Digital Twins for Industrial Applications

DEFINITION, BUSINESS VALUES, DESIGN ASPECTS, STANDARDS AND USE CASES

An Industrial Internet Consortium White Paper

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This whitepaper provides practical guidance on digital twin, including the definition, benefits, architectures and the necessary building blocks to implement one. We illustrate the relationships between an Industrial Internet of Things (IIoT) system and its twin with use cases.

We identify:

- the defining characteristics of a digital twin,
- relations among digital twins to form composite systems,
- the role of digital twins in the lifecycle of entities, considering the scenarios with and without digital twins and the business value of digital twin,
- digital twin internal design,
- followed by a more detailed description of various design decisions,
- an overview of standards for digital twin, which could be considered in the design of digital twins and
- example usages of digital twins in various industries.

This whitepaper can be used by business managers seeking effective means to improve the efficiency of the system, system architects of an IIoT system, and other practitioners and testbed teams by:

- identifying and evaluating standards, practices, and characteristics best suited for addressing digital twins holistically and highlighting gaps where needed and
- identifying deployment models and crosscutting functions that address patterns and characteristics for digital twin deployment.

IIC Digital Twin Definition

A digital twin is a formal digital representation of some asset, process or system that captures attributes and behaviors of that entity suitable for communication, storage, interpretation or processing within a certain context.

The digital twin information includes, but is not limited to, combinations of the following categories:

- physics-based model and data,
- analytical models and data,
- time-series data and historians,
- transactional data,
- master data,
- visual models and
- computations.

The icon in Figure 1 captures the multiple facets of a digital twin. It is used throughout the paper to depict a digital twin.

Figure 1 The icon of digital twin

RELATIONSHIPS AMONG DIGITAL TWINS IN SYSTEMS

The level of abstraction of a digital twin is such that it is sufficient for the requirements of the use cases for which the digital twin is designed.

A *discrete digital twin* is a single entity that provides value without needing to be broken down further. For example, the gearbox or motor for a ball mill in mining can be monitored and reported on at this entity level. Assembling discrete digital twins to create a composite digital twin is shown in Figure 2 as a vertical expansion that describes the increase in composition from a single to many entities.

A *composite digital twin* is a combination of discrete digital twins that represent an entity comprising multiple individual components or parts. The composition may take place at different levels. For example, a production cell is a composite entity, whose digital twin consists of the digital twins of the devices within the production cell. An entire plant is a system, whose digital twin consists of several others composite digital twins.

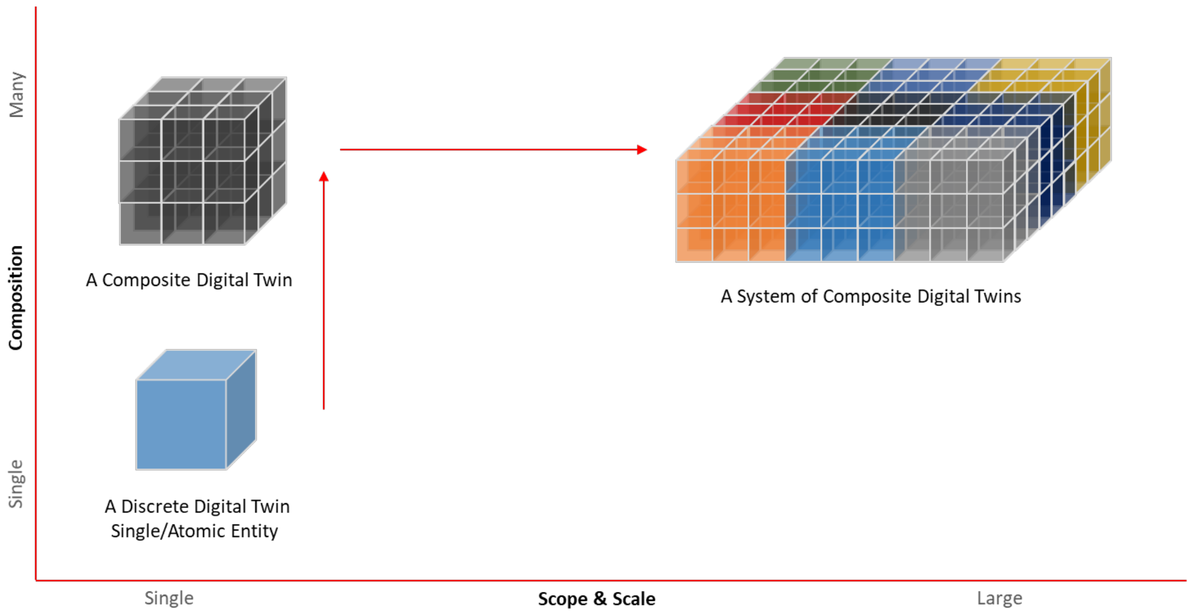

Figure 2 Creation of a composite digital twin

As depicted in Figure 3, the relationship between digital twins in a composition may be:

Hierarchical: Just like their real-world counterparts, a set of component digital twins can be assembled into an equipment digital twin, a set of equipment digital twins can be assembled into a production line digital twin, a set of production line digital twins can be assembled into a factory digital twin and so on.

Associational: There are associations between digital twins, just like their real-world counterparts. A gas pipeline digital twin is associated with its gas production and consumption equipment digital twins.

Peer-to-peer: The peer-to-peer relationship is observed in a group of equipment of same or similar types, which perform the same or similar functions. The total effect of all the equipment is the simple sum of the effect produced by each piece of equipment. For example, in a wind farm, a group of wind turbine engines forming the composite digital twin of the wind turbine.

