# Joint Technical Report Digital Twin / Asset Administration Shell

Sino-German Intelligent Manufacturing /
*Industrie 4.0* Standardisation Sub-Working Group

IMS 国家智能制造标准化总体组 National Intelligent Manufacturing Standardisation Administration Group

STANDARDIZATION COUNCIL INDUSTRIE 4.0

PLATTFORM INDUSTRIE 4.0

GPQI Dialogues for Innovation and Trade

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Standardization Administration of the P.R.C.

# Partners involved

**SINO-GERMAN STANDARDIZATION COOPERATION COMMISSION**

The central body for standardisation cooperation between Germany and the People's Republic of China is the Sino-German Standardization Cooperation Commission (SGSCC). Under the chairmanship of the German Federal Ministry for Economic Affairs and Climate Action (BMWK) and the Standardization Administration of the People's Republic of China (SAC) as part of the State Administration for Market Regulation (SAMR), experts from standardisation organisations, authorities and companies from both countries work on a variety of topics in the Commission. These include electromobility, Industrie 4.0, medical technology, IT security as well as autonomous and networked driving. Professional exchange within SGSCC is conducted by the German Institute for Standardization (DIN), the German Commission for Electrical, Electronic & Information Technologies of DIN and VDE (DKE) and the Standardization Administration of China (SAC).

**SUB-WORKING GROUP INDUSTRIE4.0/INTELLIGENT MANUFACTURING**

The Industrie 4.0 sub-working group of the SGSCC is the decisive platform for the Sino-German exchange on standardisation for I4.0. Founded in May 2015, it supports the coordination of common positions in international standardisation bodies and the promotion of IEC/ISO standards. Through technical exchange in the sub-working group (SWG), existing standardisation gaps are identified and bilateral cooperation in these areas is promoted. The cooperation of BMWK with SAMR and the Ministry of Industry and Information Technology (MIIT) of the People's Republic of China in the SGSCC is supported by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH within the Global Project Quality Infrastructure (GPQI). On behalf of BMWK, GPQI advises and supports technical policy dialogues and implements agreed technical measures in collaboration with the actors involved.

At the technical level, the work is led by the German Standardization Council Industrie 4.0 (SCI 4.0) and China's National Intelligent Manufacturing Standardization Administration Group (IMSG). In semi-annual meetings, priority topics are agreed for the SWG, which are implemented during the year under the guidance of experts from the two countries.

- The SWG I4.0/IM is currently (2022) addressing the following areas of activity
- Digital Twin/Asset Administration Shell (TEG DTw/AAS)
- Artificial intelligence in industrial applications (TEG AIAI2M)
- IT security (TEG ITSec)
- Functional safety (TEG FuSa)
- Predictive Maintenance and Condition Monitoring (TEG PM/CM)
- Use cases and applications (TEG UCA)
- Network Communications and Testbed (TEG NetCom)

The results developed within the framework of SWG I4.0 to date have been published by BMWK and SCI4.0 in collaboration with SAMR, MIIT and IMSG and can be accessed under the following link

**NATIONAL INTELLIGENT MANUFACTURING STANDARDISATION ADMINISTRATION GROUP**

The National Intelligent Manufacturing Standardisation Administration Group (IMSG) was established to promote and accelerate the progress of intelligent manufacturing in China under the leadership of the Standardisation Administration of China (SAC) and Ministry of Industry and Information Technology (MIIT). It is responsible for carrying out practical work on intelligent manufacturing standardisation, including participation in international standard-setting on intelligent manufacturing as well as organising exchange and cooperation on international standards.

**STANDARDIZATION COUNCIL INDUSTRIE 4.0**

The Standardization Council Industrie 4.0 (SCI 4.0) was founded at the Hannover Messe 2016 as a German standardisation hub by Bitkom, DIN, DKE, VDMA and ZVEI. The initiative aims to initiate standards for digital production and to coordinate these standards nationally and internationally. SCI 4.0 orchestrates implementation of the standardisation strategy of the German Platform Industrie 4.0, which includes coordination with standardisation organisations (SDOs) and international partners as well as interlocking with pilot projects. The aim of this coordinated approach is to ensure that standards exploiting the potential of Industrie 4.0 are developed in a coordinated manner. SCI 4.0 is supported by DKE and the German Federal Ministry for Economic Affairs and Climate Action (BMWK).

**PLATTFORM INDUSTRIE 4.0**

The Plattform Industrie 4.0 is the central network in Germany for advancing the digital transformation in production. More than 350 stakeholders from more than 150 organisations are actively involved in the Plattform, in close cooperation between politics, business, science, trade unions and associations. As one of the largest international and national networks, the Plattform supports German companies in implementing Industrie 4.0, especially by making existing Industrie 4.0 practical examples known to companies and bringing them into the mainstream. In addition, it provides important impetus, with concrete recommendations for action in over 200 specialist publications and refers to support services and test environments. The Plattform's numerous international collaborations underline its strong role in international discussions on the topic of Industrie 4.0.
You can find more information at **www.plattform-i40.de**.

**GLOBAL PROJECT QUALITY INFRASTRUCTURE**

The German Federal Ministry for Economic Affairs and Climate Action (BMWK) established the Global Project Quality Infrastructure (GPQI) to promote the development of well-functioning and internationally coherent quality infrastructures. GPQI supports political and technical dialogue and implements bilaterally agreed activities in collaboration with all relevant stakeholders. The project aims to reduce technical barriers to trade and enhance product safety through bilateral political and technical dialogue on quality infrastructure (QI) with some of Germany's key trading partners.

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# 1. Introduction

## 1.1 Introduction to Intelligent Manufacturing & I4.0/IM objectives in general

### The COVID-19 pandemic has accelerated the digital transformation

The worldwide spread of COVID-19 turned into a shock both to the economy and the labour market, with impact on the supply of goods and services. The resulting demand in consumption and investment posed a challenge to global trade. Now that restrictive measures introduced to control the pandemic have eased, however, and production activities are progressively reopening, adoption of Industrie 4.0 (I4.0) technologies is set to become a factor in the survival of many companies.

