm condition, prompts the digital twin for appropriate action and awaits instructions. The pairing of a digital twin with its target entity offers many control loop opportunities for utilizing the synchronization of state to manage the actions of the target entity and understand the consequences of those actions with subsequent digital twin analysis. These opportunities can occur during development of either the target entity or its target, or during operation of either the target entity or its target.

EXAMPLE During product development, feed-back information about product testing performance can be used to improve subsequent development efforts about the target entity.

During digital twin system operation, performance related tasks for functional components and interoperation tasks with the system's environment occur. For both kinds of tasks, data, information and knowledge about the state of the system or its components are analysed to generate either a signal for a system internal actuator or to learn a new pattern of interoperation that can make the system more mature.

In operation the system can perform adjustments to functionality that is internal to the system or perform adjustments to functionality as a consequence of external observation and interoperations. Whereas the former can be executed autonomously, the latter is dependent upon interoperation that is not known in advance. A digital twin can make assumptions and provide predictions about expected target system state behaviour that improve further target system autonomous performance adjustments.

5.3.3 Digital twin and simulation

A simulation and a digital twin both replicate a system’s various processes by digital representations, such as statistics models, engineering models and so on. However, a digital twin runs in a virtual environment. A digital twin has more opportunities for examination and evaluation of target system performance. A digital twin shares two important aspects with a simulation.

a) A typical simulation is a programme that studies through examining and evaluating a particular entity. However, a digital twin can execute any number of useful simulations to study multiple entities. By utilizing continuously updated data related to a wide range of areas, combined with the added computational power that accompanies a virtual environment, a digital twin is able to study more issues from more vantage points than an offline simulation can – with greater ultimate potential to improve products and processes.

b) Simulation programmes can simulate entities in an offline or online manner, which depends on the capabilities of the simulator. However, a digital twin should comprise specific synchronization and feedback characteristics. For example, digital twins are conceptually designed around a loop between the physical entity and the digital representation. When insights are created, another loop is used to interact with the physical entity.

Consequently, simulation is one of the core technologies for creating and running a digital twin with predictive capabilities.

5.3.4 Digital twin and cyber-physical system

A cyber-physical system (CPS) can realize mutual mapping, timely interaction and efficient cooperation between human, machine, object, environment and information in physical space and information space by integrating advanced information technologies such as perception, computing, communications, and automatic control technology, and technology interoperability.

A digital twin may be connected to a CPS to support decision-making in complex processes.

A CPS focuses on overarching system operability on technical system implementation, while a digital twin emphasizes model construction. Digital twin can be seen as an enabling technology for the modelling of a CPS. Its applications include equipment, production lines, factories and workshops that comprise a manufacturing CPS for example.

5.3.5 Digital twin and Internet of Things

Relying on the accurate determination of target entities, a digital twin replicates properties and characteristics what can be mapped to a system in the virtual environment. The frequency of synchronization between the target entity and its digital representation should be sufficient that, allowing for measurement and communications delays, there is little or no appreciable difference between the state of the target entity and its digital representation at any given time. For example:

- Taking advantage of the Internet of Things (IoT), physical data from the entities – examples: geometric characteristics, operation status, and environmental parameters – drives the activities of a digital twin. Without physical data collection of the Internet of Things, models in the virtual environment are unable to interact with entities, and cannot be determined as the digital twin.
- The IoT is a collection of capabilities that enable the transfer of data across applications by several means with varying time constraints. It can invoke post-processing and service tolls for data as required by applications. Sometimes limited by the number, size, cost or accuracy of sensors, some characteristics of target entities are unable to be mirrored to the digital twin. But digital twin can benefit from AI and ML, as well as IoT, which can be applied further, like for monitoring and prediction. For example, to achieve more comprehensive decision support, a digital twin can combine the data collection of the IoT, the processing of big data and the modelling and analysis of AI to evaluate the current state, diagnose the problems in the past, give the analysis results, simulate various possibilities, and predict the future trend.

IoT is the underlying associated technology of digital twin, and it is the necessary condition for the digital twin interaction with target entities.

5.4 Digital twin applications

5.4.1 General

Digital twins are already extensively applied in many areas, such as manufacturing, buildings, healthcare, cities, mining, energy, agriculture, etc. Each target entity of digital twin is created in response to one or more than one explicit or implied use case. Any particular target entity can be paired with one or more than one digital twin where each digital twin has a purpose related to a portion of the target entity. In this common situation, digital twins interacting with the same target entity can have different rates of synchronization appropriate to their individual purpose or operational constraints as specified by the applications they serve.