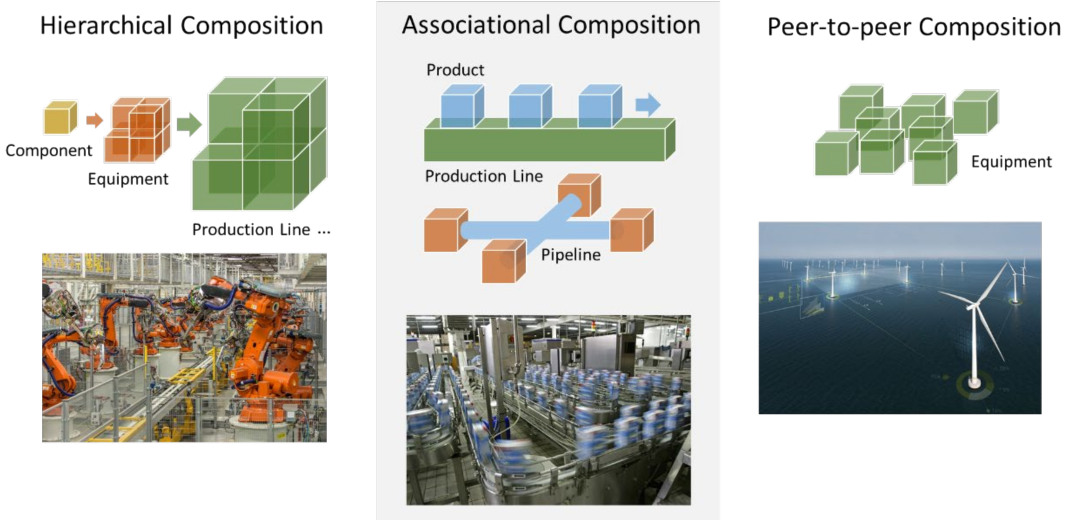

Figure 3 Relationship between digital twins in a composition

DIGITAL TWIN IN ENTITY LIFECYCLE

As depicted in Figure 4, the information about an entity is usually scattered across multiple information sources, which are developed and maintained by different organizations. This leads to broken information flow across the lifecycle of the entity because these information sources may not exchange information properly. Some information may be duplicated or inconsistent and some information may be missing. As a result, significant time is required to find the relevant information, convert it to a suitable format and realize the semantic relationships therein. Moreover, this may lead to conflicting operational intelligence and can result in poor decision-making. In addition, information silos hinder adoption of advanced techniques such as advanced analytics and artificial intelligence, which require accessing large amount of information.

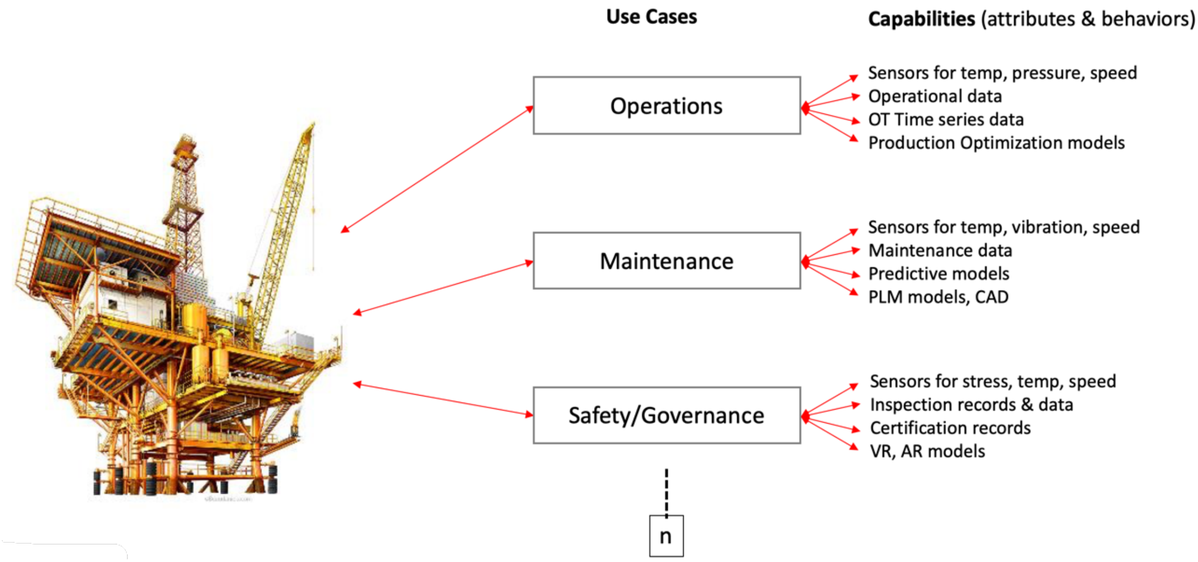

Figure 4 Operations without a digital twin

Figure 5 shows how digital twins help to tackle the information silo problem. A digital twin serves as a proxy that collects data centrally for every entity and then makes that information available to different areas of the business for their specific applications through integration interfaces, such as Application Programming Interfaces (APIs). This improves decision-making through a shared understanding of operational status and reduces the overall lifecycle cost of operating and maintaining a plant.