During the period of the COVID-19 emergency, I4.0 technologies accelerated the shift towards sustainable manufacturing. For if there is one priority that is crucial to economic recovery, it is to achieve sustainable development, addressing biodiversity loss and climate change, and in so doing promote the principles of the circular economy. Furthermore, consumers are paying increasing attention to the production and consumption of sustainable goods.[1] International standardisation uniformly supports all 17 of the SDGs.[2] The responsibility actively taken up by international standardisation bodies is developed based upon the standardisation in ISO 26000.

The Digital Twin, in general, and Asset Administration Shell in particular for industrial automation, will serve as crucial tools in speeding up efforts to pinpoint stress points and represent scenarios in product creation and operations, with a view to improving the efficiency of asset utilisation and risk assessment, etc. They can also help in managing uncertainty and preserving business continuity. The post-pandemic touchless society will have a significant impact on service levels. Contactless delivery of products and services will be paramount. Digital Twin can help everyone – from manufacturers to healthcare providers – to mitigate the unnecessary risk of contact or draw up contingency plans for disrupted supply chains.[3] As well as providing predictive maintenance, greater transparency and insight into product behaviours, Digital Twin can also be used to create what-if scenarios and enable data-driven decision-making. Businesses will be able to perceive and understand better the impacts and trade-offs and make informed decisions in terms of capacity and inventory in supply chains, etc. As well as supporting immediate business demands, Digital Twin can also help enterprises future-proof their operations and build more resilient contingency plans for the long term.

As with any new emerging technology, enterprises should understand not just the benefits and challenges but also the business needs before employing it. Digital Twin has a wide range of applications because it can model everything from individual components right up to entire processes and product lifecycles. But the challenges in terms of data security need to be considered alongside the necessity for robust, real-time connectivity, specific technical skills and the deployment and maintenance of sensor networks that allow the Digital Twin to capture environmental and operational data.

### Overall CN perspective: The Fourteenth Five-Year Plan and long-term goal for 2035

The Outline of the 14th Five-Year Plan (2021-2025) for National Economic and Social Development and Vision 2035 of the People's Republic of China was published on 12 March 2021. This document includes 19 sections on economic and social development. Specifically, Part V – An Initiative to Build a Digital China – underscores the need to tap the full potential of data and build a digital economy, a digital society and digital governments, using digital methods to drive changes in manufacturing, agriculture, lifestyle and governance. Given these challenges, the long-term goal is scheduled for realisation in 2035. For the manufacturing sector, MIIT published the Smart Manufacturing Fourteenth Five-Year Plan on 28 December 2021, emphasising the need to develop Digital Twin equipment and Digital Twin infrastructure in order to create typical and high-quality Digital Twin scenarios. The view from China is that although IoT, big data, cloud computing and artificial intelligence have infiltrated manufacturing, they still need Digital Twin as an integrated technology and method to achieve higher productivity, lower unit costs, better product quality, faster market responsiveness, less resource consumption, less environmental influence and greater sustainability.

### Overall DE perspective: Germany's holistic approach to shaping global, secure and interoperable digital ecosystems

Smart manufacturing has attracted worldwide attention in recent years. Over the past seven years of Sino-German cooperation, the term Industrie 4.0 has developed from a catchword to a validated and tested approach and today describes a fundamental innovation and transformation process in industrial value creation. Key aspects of this change are new forms of management and work within global, digital ecosystems. This industrial evolution is expected to transform our economies, since innovation and digitalisation call for a paradigm shift in industrial production and products. Consequently, the new road ahead for the manufacturing industry is also to integrate and embrace the digital evolution. Today's rigid, well-defined value chains are being replaced by flexible, highly dynamic and globally networked value networks involving new types of cooperation. Data-driven business models place customer benefits and solution orientation in the foreground and replace product centricity as the predominant paradigm of industrial value creation. Availability, transparency and access to data are central success factors in the networked economy and decisively define competitiveness.

This leads to a significant overlapping of previously separate areas of standardisation. Issues, requirements and working methods that were previously relevant to the information and communication technology sector, for example, now also affect mechanical engineering and the electrical industry to an even greater extent.

So it is now time to think more about Industrie 4.0. What might a global digital value system look like? And how should we identify and implement the right normative framework for a global digital ecosystem?

## 1.2 Objectives of this report

This joint report on Digital Twin/Asset Administration Shell (AAS) is one of the bilateral harmonisation outcomes of the sub-working group (SWG) on Industrie 4.0/Intelligent Manufacturing. The SWG acts under the programme of the Sino-German Standardization Cooperation Commission (SGSCC). The report is compatible with former publications in the Sino-German programme, such as the Alignment Report for Reference Architectural Models etc.

One of the main goals of this report is to expound the basic concepts and requirements regarding joint standardisation of Digital Twin and Asset Administration Shell. The outcomes of the joint report are mutually shared by working group participants, as well as in international standardisation organisations, primarily in IEC and ISO. It gives an overview of the various collaboration and standardisation activities related to this topic, in particular providing information on the status of work and potential mutual approaches in the two countries. The document will also present exemplary use cases that are important in these fields. It is important to take into consideration in this technical context the identification of core national and international stakeholders and technologies. This is a key factor to be understood in the whole process, as it helps to foster similarities between the mutual approaches of both countries.
Last but not least, the joint report sets out to develop and support a perspective on asset-oriented Digital Twin distributed in larger infrastructures and then to formulate an alignment with digital

models, for which industrial domains and life-cycle phases will be part of Digital Twin handled by large infrastructure.

In this research report, China and Germany have identified the similarities and differences in the definition, use cases and implementation of Digital Twin and Asset Administration Shell, gained some common understandings and jointly participated in the formation of ISO and IEC-related standardisation teams. Since China and Germany have similar standardisation organisation structures and standards research paths, the two countries will promote ISO/IEC international standardisation work, develop standards and then promote test-bed projects from the perspectives of semantics, communication interfaces and model construction, etc.

## 1.3 Definitions

As an introduction to the topics, we provide a brief overview of other definitions relating to Digital Twin and Asset Administration Shell. For this reason, we choose to focus on the definitions given by relevant standardisation bodies, academia and industry. More detailed information and an overview on the scope of the committees set out below is provided in Annex 2 to this document.