EXAMPLE: Digital twin applications that operate in the autonomous internal mode can generally have a higher rate of synchronization with the target entity than an application that is constrained by dependency upon external execution of application resources like a complicated simulation engine.

5.4.2 Manufacturing

5.4.2.1 General

Since a digital twin is meant to mirror a product life cycle, it has become ubiquitous in all stages of manufacturing, guiding products from design to finished product, and all steps in between.

EXAMPLE AAS is seen as one interoperable manifestation of a digital twin in manufacturing that facilitates tighter integration within and across the three dimensions (i.e. concept, physical, symbol) of smart manufacturing ecosystems. For smart manufacturing ecosystems, a digital representation of the manufacturing environment including produced products is required.

5.4.2.2 Power-generation equipment

Large engines – including jet engines, locomotive engines, and power-generation turbines – benefit tremendously from the use of digital twins, especially for helping establish timeframes for regularly needed maintenance. The use of digital twins enables more effective research and design of products, with an abundance of data created about likely performance outcomes. Research and design efficiencies come from monitoring the target entity after production to improve the design of a later model of that same entity. That information can lead to insights that help companies make needed product refinements before starting production. The digital twin can even help manufacturers decide what to do with products that reach the end of their product life cycle and need to receive final processing, through recycling or other measures. By using the digital twin, they can determine which product materials can be harvested.

5.4.2.3 Automotive industry

Cars represent many types of complex, co-functioning systems, and digital twins are used extensively in automotive design, both to improve vehicle performance and increase the efficiency surrounding their production. Even after a new product has gone into production, the digital twin can help mirror and monitor production systems, with an eye to achieving and maintaining peak efficiency throughout the entire manufacturing process. When the product is in use, digital twins can also provide guidance and monitoring for recycling and decommissioning.

5.4.3 Buildings and civil infrastructure

Big physical structures, such as large buildings or offshore drilling platforms, can be improved through the digital twin. The digital twin is also useful in designing the systems operating within those structures, such as HVAC (heating, ventilation, air-conditioning and cooling) and pumps to enable safe work practice.

5.4.4 Healthcare

Just as products can be profiled with the digital twin, so can patients who are receiving healthcare services. The same type of system of sensor-generated data can be used to track a variety of health indicators and generate key insights.

5.4.5 Cities

Urban planning and management activities are aided significantly using the digital twin, which can show 3D and 4D (four dimensions, x-y-z and time) spatial data in near real time and incorporate augmented reality systems into built environments and use disaster information to improve resilience.

5.5 Digital twin system context

5.5.1 General

Figure 1 depicts elements of a generalized digital twin system context showing the major components and features common to many such contexts including the digital twin entity, a corresponding target entity, various resources and the externalities with which the digital twin system interoperates.

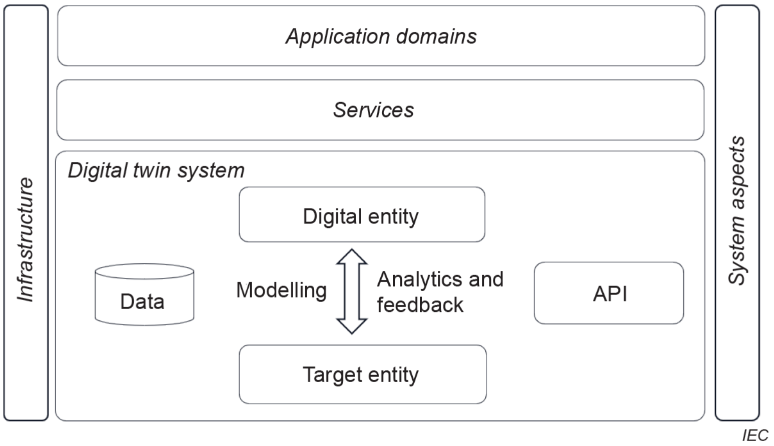


Figure 1 – Digital twin system context diagram

Subclauses 5.5.2 to 5.5.6 describe the major components of the digital twin system context as shown in Figure 1.

5.5.2 Digital twin system

Digital twin system is a hybrid entity, or system of systems, composed of target entities, digital entities, data connection between the two, and models, data and interfaces involved in the data connection process. Digital twin system contains at least one target entity and its digital entity, with their synchronization and interaction with stakeholders to improve one or some performance indicators of the target entities in one or some life cycle stages of the target entities.