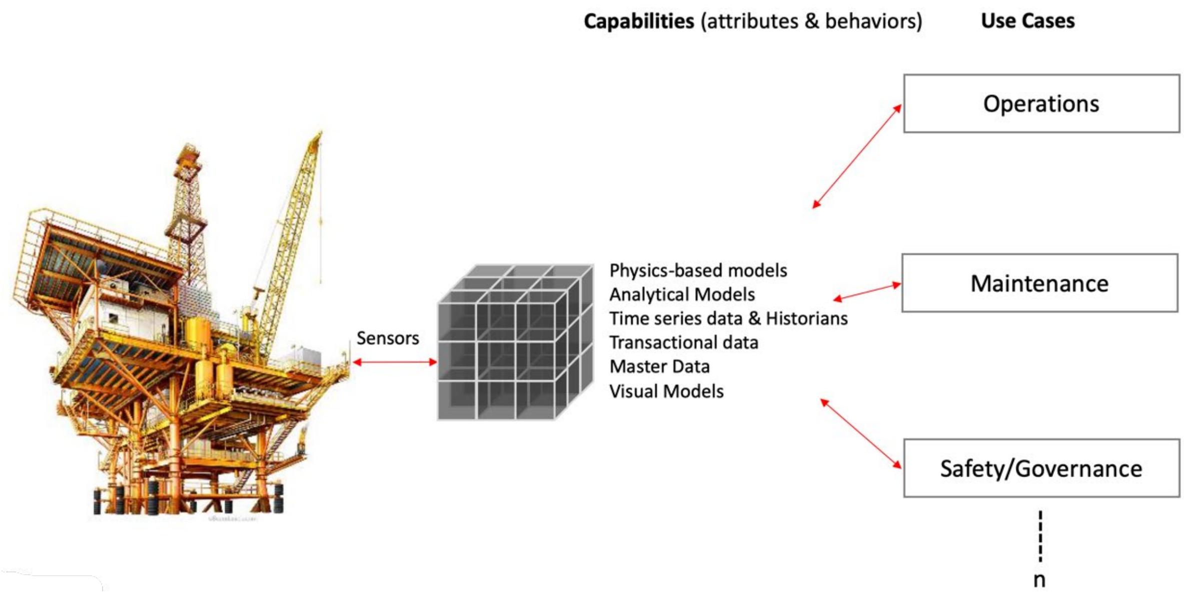

Figure 5 Operations with a digital twin

Figure 6 shows an example of how digital twins evolve during the lifecycle of an entity, beyond the boundaries of an organization. In manufacturing systems, a manufacturer can add new product types to the type catalogue. The customer decides on the product types she would like to purchase from the catalogue and then places an order. The product is manufactured and shipped to the customer. Meanwhile, the customer may adopt various engineering and virtual commissioning tools to engineer the product, identify its parameters and interactions with other products in the plant. When the real product is received by the customer, it is installed in the plant, commissioned and brought into operation. During the operation phase, various maintenance services may be applied to the product. The maintenance information may be used by the customer to adjust its future selection of products. The manufacturer may be informed of the detected issues in the product and the manufacturer may consider this input to increase the quality of its product.

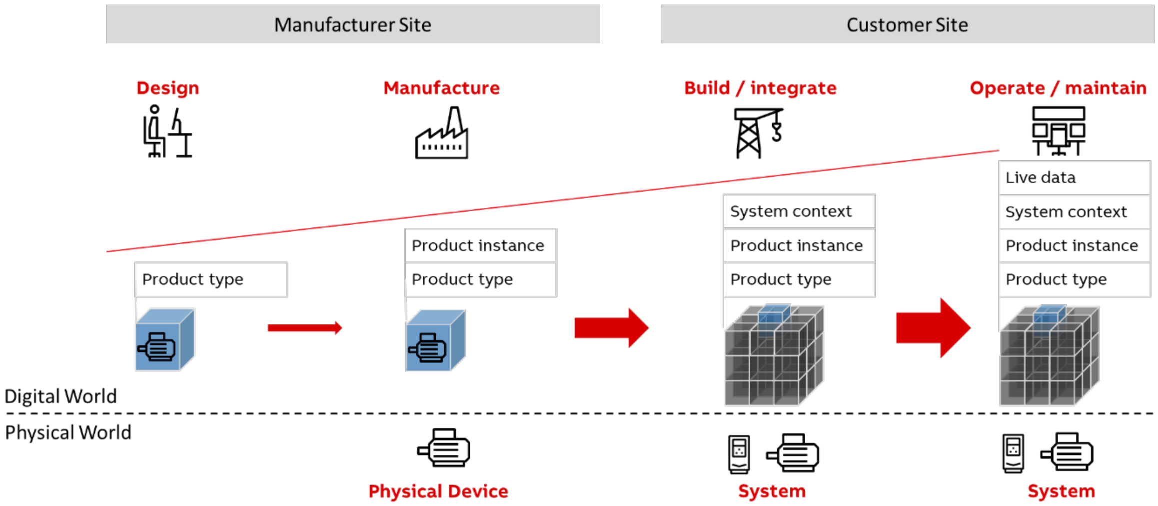

Figure 6 Digital Twin reduces information silos

The simple example above shows a flow of information across the boundary between the manufacturer and customer. Today this flow is largely broken. For example, within one company there might be multiple tools for selecting, engineering and virtual commissioning that are not well-connected to each other and cannot exchange information with each other. The operational information of the product may be maintained in the firmware of the product; the maintenance information is kept in dedicated databases and is disconnected from the selection phase. Even if there is contractual agreement to send part of operational and maintenance information to manufacturers, this information is scattered in databases and the product firmware and we cannot easily aggregate this information in an economic, accurate and timely manner.

The digital twin of an entity is a means of, and is the single interface to, accessing its lifecycle information. Digital twins can be defined for any entity of interest for an organization. In our example, the manufacturer may define digital twins for the product type, by including all relevant information such as market analysis, computer-aided design drawings, documentations and performance information received from the customer. They may also define a digital twin for their product and keep production and maintenance information received from the customer in that digital twin. This provides the manufacturer with a single interface to access all the product and product type information, and may be of value to multiple companies. There may be separate digital twins for a single entity because the context is different and the information is used in different ways.

There are also semantic relationships between the digital twins of various entities, just as there are in the real world. Failure to establish these would leave the uncommunicating digital twin an information silo to itself. Since the information comes from different sources, at different times and in different formats, establishing such relations automatically is one of major challenges in designing digital twins.

By offering a single entry-point to access the lifecycle information of entities, and by maintaining relations among the information within one digital twin and across multiple digital twins, various business advantages can be achieved. For example:

Digital twins can serve as the *foundation* for advanced analytics and artificial intelligence applications to consume and enrich digital twin content. Alternatively, advanced analytics and AI applications can be part of a digital twin, making it an intelligent and self-contained entity.

It is not always possible to measure every crucial physical parameter of interest. Digital twins can be used to develop high-fidelity *soft-sensors* or *virtual sensors* through physics-based models incorporated into the digital twin and serve as a proxy for the physical measurements. It may be necessary to undertake advanced analytics and simulation, using the digital twin, of the underlying process to predict future behavior.

Measurements received from sensors reporting operational parameters of an asset are *not always accurate* due to failure or drift in sensor performance. When anomalies arise due to a faulty sensor and not due to any underlying operational malfunction in the physical asset, alarms need not be issued and unnecessary shutdowns avoided. Physics-based models and the digital twin representing the asset can be used to reconcile the data to enhance measurement quality and ensure that measurements received are indeed genuine. For example, in the digital twin of a power plant, a simple mass-heat balance in a circuit can help reconcile data and also detect possible sensor failures.