**Definition of Digital Twin from standardisation bodies**

| | |
|---|---|
| **ISO [TC184]**[4] | A Digital Twin is a fit-for-purpose digital representation of an observable manufacturing element with synchronisation between the element and its digital representation. |
| **IEC [TC65/WG24]** | The conception of the Asset Administration Shell (AAS) is seen as one interoperable manifestation of a Digital Twin in manufacturing that facilitates tighter integration within and across the three dimensions of smart manufacturing ecosystems. For smart manufacturing ecosystems, a digital representation of the manufacturing environment including produced products is required. |
| **ISO/IEC JTC 1 [SC41/AG27]** | A Digital Twin is a model (1) that mirrors a unique physical object, process, organisation, person or other abstraction. A Digital Twin is a digital representation of a particular physical entity or a process with data connections that enable convergence between the physical and digital states at an appropriate rate of synchronisation and provides an integrated view throughout the lifecycle of the physical entity or the process that helps optimise the overall performance. |
| **ISO/IEC JTC 1 [SC41/WG 6]**[5] | A Digital Twin is a digital representation of a target entity with data connections that enable convergence between the physical and digital states at an appropriate rate of synchronisation’<br><br>Note 1 to entry: Digital Twin has some or all of the capabilities of connection, integration, analysis, simulation, visualisation, optimisation, etc.<br><br>Note 2 to entry: Digital Twin may provide an integrated view throughout the lifecycle of the target entity. |

**Digital Twin defined in academia**

A Digital Twin is a virtual representation of real-world entities and processes, synchronised at a specified frequency and fidelity.

- Digital Twin systems transform business by accelerating holistic understanding, optimal decision-making and effective action.
- Digital Twin use real-time and historical data to represent the past and present and simulate predicted futures.

Digital Twin is motivated by outcomes, tailored to use cases, powered by integration, built on data, guided by domain knowledge and implemented in IT/OT systems.[6]

**Digital Twin defined in industry**

A Digital Twin is a virtual representation of real-world entities and processes, synchronised at a specified frequency and fidelity

- Digital Twin systems transform business by accelerating holistic understanding, optimal decision-making, and effective action.
- Digital Twins use real-time and historical data to represent the past and present and simulate predicted futures.
- Digital Twins are motivated by outcomes, tailored to use cases, powered by integration, built on data, guided by domain knowledge and implemented in IT/OT systems.[7]

## 1.4 Concepts of Digital Twin systems in manufacturing sectors

For smart manufacturing, the concept of a Digital Twin system (Figure 6) is of high relevance. However, there are a variety of different definitions for Digital Twin systems discussed, e.g., a Digital Twin to be 'the digital representation of a cyber-physical entity, including all necessary attributes and behaviours, sufficient to meet the requirements of a set of use cases'. Many different standardisation organisations started to work on the concept of Digital Twin, which has resulted in different definitions of the Digital Twin in standards as shown in section 1.3.

The concept of the Asset Administration Shell (AAS) can be seen as one manifestation of a Digital Twin system from manufacturing that facilitates tighter integration within and across the three dimensions of smart manufacturing ecosystems, e.g., as modelled in the RAMI4.0.

Because of different existing views on Digital Twin concepts, there is a rising concern for the harmonisation of these concepts coming from various domains. These concerns are about different developments that will not fit with each other, or interoperability that will not be awkward, or designed and thus expected synergies and efficiencies that will not take place. Annex 2 contains a list of the relevant coordination committees which aim to achieve effective liaison between each other (see Chapter 4).

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# 2. Use cases and application scenarios: bolstering standardisation in the field of Digital Twin and Asset Administration Shell

## 2.1 Basic reflections

There is now a growing international consensus that new standardisation activities are particularly useful if the underlying driving use cases are formulated and clearly understood. In this respect, an internationally uniform understanding of use cases in the context of Industrie 4.0 is a central starting point for standardisation work. Use cases are an instrument here to build a bridge between the driving challenges facing the manufacturing industry and the corresponding possible technical solutions. Use cases then also offer the possibility of deriving new requirements for standardisation.[8]

The core of this recommendation is a proposal to basically distinguish between three different categories of use cases:

- business scenarios, where value-added relationships between companies and their business models are described from a business perspective;
- use cases, where a technical system is described in its application context, namely how actors outside the technical system interact with it and with each other;

### Use case approaches within IEC

IEC has undertaken significant work on use cases. The rationale for creating a community of use cases at standardisation level has been discussed in IEC System Committee Smart Manufacturing (IEC SyC SM) WG1 and in particular by IEC TC65/WG 23 by driving activities towards IEC TR 63283-2 Industrial-process measurement, control and automation – Smart Manufacturing – Part 2: Use cases

The identification of needs driven by the harmonisation efforts regarding use cases and application scenarios is also indispensable for the scope discussions on Digital Twin and AAS. This picture has also been actively driven and implemented within the Sino-German Sub-working Group I4.0/IM, particularly within the work of the Technical Expert Group Use Cases and Application Scenarios.[9]

### Use case approaches within ISO/IEC/JTC 1

ISO/IEC JTC 1/SC 41 has also undertaken important work on use cases in the field of Digital Twin. These activities were undertaken in JTC/SC41/WG6. ISO/IEC TR 30172 Digital Twin – Use cases will provide a collection of representative use cases of Digital Twin applications in a variety of domains. The Digital Twin use case template was designed to collect use cases efficiently and is based on comparison between use case templates provided in IEC 62559-2, ISO/IEC TR 22417, JTC 1/ AG 8 and SC 41/AG 25. In addition, by reference to PWI on Guidelines for IoT and Digital Twin Use cases by JTC1/SC41 would define interactions between external actors and the system to attain particular goals. Three basic elements make up a use case: actors – users that interact with the system; system – use cases capture functional requirements specifying the intended behaviour of the system; goals – use cases initiated by the user to fulfil goals describing activities and variants involved in attaining goals.