The target entity in the digital twin system includes the physical entity and process. The digital entity in the digital twin system is a combination of computing elements or data elements formed through digital twin technology based on the characteristics of the target entity. The target entity should provide modelling data and near real-time operating data to the digital entity, and the digital entity should feedback the analysis results to the target entity, thus they promote each other.

The digital twin system may use APIs and other interfaces for data interaction. At the same time, the digital twin system may interact with external modules such as infrastructure through APIs and other interfaces.

5.5.3 Services

Digital twin may have the capabilities of connection, integration, analysis, simulation, visualization, optimization, etc. In specific application scenarios, the digital twin system can provide services such as virtual and real connection and integration, state analysis, physical simulation and simulation, performance optimization.

5.5.4 Application domains

The digital twin is already extensively applied in many vertical industries, such as manufacturing, medical, urban, etc.

5.5.5 Infrastructure

Infrastructure is an indispensable supporting component to ensure the normal operation of the digital twin system, including sensors, actuators, networks, geographic information systems and so on.

5.5.6 System aspects

System aspects should include integration, governance, security and privacy, and data ethics, which are integral to ensuring that the digital twin system coexists in harmony with other systems in the ecosystem. Among them, data ethics can help guide decisions about the purpose of data collection, what data should be collected, how it should be used and who can access it.

5.6 Life cycle process for digital twin

The digital twin life cycle process describes the evolution of a digital twin from inception through retirement. The life cycle of digital entity and target entity are distinct. The life cycle of a digital twin and its corresponding target entity have similar process groups, but sometimes they do not align at all milestones in time. Figure 2 provides the stages and high-level processes that can apply to the development and life cycle of a digital twin system.

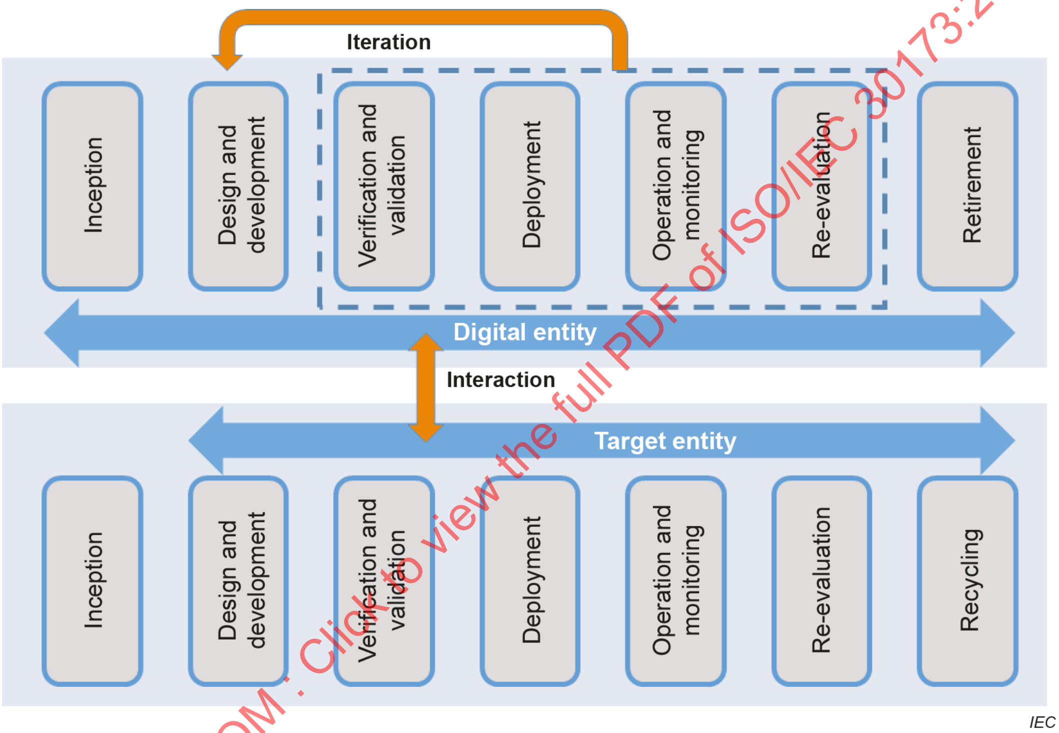


Figure 2 – Digital twin life cycle phases

The life cycle of a digital entity shall include inception, design and development, verification and validation, deployment, operation and monitoring, re-evaluation and retirement. The life cycle of a target entity shall include development, verification and validation, deployment, operation and monitoring, re-evaluation and recycling. However, the system processes occurring with their respective segments can differ in significant ways depending upon the digital twin's purpose and the point in time when decisions are made to pair the two entities.