Digital twins *ease collaborative engineering* through all lifecycle phases. This reduces the time spent on finding, exporting and importing information into tools required for any lifecycle task.

Digital twins can *resolve operational or maintenance issues* that would otherwise result in expensive downtime.

Digital twins *increase quality* since many errors in production are caused by relying on wrong or outdated information.

Digital twins can be made available to anyone, anyplace and at any time. Sharing expertise around the world allows for 24/7 service and fast reaction time while maximizing expert use. In case an implementation needs on-site operation, a local engineer can be mobilized and remote experts can provide support.

Digital twins therefore provide a *systematic methodology*, technology and tools to represent complex physical and logical environments and enabling effective monitoring, diagnosing, predicting and prescribing action of physical and logical entities.

Design of Digital Twin

To represent objects in the real world dynamically, digital twin instances should be connected to their respective real-world twin, sometimes in real time, to collect and organize data from the corresponding real-world objects. The digital twin should enable computational and analytic models to analyze these data to describe, diagnose, predict and simulate the states and behaviors of the real-world objects and systems. The insights obtained from such analysis can be combined with business logic and objectives to prescribe actions to optimize the production processes. To achieve that, the design of digital twin must include service interfaces for intelligent industrial applications to access the data and analytic results.

As Figure 7 shows, a digital twin comprises data and computational models (hereafter just “models”) and service interfaces just like an object in an object-oriented programing language has member data, methods and interfaces.

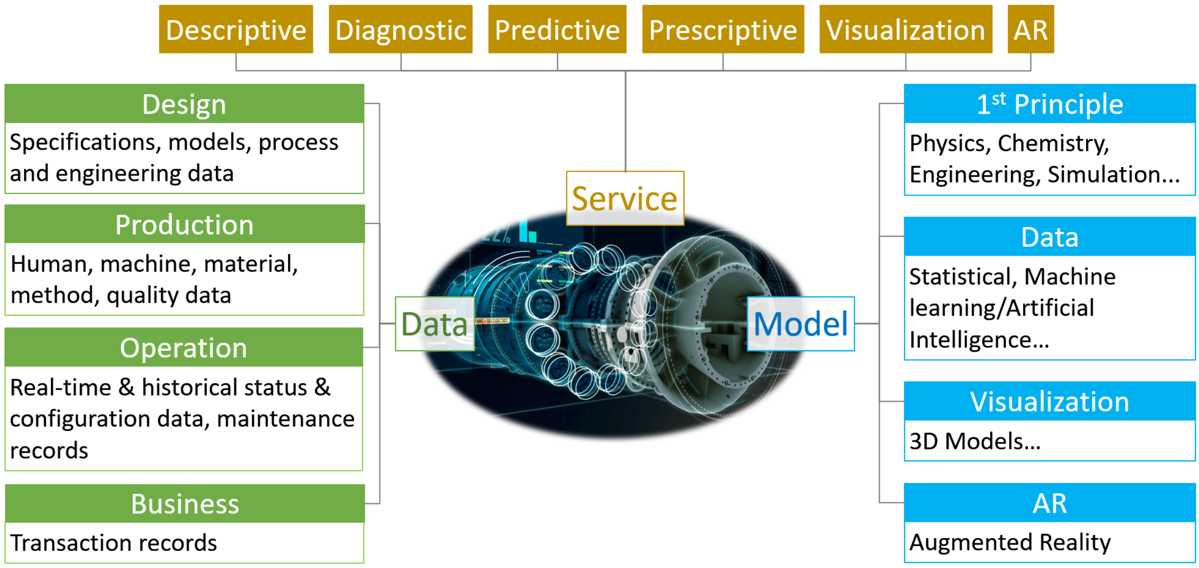

Figure 7 The constituents of a digital twin

Data: a digital twin should contain data about its real-world twin that are required by the models to represent and understand the states and behaviors of the real-world twin. In many cases, it may consist of data in the full lifecycle of the real-world object, in the case of equipment, data during the design phase (specifications, design models, production process and engineering data), production phase (data about worker, production equipment, material and parts, production methods and quality assurance data), operation phase (data about installation and configuration, real-time and historical state and status as well as maintenance records) and even end-of-life procedural data. It may also contain business data such as transaction records.

Models: A digital twin should contain computational or analytic models that are required to describe, understand and predict the twins’ operational states and behaviors, and models that are used to prescribe actions based on business logic and objectives about the corresponding real-world object. These models may include models based on physics or chemistry, engineering or simulation models, data models based on statistics, machine learning and Artificial Intelligence (AI). It may also include 3-D models and augmented reality models for aiding human understanding of the operational states or behaviors of real-world objects.

Service (interface): a digital twin should contain a set of service interfaces for industrial applications or other digital twins to access its data and invoke its capabilities.

Though the form and content of real-world objects vary a great deal, there should be high-level invariant constructs with some common data attributes and models within each digital twin, so that they can be accessed and invoked via a common approach.

As shown in Figure 8, we can construct digital twins according to the types of their respective real-world counterparts. The instances are created based on their types' templates, according to the configuration of its environment. Similarly, we may establish logical relations between instances according to their types.