## 2.2 Use cases of design and operational phases

### 2.2.1 Reference examples of use cases in design phases

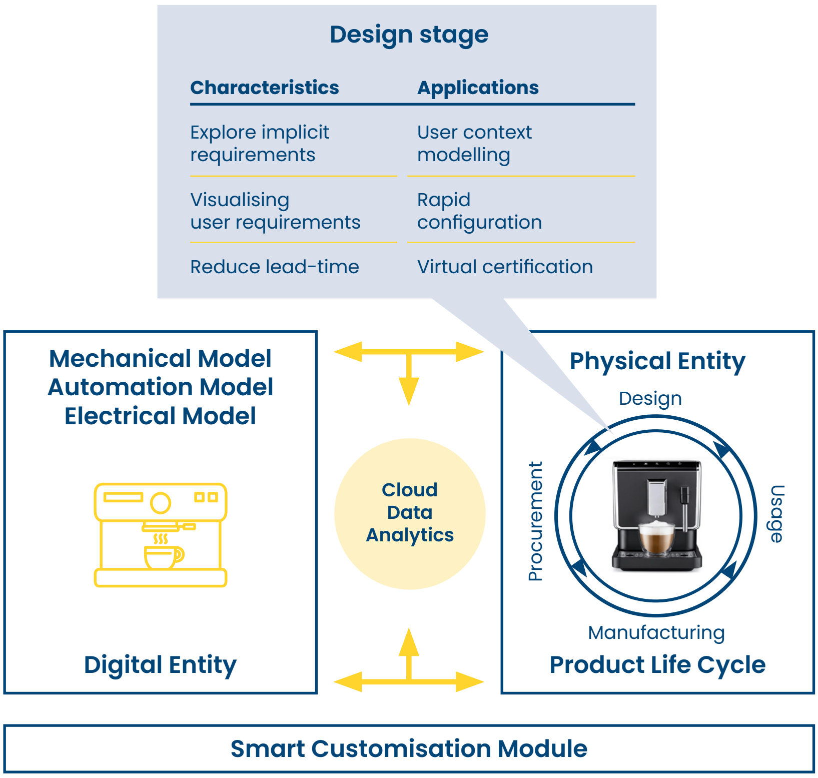
#### New paradigm of smart customisation through Digital Twin

The mainstream of customisation is to adapt the product to customers' new needs by predicting customer requirements, enhancing customer participation and offering interactive services. However, the previous customisation frameworks are unable to achieve this goal since they deal only with data concerning the physical world. Without any data fusion, modelling and simulation technologies, manufacturers' understanding of these data tend to be very superficial and fragmented.

As an integration technology, the Digital Twin firstly expands data sources into the virtual space, which significantly enhances customisation capabilities in terms of quality and reliability. Secondly, the Digital Twin allows customers to better participate in the customisation process, especially in the virtual environment. Finally, services offered by the Digital Twin will become more personalised.

In the product design stage (the most important stage), data generated from the Digital Twin facilitate the holistic exploration of customer needs and hence increase configuration effectiveness and reduce customer dissatisfaction in advance. The Digital Twin uploads product data in the virtual space to simulate expected scenarios, through which designers can quickly identify implicit demands and resolve potential risks in advance. Rapid configuration recommends and optimises configurations according to customer requirements, module functionality, resource availability, etc. Virtual verification enables designers to test product functionality and resolve potential product defects at an early stage, thereby significantly reducing lead time.

**Figure 1:** Data-driven smart customisation framework



### Siemens' multidisciplinary design

Siemens has designed a multidisciplinary collaborative design and development platform for complex mechanical products driven by Digital Twin. In the conceptual design stage of the product, the primary conceptual model, function model and behaviour rule model of the product are established. Based on the results of the conceptual design, the process of mechanical design, electrical design and automation design will be advanced simultaneously. The information integration and data interaction of multiple platforms are realised through the interface provided by the database platform. Then, by simulating the equipment model of the integrated electrical and automation components, the design results are quickly verified and timely feedback is provided to continuously improve and optimise the Digital Twin model of the equipment.

### Boeing: design and manufacturing collaboration

Boeing used the digital bus based on the product model data interaction specification proposed by NIST to improve existing virtual prototypes, build a manufacturing-oriented Digital Twin design model, and initially realise the collaboration between design and manufacturing.

The digital bus based on the STEP standard starts at the design stage. In the design process, product designers must consider not only the geometric information of the product, such as tolerances, machining steps, tooling requirements, walking paths, measurement requirements, etc., but also information on product manufacturing from the technologists' point of view. A design model is then created, based on information from the PMI and STEP standards. It is then transferred to the manufacturing phase via the digital bus. When using a CNC machine tool to process parts or use a measuring instrument to detect dimensions, the corresponding PMI real data updates the design model in real time through the digital bus and obtains the Digital Twin of the current part processing and inspection.

## 2.2.2 Reference examples of use cases in the operational phase

### Digital Twins in engineering

In manufacturing, multiple value chains need to be synchronised to meet the demands of current markets. Product life cycles are becoming shorter, production processes more demanding. New technologies and materials are to be introduced. Manufacturing equipment needs to follow these requirements, needs to integrate components from a multitude of suppliers and new engineering skills need to be introduced. Using Digital Twins of both product design and manufacturing components, engineering can be sped up and quality can be increased by virtual commissioning and simulation techniques. A systematic approach will allow all engineering disciplines to work on integrated model structures. Interoperable data formats will allow the inclusion of new partners, such as experts and engineering service providers. Interoperability in production processes can leverage platform-based manufacturing approaches, allowing scaling of production and fostering adoption to ever-changing market requirements.