The interaction between the digital entity and the target entity should be continuous, within the constraints of the appropriate rate of synchronization, during the entire life cycle of the digital entity. In the phase of coexistence between the target entity and the digital entity, the two should remain related and interact with each other.

A digital entity is different from the target entity in the life cycle process, and there is an iterative process. Changes in the digital entity during verification and validation, deployment, operation and monitoring, and re-evaluation (as the dotted rectangle in Figure 2) can be iteratively fed back to the design and development phase to improve the models or entities. The flow between the digital entity and target entity does not have to be fully automatic and can include a human-in-the-loop sometimes.

5.7 Types of digital twin

5.7.1 General

The target entity of the digital twin can be for a certain component, or it can be for a complete system or process. Based on the scope of the target entity, the digital twin can be classified as component digital twin, asset digital twin, system digital twin or process digital twin.

5.7.2 Component digital twin

The component digital twin is typically a major element that has a significant impact on the performance of the target entity to which it belongs. It is related to the level of complexity within the system.

EXAMPLE A component digital twin can relate to a complex motor or pump within a system, where the system itself has a separate system-level digital twin.

5.7.3 Asset digital twin

Asset digital twin can be collections of component digital twins and can consist of component digital twins. Asset digital twins provide visibility at the unit level.

NOTE Where an asset consists of a single component, it can be considered both an asset digital twin and a component digital twin.

5.7.4 System digital twin

A system digital twin is a collection of target entities and digital entities that together perform a system- or network-wide function. A system digital twin provides visibility into a set of interconnected or interdependent target entities.

5.7.5 Process digital twin

A process digital twin is a digital twin that provides a view into a set of activities or operations. The process digital twin can consist of a set of physical entities or system digital twins, but focuses more on the process itself rather than the physical entities.

6 Digital twin stakeholders

6.1 General

In the context of digital twin as shown in Figure 3, this Clause 6 contains descriptions of stakeholders that play distinct organizational roles in the digital twin value chain, including digital twin system stakeholders (6.2) and ecosystem partners (6.3).

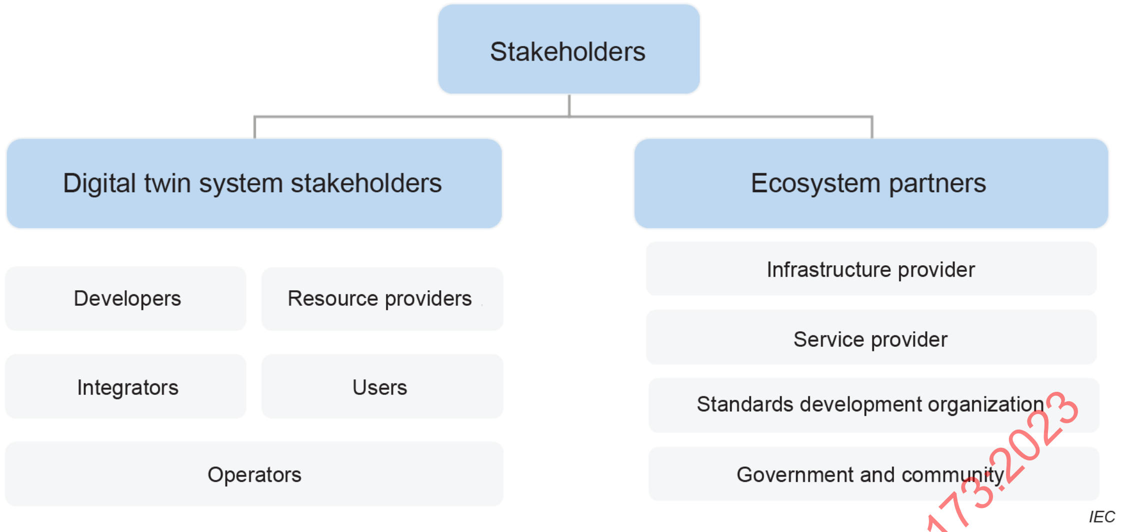


Figure 3 – Digital twin stakeholders

6.2 Digital twin system stakeholders

6.2.1 Developers

Developers refers to stakeholders who complete the digital twin system design and development process based on the needs from users. Developer-related activities shall include requirements analysis, planning and design, development and implementation, and testing and verification.