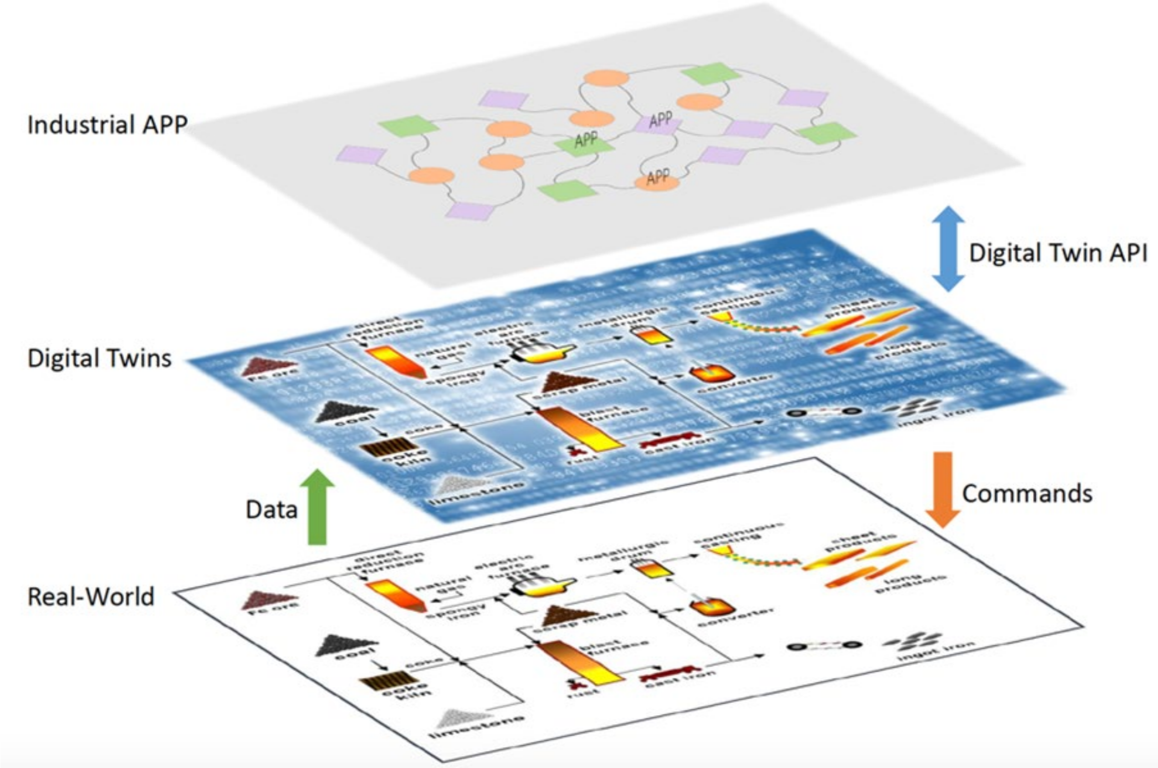

Figure 8 Digital Twins bridge the Design and Applications

TECHNICAL ASPECTS OF DIGITAL TWIN

Figure 9 shows some technical aspects of a digital twin; each of which are explained below.

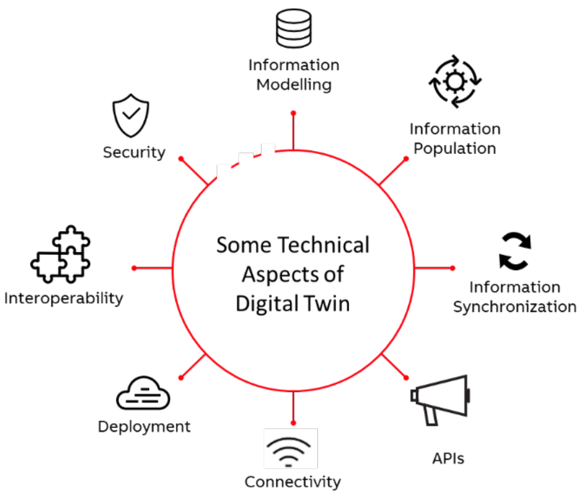

Figure 9 Technical aspects of digital twins

Information modelling: The core element of digital twin is information, which is related to different lifecycle phases of the underlying entity. Various key decisions must be taken in this regard. Examples are:

- a meta-model for digital twins describing the required internal models for use cases,
- mechanisms to structure and modularize the content of digital twins and to extend the content when new kinds of information become available over the entity's lifecycle,
- standards that must be adopted to define the structure and content of digital twins so that cross-company information exchange is facilitated,
- mechanisms to map existing information to such standards
- mechanisms to model relations among the information within one digital twin and
- means to model various kinds of digital twin assemblies.

Information population: Information for digital twins originate from various sources. Some may be maintained inside the digital twins. For example, if an advanced analytics application uses a digital twin content as its input, the application may only store the results of the analysis into the digital twin itself. Various key decisions must be taken regarding the information population from information sources into digital twins, such as mechanisms to:

- populate information from various sources such as devices, applications, databases or other digital twins,
- copy the information into digital twins, or to reference the information from digital twins, or a combination of these on demand,
- cache the information and
- populate online and offline information (such as for online monitoring of real-world entities or in offline simulation tests).

Information synchronization: The considerations here are:

- means to synchronize information between a digital twin and the relevant information sources in both directions from information source to digital twin and vice versa,
- mechanisms to synchronize information among multiple digital twins taking part in various composition forms,
- policies (such as security and synchronization frequency) to perform information synchronization and
- standards and means to ensure interoperability of digital twins and their information sources to facilitate information synchronization.

APIs: Digital twins interact with other components. To facilitate the interactions, various APIs must be in place. We need APIs:

- that are suitable for different kinds of applications (such as real-time simulation applications, analytics applications and artificial intelligent applications) that consume and populate digital twin content,
- for interacting with other digital twins possibly across vendors,
- for interacting with the corresponding underlying entity to facilitate information collection from and control of the entity and

- for interacting with other information sources to enrich and synchronize the content of digital twins.

Various key decisions must be taken regarding the information access APIs, such as:

- mechanisms for offline information access (such as the form of files in different formats),
- mechanisms for online information access (such as in form of RESTful APIs),
- mechanisms for exchanging information in bulk or stream,
- APIs for interacting at the levels of cloud, edge and device (such as cloud-to-cloud, device-to-cloud and cloud-to-device) and
- standards for APIs to facilitate interoperability across vendors.

Connectivity is the key enabler for interactions with and among digital twins. Various key decisions must be taken regarding connectivity. Examples are:

- mechanisms for uniquely identifying a digital twin and its underlying entity to establish connection among them,
- mechanisms for automatically discovering the underlying entity in network to establish the connection to its digital twin,
- mechanisms to discover other digital twins to establish connectivity among them and
- connectivity standards to facilitate interoperability across vendors.