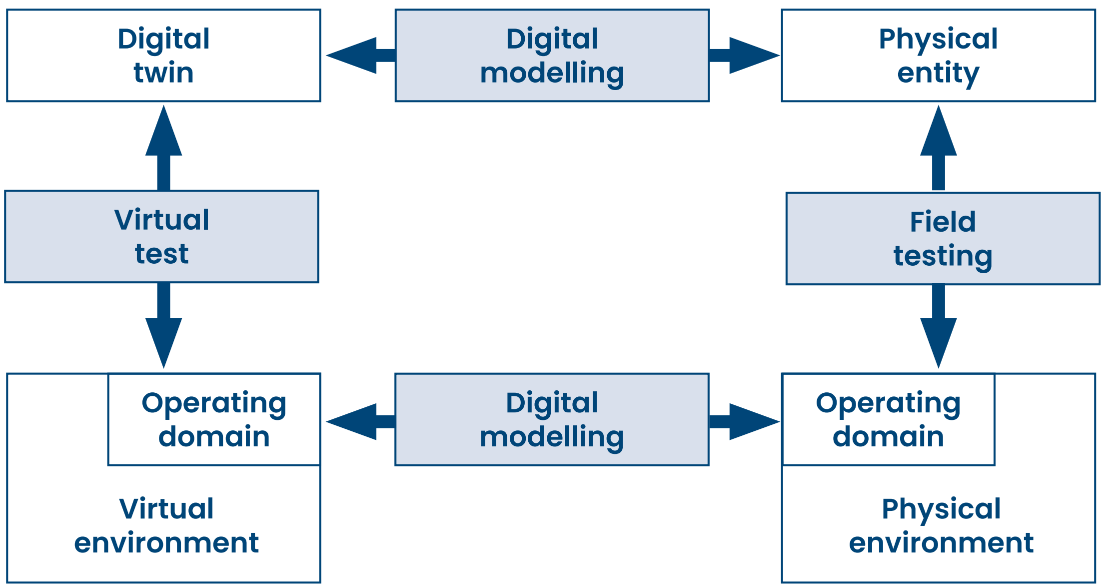
### Collaborative Condition Monitoring

The use case Collaborative Condition Monitoring (CCM)[10] addresses multilateral cooperation between component manufacturers, machine builders/system integrators and factory operators. It was introduced by Platform Industrie 4.0 as a manufacturing industry use case to GAIA-X, the European federated data infrastructure project. Today, only bilateral cooperation between machine builders and automation component manufacturers on the one hand, and between factory operators and machine builders on the other, is common practice. This leaves large potential for data-driven business models unlevered. This is valid especially for condition monitoring, where all three players would be able to benefit from sharing data across multiple company boundaries. Motivating many – sometimes competing – companies to cooperate raises several questions regarding infrastructure, semantics, security, business and legal issues. The multilateral CCM use case was established to address these questions. Trust between partners and digital sovereignty regarding each company's own data are key for CCM as well as GAIA-X. Therefore, the CCM use case was established as one of the main manufacturing industry use cases for GAIA-X, a European initiative that also addresses other industries.

An engineered physical entity may be modelled for the purpose of optimising its design, testing its functionalities and assessing its conformity through simulation prior to field testing. The digital representation or Digital Twin of the physical entity may then need a digital model of the physical environment in which the physical entity may operate.

If virtual testing is planned in the process, using both the Digital Twin of the physical entity and the virtual operating domain or digital representation of the operating domain in which the physical entity will operate within the physical environment, conformity assessment testing activities will then rely on a combination of field testing and virtual testing.

**Figure 2:** Flow chart of conformity assessment by Digital Twin



# 3. Important stakeholders and technologies relating to Digital Twin

## 3.1 Important stakeholders

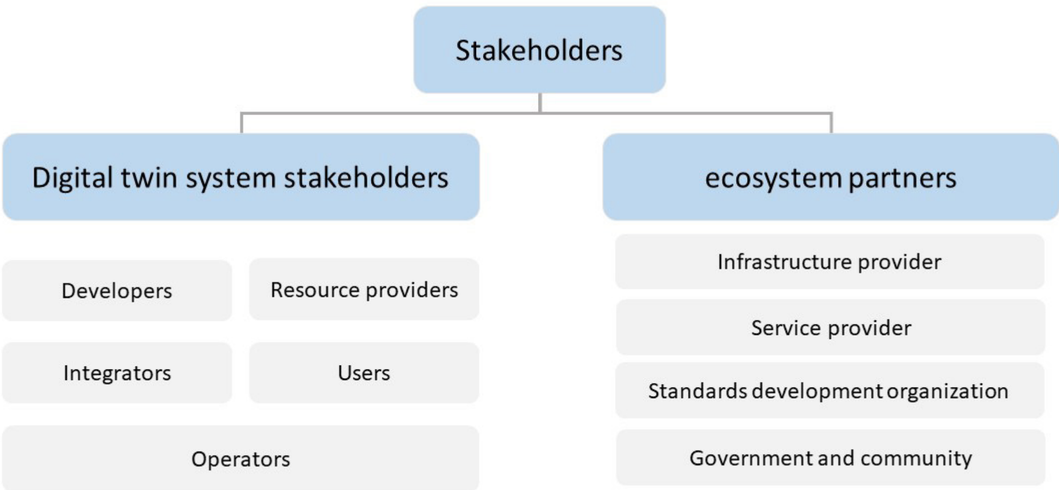
Figure 3 shows the composition of Digital Twin stakeholders, including Digital Twin system stakeholders (developers, resource providers, integrators, users, operators) and ecosystem stakeholders (infrastructure provider, service provider, standards development organisation, government and community). A detailed description can be found in ISO/IEC CD 30173 Digital Twin – Concepts and Terminology.

### Standards development organisations

These are ecosystem stakeholders that concern and provide general rules and technical specifications for connection/interaction of Digital Twin systems elements as well as for the co-existence of Digital Twin eco-partners. As the ecosystem surrounding Digital Twin is complex and steadily growing, many activities, including interdisciplinary approaches, have been realised among national and international standardisation bodies. A specific overview of the Digital Twin standardisation environment can be found in Annex 2.

However, a significant number of activities involving consortia and organisations are also developing concepts, as the shared characteristics of these digital manufacturing approaches will include standards and interoperability, artificial intelligence, Internet of Things (IoT) connectivity, openness, scalability, plug & play mechanisms and security, which all demand a seamless and easy integration of different solutions. The challenge for consortia is to harmonise their requirements with those defined in the international standards of ISO and IEC.

**Figure 3:** Composition of Digital Twin stakeholders, including Digital Twin system stakeholders (developers, resource providers, integrators, users, operators) and ecosystem stakeholders (infrastructure provider, service provider, standards development organisation, government and community). A detailed description can be found in ISO/IEC CD 30173 Digital Twin – Concepts and Terminology.



#### Government and community

In line with the description in Figure 3, ecosystem stakeholders are required to provide governance of the Digital Twin ecosystem in lawful, consensual and social perspectives.