6.2.2 Resource providers

Resource providers refers to stakeholders who provide resources for any part or the entire life cycle of the digital twin system. The resources shall include basic hardware equipment, development environment, simulation, modelling and other software, model, parameters of the target entity, environmental parameters and other data, network, platform, security and other services.

6.2.3 Integrators

Integrators refers to the stakeholders who complete the integration requirements of any or all activities associated with the digital twin system. Integrator-related activities shall include integration design, deployment and implementation.

6.2.4 Users

Users refers to stakeholders who use the digital twin system to meet their needs. User-related activities shall include proposing related requirements, using the digital twin system to perform related operations, and feeding back information generated during the use of the digital twin system.

6.2.5 Operators

Operators refers to stakeholders who provide technical support for users to ensure the normal operation of the digital twin system. Operator-related activities shall include problem discovery, fault resolution, maintenance, and the establishment of a fault knowledge base.

6.3 Ecosystem partners

6.3.1 Infrastructure provider

Infrastructure provider refers to ecosystem stakeholders that provide organized infrastructures for the digital twin ecosystem and maintain the different networks for the stakeholders and eco-partners.

6.3.2 Service provider

Service provider refers to ecosystem stakeholders that provide technical service or applications involving digital twin system functions or capabilities to create value for common usage or vertical users, or provide technical resolutions of integration and governance of digital twin system and the eco-partners as well as trustworthiness solutions to support the functioning of the digital twin ecosystem.

6.3.3 Standards development organization

Standards development organization refers to the ecosystem stakeholder that is concerned with and provides general rules and technical specifications for one or both of connection and interaction of digital twin system elements as well as for coexistence of digital twin eco-partners.

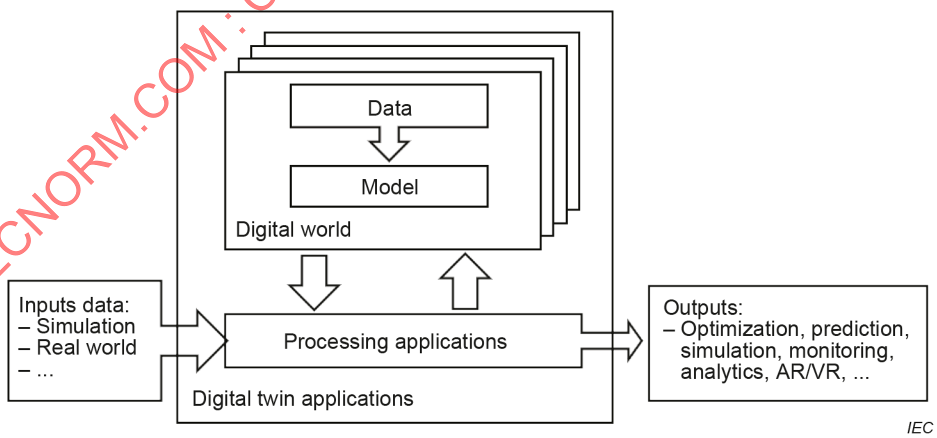
6.3.4 Government and community

Government and community refers to ecosystem stakeholders that provide the governance of the digital twin ecosystem from legal, consensus and social perspectives.

7 Functional view of digital twin

Figure 4 presents a functional view of digital twin. The purpose of this view is to provide a non-technical description of what digital twin systems do to achieve a result.

Note: Details about the functional view of digital twin are outside the scope of this document and are addressed in related standard, i.e. Digital Twin reference architecture.



Key

AR augmented reality

VR virtual reality

Figure 4 – Functional view of digital twin

Digital twin systems can be created by digitalizing and simulating target entities in the digital domain, establishing connections between the target entities and digital entities, and forming a closed or open loop by gathering data from the physical domain, integrating optimization in the digital domain, then making decisions, and applying adjustments to the physical domain based on those decisions.

Digital twin systems can have several distinguishing features compared with conventional non-DTw systems, in particular the ability to improve the target entity by:

- increased visibility;
- reduced time to market;
- sustainably optimized operation;
- reduced energy consumption;
- reduced maintenance cost;
- increased user engagement;
- fusion of information technologies.