Deployment: Digital twins can be deployed on a spectrum from the edge to the cloud, based on the requirements of the application. The decision is typically based on factors such as:

- latency and response time requirements,
- interoperability and integration with other systems,
- control requirements and
- complexity and power requirements of analytics.

To deploy digital twins, we need mechanisms to:

- deploy the content of a digital twin in locations such as IoT device, edge and cloud,
- discover individual digital twins distributed on different locations to form composite digital twins and
- support polymorphic digital twins, meaning that a digital twin can be deployed in different forms at different deployment locations.

As shown in Figure 10, one instance must be regarded as the master working copy with its master models, master data and its associated definitions stored and managed in a repository. The other instances can be tailored for different applications, for example, offline instances for simulation purpose and online instances for remote monitoring. In the latter case, the information will be updated from its real-world counterpart to reflect the truth of the real-world ("ground truth"). Sometimes the digital twin can be deployed adjacent to the real-world counterpart to perform on-location monitoring or analysis of the real-world counterpart asset to provide (near-)real-time feedback to optimize the operation of the asset.

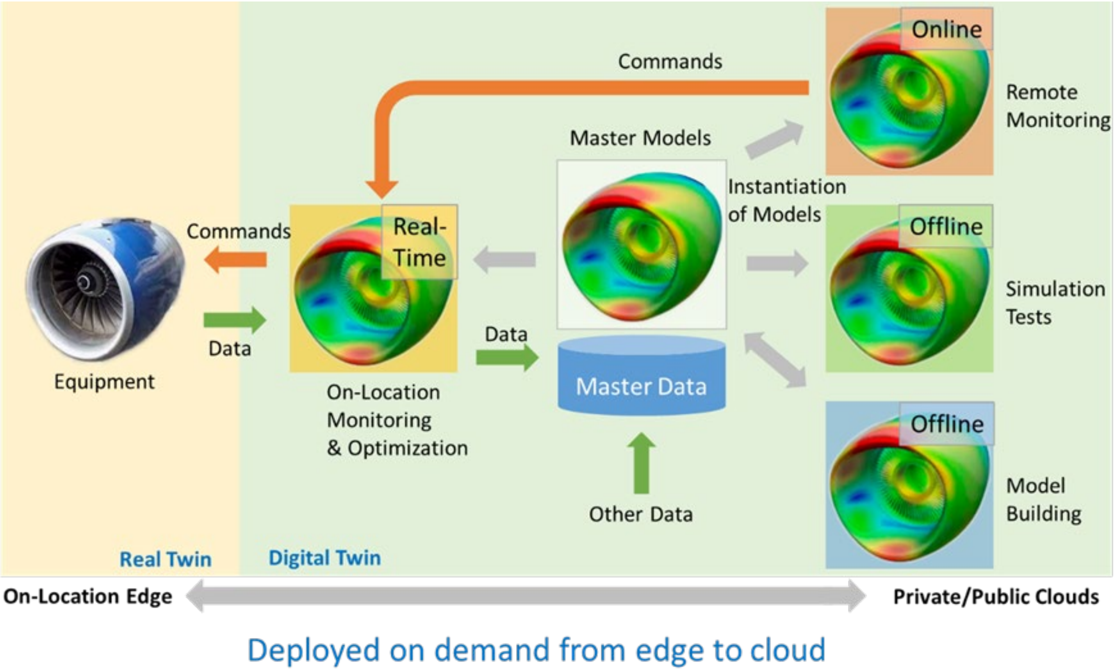

Figure 10 Deployment Model of Digital Twins

Security: The interactions of digital twins with different entities have different security considerations. Various key decisions must be taken regarding deployment of digital twins. Examples are:

- mechanisms to secure access to the content of one digital twin, for example via role-based access control,
- mechanisms to secure access to the individual digital twins coming from different vendors constituting composite digital twins,
- mechanisms to secure the interactions to the underlying entity via its digital twin,
- methods of ensuring the authenticity of information, models and other metadata such as the identities of other parties and their cryptographic keys and their access rights and privileges,
- methods for secure deployment of digital twins and ensuring that correct, untampered versions of software are executing to enhance the trustworthiness of the solution that may help protect the intellectual property of certain types of digital twins and
- methods, where relevant, to aid in the resolution of disputes should it be required to establish the provenance or timing of any information.

Interoperability is “the ability for two or more systems or applications to exchange information and to mutually use the information that has been exchanged”. International standards or mutually-agreed communication protocols are needed to define syntax of information, semantics of information, expected behavior and information exchange policies so as to achieve interoperability.[1] Various key decisions must be taken regarding the interoperability aspects of digital twins. Examples are:

[1] ISO/IEC Organization. 2019. ISO/IEC 21823-1 Internet of things (IoT)– Interoperability for iot systems – Part 1: Framework.

- mechanisms and standards to ensure the interoperability of multiple digital twins with each other,
- mechanisms and standards to ensure the interoperability of various applications with digital twins,
- mechanisms and standards to ensure the interoperability of digital twins with their underlying entities and
- mechanisms and standards to ensure the interoperability of digital twins with underlying information sources.

STANDARDS AND FRAMEWORKS

There are various activities regarding standardization of digital twins, even if not directly termed as “Digital Twin”. IEC 62832 is a well-established standard, which defines a digital factory framework with the representation of digital factory assets in its center, although it is not called digital twin. ISO/IEC JTC1 provided a technology trend report by its joint advisory group on Emerging Technology and Innovation (JETI). In the report, “Digital Twin” was identified as the number one area needing in-depth analysis, where JETI is also looking at how cooperation with the open source community can be established.[2]

In 2019, the ISO/TC 184 Advisory Group noted that there is no “standard-based foundation within ISO for the data architecture of the ‘Digital Twin’”.[3] As a result, a group has been formed to study the formalization of the digital twins. In addition, in 2019, the IEEE Standards Association, initiated a project IEEE P2806 that aims to define the system architecture of digital representation for physical objects in factory environments. A similar approach is taken by Digital Twin Manufacturing Framework ISO/AWI 23247 within ISO TC 184/SC4/WG15. This framework enables plug and play for twin elements, focusing mainly on the interfaces and functions of digital twins.