The regulatory process needs to reflect the new challenges and possibilities offered by Digital Twin technologies and actively participate in the formulation of international standards to improve consistency between Chinese standards and international standards. It must enhance dialogue and standard-setting coordination with China to provide a level playing field for companies in both countries and deepen cooperation in information and communications, the digital economy and renewable energy.

## 3.2 Key technologies

### 3.2.1 Identification

#### International Registration Data Identifier (IRDI)

These identifiers are used to ensure the semantic reference to an element which is unique in the overall system. The IRDI is based on the international standards ISO/IEC 11179-6, ISO 29002, and ISO 6532. Every institution registered by the registration authority has a unique ICD (International Code Designator) identifier.

#### Generic Trust Anchor Application Programming Interface for Industrial IoT Devices as per ISO/IEC TS 30168 standards development

This specification describes a generic programming interface for the integration of secure elements within industrial IoT devices. This includes requirements from industrial usage scenarios and applications. This document also provides guidance for implementation, testing and conformity validation. Publication is expected by the end of 2023.

#### Identification Link – unambiguous biunique machine-readable identification

IEC 61406 specifies minimum requirements for a globally unique identification of physical objects that also constitutes a link to its related digital information. This identification is designated hereinafter as the 'Identification Link' (IL), with the encoded data designated as IL string. The IL string has the data-format of a link (URL/URI). The IL is machine-readable and is attached to the physical object in a 2D symbol or NFC tag.

#### Digital nameplate – digital product marking

IEC 63365 applies to products used in the process measurement, control and automation industry. It establishes a concept and requirements for the digital nameplate and provides alternative electronically readable solutions (e.g. 2D codes, RFID or firmware) to current conventio-

**Figure 4:** Digital Twin key technologies

**Digital Twin key technologies**

| Identification | Connection | Calculation | Cooperation |
|---|---|---|---|
| IRDI | 5G and beyond | AI | Extended reality technologies |
| Generic Trust Anchor | IoT | Knowledge graph | Semantic properties /ECLASS/ CDD |
| Identification Link | | Deep learning | |
| Digital nameplate | | | |
| Dependability | | | |

nal plain text marking on the nameplate or packaging of products. Digital nameplate information is contained in the electronically readable medium affixed to the product, the packaging or accompanying documents.

This standard does not specify the contents of either the conventional nameplate or the digital nameplate, which are subject to regional or national regulations and standards.

This document does not specify requirements for the Identification Link string (globally unique, machine-readable identifier), which is covered by IEC 61406 Identification Link – unambiguous biunique machine-readable identification.

**Dependability**

Dependability management is coordinated via IEC/TC 56 and partly for devices and systems via IEC/TC 65 and describes the ability to perform as and when required and is time-dependent in application. Dependability can be expressed in terms of the core attributes of availability, reliability, maintainability and supportability that are tailored to application-specific functional and service attributes. IEC/TC 65 standards are related to products, processes and management activities. The standards provide systematic methods and tools for dependability assessment, technical risk assessment and management of services and systems throughout their life cycles.

Further definitions of terms relating to dependability are described in IEC 60050-192 and can also be found online.

- IEC TS 63164-1 Reliability of Industrial Automation Devices and Systems – Part 1: Assurance of automation devices reliability data and specification of their source.
- IEC TR 63164-2 Reliability of Industrial Automation Devices and Systems – Part 2: System reliability.

### 3.2.2 Identification of Information

**AutoID/RFID**

DIN NIA 043-01-31 WG4: Automatic identification of physical objects and information on physical objects in IT systems, particularly IoT systems – DIN SPEC 91406 DIN NIA 043-01-31 WG1 OCR: N4316_DIN_66277_OCR & RFID combined for Identification Preamble. This standard was developed by working group NA 043-01-31-04. DIN 66277 defines how to enhance a type of label with an RFID transponder and, if applicable, a 2D symbol, and how to structure the data. A type of label serves for the marking, identification and description of all kinds of operating equipment. The electronic label supplements or replaces the type of labels used up to now, on which the names of the operating equipment and its technical data are printed. RFID is an acronym for 'radio-frequency identification' and refers to a technology whereby digital data encoded in RFID tags or smart labels (defined below) are captured by a reader via radio waves. RFID is like barcoding, in that data from a tag or label are captured by a device that stores the data in a database. RFID, however, has several advantages over systems that use barcode asset tracking software. The most notable is that RFID tag data can be read outside the line-of-sight, whereas barcodes must be aligned with an optical scanner.

It should avoid unnecessary manual interaction/activity between assets with regard to identification and should ideally be implemented using one of the following means: 'Optical' – OCR (Optical Pattern/Character Recognition), 1D-Barcodes i.e. Code 25 Interleave, EAN8/13, CODABAR – or in case of enhanced information – 2D-Codes i.e. DataMatrix, PDF-417, QR Code, sometimes also called 3D/Colour as in the following new standard: ISO/IEC 23634:2022 JAB Code polychrome bar code symbology specification. This new polychrome symbology has a higher density than the established monochrome 2D-codes, such as QR Codes. JAB Codes are in addition more flexible in shape and do not require quiet zones.

Alternatively, 'wireless' is another option for the technical implementation of automatic identification, performed by RFID Radio Frequency Identification. This can be applied in different standards and frequency ranges depending on the surrounding environment and possible attachment using transponders (surface, inside, water/metal), typical ranges from centimetres (NFC near-field communication, frequency 13.56 MHz) to metre distance (UHF 868/912 MHz). In addition to these passive systems, there could also be 'active' communication at 2.4Ghz in the cm to metre range by so called 'tags' used for automatic identification.

In addition to this, common to both may be the application of interoperability/accessibility on automatic identification through: ISO/IEC 20248:2018 Data structures — Digital signature meta structure. This standard provides an open and interoperable method between automated identification services and data carriers, to read data, verify data originality and data integrity in online and offline use cases. (A new version with some clarifications is close to being published.)