The German Plattform Industrie 4.0 launched Asset Administration Shell [4] as the implementation of the digital twin for smart manufacturing, IEC PAS 63088. This was deepened by partnerships between France, Italy and Germany.[5]

ISO TS 18101-1 “provides requirements, specifications and guidance for an architecture of a supplier-neutral industrial digital ecosystem” with focus on oil and gas interoperability. In this context a digital twin is defined as “digital asset on which services can be performed that provide value to an organization”. Digital assets are not considered to be necessarily physical.

[2] https://jtc1info.org/technology/jeti/

[3] *ISO/TC 184/SC 1 N417. Ad Hoc Group: Data Architecture of the Digital Twin. 2019-06-25.*

[4] *Details of the Administration Shell. Federal Ministry for Economic Affairs and Energy (BMWi). ZVEI & Plattform Indutrie 4.0. Online: https://www.plattform-i40.de/PI40/Redaktion/EN/Downloads/Publikation/Details-of-the-Asset-Administration-Shell-Part1.html*

[5] *Structure of the Administration Shell. Trilateral Perspectives from France, Italy and Germany. Ministry of Economy and Finances & Federal Ministry for Economic Affairs and Energy (BMWi). Alliance Industrie du Futur, Piano Industria 4.0 & Plattform Industrie 4.0. Online: https://www.plattform-i40.de/I40/Redaktion/EN/Downloads/Publikation/hm-2018-trilaterale-coop.html*

Open source activities are also coming more and more into focus. In the Eclipse BaSyx project[6], the first software development kits (SDK), viewers and editors for developing digital twins all conforming to the specification of Asset Administration Shell are offered. As part of Eclipse IoT[7] Eclipse Ditto combined with Eclipse Vorto offer a generic digital twin framework.

Besides the classical standards development organizations (SDOs) like the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC), other consortia in the context of IoT such as the W3C Web of Things (WOT) work on specifications of digital representation of things.

Digital Twin In Practice

A large number of digital twin examples are proposed by different companies and researchers. This section lists a few examples from various domains.

Digital Twin in Manufacturing

A commercial aircraft comprises several supplier parts such as engines, landing gear, and avionics. As a result, the digital twin of an aircraft is a composite of twins of these parts. The airlines are the operators who usually buy or lease the aircraft from the company responsible for the full aircraft. As a result, the digital twin of the aircraft, at the time of delivery, would be the responsibility of the aircraft manufacturer. The manufacturer in turn would rely on twins of major parts like engines on the engine OEM. These twins should be able to interoperate, on single or interoperable platform(s). Over time, these twins have to be maintained for *as operated* and as *maintained* status.

As for the business value, the digital twin of an aircraft helps with predictive maintenance, operating efficiencies (such as fuel efficiency) and coming up with asset maintenance strategies. Considering that the life of an aircraft is often multiple decades and cost of maintenance over its lifetime may exceed the original cost of the aircraft, these are crucial gains of having digital twins in place.

Digital Twin in Energy and Utilities

In the pelletization process, effective control of furnace equipment and plant is necessary to achieve a high level of furnace productivity, energy efficiency and meet quality specifications.

As Figure 11 shows, the digital twin for a pelletization furnace works in tandem with the plant distributed control system. This digital twin is then employed to optimize the operation continuously in real-time by suggesting optimum set points to the operator. The digital twin comprises data and information preprocessing, equipment behavior simulation model (both data-based and physics-based) and self-learning modules and decisions (that optimize the

[6] *Details of the Administration Shell. Federal Ministry for Economic Affairs and Energy (BMWi). ZVEI & Plattform Indutrie 4.0. Online: https://www.plattform-i40.de/I40/Redaktion/EN/Downloads/Publikation/2018-details-of-the-asset-administration-shell.html*

[7] https://projects.eclipse.org/projects/iot

inputs considering process, quality, safety and environmental constraints). The digital twin uses both data-based developed from 7,000+ sensors and physics-based soft sensors to predict unknown flow rate, temperature and composition of recycled gases.

Digital twins for steel manufacturing plant will include:

- equipment level digital twin that control each equipment,
- sub-blocks that will enable building equipment level digital twin,
- connection between digital twins and existing control systems,
- process level digital twin that will control equipment within process and
- plant level digital twin that will control entire operations of plant.

When considering interoperability requirements, it is necessary to consider interoperability standards for communication between blocks as explained below.

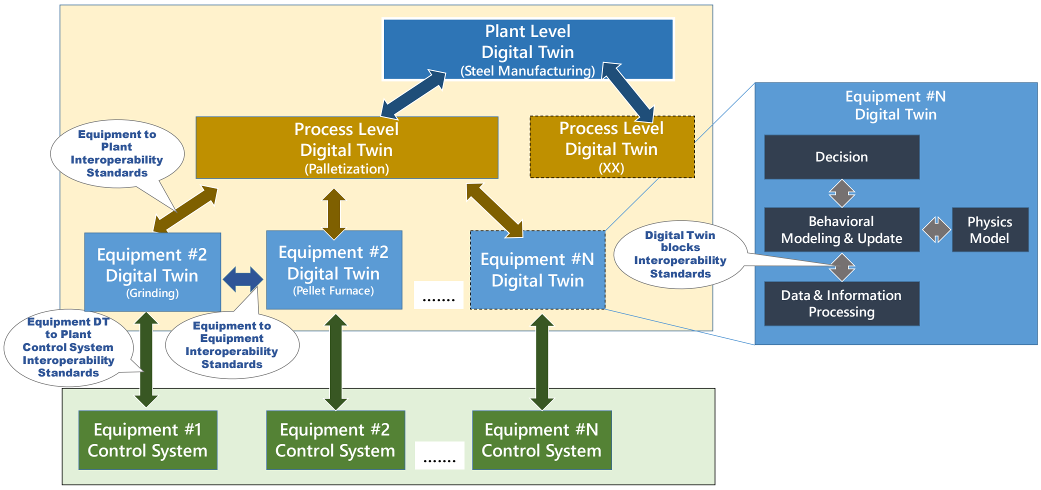

Figure 11 Digital twin in the palletization process

In this scenario, digital twins bring the following business values:

- real-time optimization controls key control parameters to provide 2% reduction in fuel consumption and 3% improvement in throughput and
- real-time computation of various quality parameters such as compressive strength of pellets and furnace operating parameters such as bed temperature, helps operators take quick and accurate decisions without need of lab-based sampling test and assumptions.