### 3.2.3 Connectivity

**5G and beyond**

5G has higher-speed, larger connections and low-latency application support capabilities compared to previous standards. Based on the capabilities of 5G, on the one hand, it can effectively empower; on the other hand, it can support the real-time closed-loop distribution of decision-making control instructions of the digital platform. It can be said that 5G makes it possible to collect rich physical world data, as well as to make real-time interaction between the physical world and the digital world possible. 5G provides networking implementation for Digital Twins and is the basic process technology for Digital Twin construction.

**IoT**

The Internet of Things is the connection and data foundation of the Digital Twin, and the key enabling technology of Digital Twin systems (see Figure 6). The Internet of Things can help to realise the online representation of physical devices, support the real-time collection and monitoring of physical device data, and support the 'closed-loop' control of the virtual world to the physical world.

### 3.2.4 Calculation & analytics

**AI**

Artificial intelligence is very important for parameter setting and strategy optimisation of the Digital Twin model. Artificial intelligence can analyse historical business data and obtain some Digital Twin model business parameters that are not easy to obtain through direct sampling. In addition, AI-related technologies can help businesses obtain knowledge accumulation and decision-making control optimisation through Digital Twins and create value for business operations.

**Knowledge graph**

By establishing the relationship between test results and defects, knowledge graph technology builds mapping to trace and locate the source and improve the quality inspection efficiency of digital equipment in product planning, R&D and design, production and manufacturing, customer service, equipment maintenance, supply chains and other life cycles.

It should be noted that there is an important difference between the knowledge graph and the process type graph (see also 4.3.4). A knowledge graph typically describes a static structure and dependencies among elements of a data type. A process type graph, however, describes the dynamics of a real-world system that is dependent on respectively taking interactions with its environment. Since dynamic systems are represented by a set of interacting variables (so-called continuous or differential variables) type graphs comprise data representing the state of the system. Thus, a graphically represented system can operationally be simulated to the past to reason about a critical state, and to the future to understand better subsequent decisions to be taken in the real-world entity to avoid damage or other malfunctioning.

**Deep learning**

Deep learning is to learn the inherent laws and representation levels of sample data. The goal is to enable machines to have the ability to analyse and learn like humans, and to recognise data such as text, images and sounds. In an ideal state, on the one hand, Digital Twin technology needs to process the feedback data through machine learning and software analysis. On the other hand, deep learning needs to rely on sufficient data sources and real scenarios. Digital Twins can provide deep and broad data sources for deep learning.

### 3.2.5 Digital Twin cooperation

#### Extended reality technologies

Extended reality technologies include augmented reality (AR), virtual reality (VR), mixed reality (MR) and holography. Among them, AR can superimpose virtual screens on real scenes to enhance reality cognition; VR can provide an immersive experience in the virtual world; MR can superimpose virtual screens on digital reality screens, supporting more immersive virtual and real superimposition effects; and holographic light reconstruction technology can construct three-dimensional images. Extended display technology can provide effective support for Digital Twin displays and provide accurate and visual decision support through the three-dimensional immersive picture. It must be noted that a support tool for Digital Twin displays must be distinguished from a semantics manipulation and derivation tool of a platform, because the latter approach is based on a formal calculus such as FO Logic or some other algebraic approach, where the former is based on symbolic graphical representations and mappings of data, functions and processes onto a graphical display. Hence graphical representation is not covered by graph theory and a graph theoretical platform usually comprises a graph manipulation simulator and a graphical display to represent the results of simulation.

#### Semantic properties / ECLASS / IEC Common Data Dictionary (IEC CDD)

The scope and level of detail of the characteristic determine how exactly an asset is described. The term 'property' has become established for characteristics with a standardised description. With the specification of the administration shell there is a specification that consistently focuses on the use of properties for information modelling. For the description of products, means of production, components and individual parts as a basis for the implementation of Industrie 4.0, production units must be enabled to transmit standardised properties combined with standardised transmission formats. This makes it possible for receiving systems to understand the data correctly and use it in subsequent processes such as purchase orders, production orders and maintenance notes. This concept is also referred to as 'semantic interoperability'. Considering a property in detail, it also has characteristics, such as a data type and a default value. To distinguish between the property of an asset and the characteristic(s) of that property, the latter is referred to as an attribute. Properties and their attributes form the basis of integration and interoperability. Each individual property is named and compiled with its attributes as data. These properties are used in various engineering phases in corresponding system models.

In the future, properties will be used throughout the entire life cycle. This results in an extension of the device and component classes, which are described by means of standardised characteristics and properties in ECLASS and IEC CDD. There are also device classes, e.g. drives and pumps, which provide OPC UA Companion Standards with properties.

The Common Data Dictionary (CDD) is an international standard, Part 4 in the IEC 61360 series. Parts 1 to 3 contain methods, methodology and the underlying information model for the creation of a CDD. The CDD serves as a common repository (CR) and contains completed templates for the industrial sector, which are company-specific and describe data catalogues, DBs or master data. A CDD thus contains descriptions that are consistent with the requirements of data integrity, system engineering, corporate product and service portfolios. To make entries in a CDD, the following recommendations should be considered: use unique identifiers for classes, properties, and relationships; use only widely used terminology from current standards, hierarchies and concepts to describe products and services from the user's point of view; use only relevant conditions and restrictions to characterise products and services; and choose technical representations to clearly describe units, data types or identifiers for their identification.