Digital Twin in Oil & Gas

The subsurface well-monitoring digital twin for an oil well lifecycle starts at the exploration phase where simulation models based on seismic and other subsurface data is used to initiate a well. The subsurface well monitoring digital twin is a composite system; the drilling model comprises four unique, independent elements, each a composite digital twin in its own right. These are the subsurface, the wellbore, the rig and surface equipment. The subsurface, in turn, comprises the surrounding geology, reservoir, and near-wellbore formations. In order to derive the objective functions to execute during well construction, these four integrated primary data elements are examples of what needs to be modeled:

- wellbore trajectory,
- drill string physics,
- pressure control (mud properties) and
- reservoir composition and integrity (near wellbore).

Well monitoring and drill rig sensors, combined with reservoir AI capabilities that scan massive amounts of geological and historical production data in a digital twin instance, enables operational control and collaboration between the subsurface reservoir and across surface operations. The subsurface well monitoring digital twin evolves over the lifecycle of a well to address additional use cases in completion, production, maintenance and abandonment.

The subsurface well monitoring digital twin offers the following business values:

- It provides a mechanism for evaluating strategies to reduce costs, optimize well operations and asset production. These digital twins provide a greater understanding of the financial, technical and operational parameters to manage wells in real-time.
- The subsurface well monitoring digital twin can improve the overall well integrity index and well construction processes, supporting the development of efficient and agile well-construction workflows and facilitate decision-making towards the most rewarding exploration, drilling, completion and production alternatives.

Digital Twin in Mining

The digital twin for a mining operation with a focus on Processing Asset Health incorporates information needed to make the best decisions around maintenance, whether condition-based or predictive in nature. It further provides information to prioritize work order scheduling based on actual asset condition parameters and metrics.

The Processing Asset Health Digital Twin is used across the business and as such needs access to various systems to ensure the information displayed is accurate and relevant to the asset and level of detail the viewer is interested in.

This digital twin interacts with:

- Enterprise Asset Management systems (EAM),
- local and enterprise historian,
- IT-system of the customer and
- existing control systems.

In this scenario, digital twins bring the following business values:

- The ability to improve mean time between failures and mean time to fail to assist with the mine's asset performance management practices. This is achievable due to the information being available closer to real time than previously possible. Combining this with key information from the EAM system brings different system information together in a digital twin to aid key decision making.
- It realizes the mines' full potential to minimize plant losses due to equipment maintenance issues.

- It increases the accuracy of scheduling, which in turn aids in the move to more condition-based monitoring and ultimately predictive monitoring of assets.
- It reduces overall cost with more transparency in asset health and maintenance schedules.

Digital Twin in Process Automation

The digital twin of a chemical product batch unifies all the required information of the product batch. The information of interest is the production parameters (such as temperature, pressure and humidity) during the production of the specific batch.

The digital twin provides information for monitoring the relevant aspects (viscosity, pH-value and state of aggregation) of the current product status. On the basis of this data, simulations may be carried out to predict the optimal production parameters for further processing steps, to guarantee the planned product quality.

Changes in the product properties can be logged in a time-series database, which makes it possible to trace down excesses of quality-critical values to the time and location and so identify the cause. These functionalities make the digital twin of a product a key part of the quality-management process.

Since the digital twin of a chemical product batch grants insight in the data history of that batch, it can be delivered to the customer in addition to the real product. The gathered data supports the customer in further processing steps or in the end use.

In this scenario, digital twins bring the following business values:

- Transparency and traceability of production parameters may be used in regress claims.
- Bad product quality may be detected directly, preventing the execution of further expensive production steps.
- The analysis of product quality and preceding production parameters leads to further knowledge in production.
- Overall product quality can be improved through intelligent simulation of production parameters.

Conclusion

Although most companies offer digital twin as part of their IoT offering, the notion of digital twins existed before IoT, under different names and different definitions. As a result, there have been different interpretations of digital twins, driven by the use cases in which digital twins play a role. Although the set of decisions that architects face to design different digital twins overlap, this diverse understanding of digital twins is a barrier to propose generic, yet abstract architectures, for digital twins and their position in industrial systems.

In this white paper, we took a step towards providing a concrete definition of digital twin from an Industrial Internet Consortium (IIC) perspective and elaborated on scenarios in which digital twin plays a significant role to increase efficiency of current use cases and to enable new use cases. The listed technical aspects and decisions for designing digital twins lay the foundation for the further work on including digital twins in the Industrial Internet Reference Architecture (IIRA)[8]. Along these lines, since security and interoperability are two important quality attributes of digital twins, further work will be carried out to propose means to fulfill these quality attributes.

Appendix

Definitions

Digital Twin

Digital representation, sufficient to meet the requirements of a set of use cases.

note: in this context, the entity in the definition of digital representation is typically an asset, process or system.

source: Industrial Internet Vocabulary Technical Report, IIC

Asset

Major application, general support system, high impact program, physical plant, mission critical system, personnel, equipment or a logically related group of systems

source: NISTIR 7298, rev 2

Digital Representation

Information that represents attributes and behaviors of an entity.

source: Industrial Internet Vocabulary Technical Report, IIC

Entity

Item that has recognizably distinct existence.

note: e.g. a person, an organization, a device, a subsystem or a group of such items.

source: ISO/IEC 24760-1:2011

Attribute

Characteristic or property of an entity that can be used to describe its state, appearance or other aspects.

source: ISO/IEC 24760-1:2011

[8] *https://www.iiconsortium.org/IIRA.htm*

AUTHORS AND LEGAL NOTICE

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