# 4. Mutual approaches

## 4.1 Approaches of Asset Administration Shell

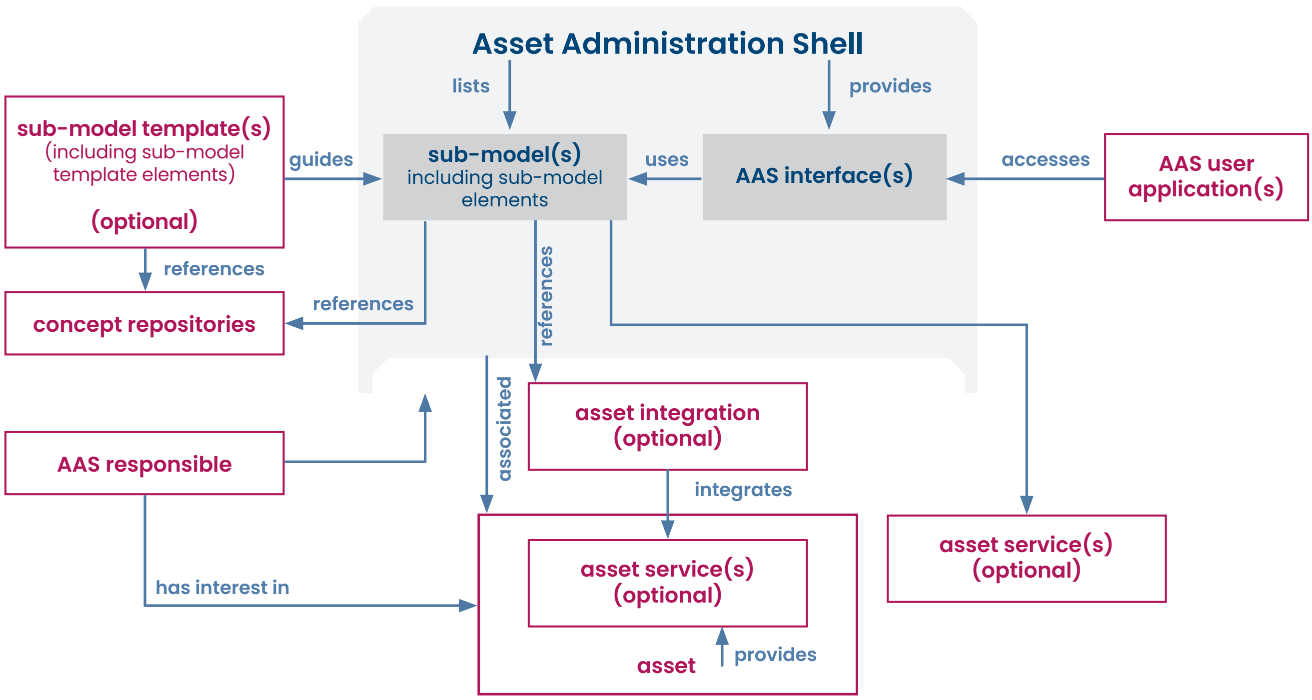
### 4.1.1 General

The overall conceptualisation of the Asset Administration Shell is well described in IEC 63278-1. This first part will describe the general structure requirements with which each possible Asset Administration Shell must comply. In the second part (IEC 63278-2) of the series, this will be developed further towards a meta model of the Asset Administration Shell. Individual Asset Administration Shells can be created based on these specifications. These Asset Administration Shells will be the actual containers of information and, in line with the concept of asset orientation, will provide information and services with respect to the described asset. The information contained inside an individual Asset Administration Shell may be arranged in different ways. In order to provide interoperability, this contained information needs to be associated with well-known concepts that are shared between different stakeholders of Asset Administration Shells. These concepts can be seen as elements in ontologies which describe a certain domain of knowledge. Some of the requirements in this first part of the series will ensure that existing ontologies, dictionaries and repositories could be used to specify the Asset Administration Shell structure[12] with regard to semantics interoperable information though use of the AAS (Asset Administration Shells). An AAS interface provides access to information and services of and related to an asset.

### 4.1.2 Conceptual framework of the AAS

The conceptual framework of the AAS is illustrated in Figure 5. The figure shows the AAS parts in grey

**Figure 5:** Administration Shell components and relationships



and the related roles in purple. The grey colouring illustrates the scope of the IEC 63278 series.

The normative definition of these entities and associated roles are given in IEC 63278-1. The following is a short summary of these concepts and elements:

### An Asset Administration Shell is associated with an asset

An asset is an entity which has a value for an individual or an organisation. An asset is represented by an AAS. The AAS responsible determines what an asset is, IEC 63278-1 does not make any specifications. An asset has a unique identifier. There can be various kinds of relationships between different assets and consequently represented by an AAS.

### There are one or more sub-models listed in an AAS

A sub-model listed in an AAS represents information and describes services. It therefore represents a specific aspect of an asset. The AAS enables the execution of services described by a sub-model via the AAS interface and the AAS accesses asset-related services and uses asset integration to access asset services. A sub-model can use a sub-model template to guide its creation. A sub-model has a unique identifier. Sub-models comprise sub-model elements with different purposes, including structure, information, relationships and services. Sub-model template elements and sub-model elements can refer to concept repositories for entries of standardised semantics.

### Concept repositories

Concept repositories serve to define common accepted vocabularies and their relationships. Such a common vocabulary is the basis for enabling two or more software applications to exchange information and mutually use the information and services provided.

### An Asset Administration Shell provides AAS interface(s)

The purpose of the AAS interface is to enable an AAS user application to access information and services of the asset or related to the asset. An AAS can have several AAS interfaces. It is possible to allow several AAS user applications to access information from the same Asset Administration Shell via its AAS interface(s). The set of information that can be accessed may differ for different AAS user applications.

### An AAS user application is a software application which accesses an AAS via its AAS interface(s) for use by humans or for automated processing

The purpose of the Asset Administration Shell is to enable two or more systems or software applications to exchange information. Many different software applications in factories and plants are expected to be AAS user applications. An AAS user application may also be an AAS accessing another AAS via its AAS interface(s). The development or execution of an AAS user application can be guided by a sub-model template.

### Asset service and asset-related services

The AAS logically references services provided by the associated asset and further related services. By this means, these services can consistently be accessed by AAS user application, while being under the governance of the AAS responsible.

## 4.1.3 General structure for an Asset Administration Shell

Furthermore, in IEC 63278-1 the general structure for an Asset Administration Shell is defined by stating requirements, recommendations and permissions. If a particular implementation of the Asset Administration Shell fulfils these provisions, coverage of the conceptual framework as above is given and interoperability is achieved.

## 4.1.4 Key objectives

The Asset Administration Shell aims at the following key objectives (as stated in the non-normative introduction of IEC 63278-1):

- Asset Administration Shell aims at establishing cross-company interoperability;
- Asset Administration Shell is intended for non-intelligent and intelligent products;

- Asset Administration Shell aims at covering the complete life cycle of products, devices, machines and facilities;

- Asset Administration Shell aims at enabling integrated value chains;

- Asset Administration Shell is intended to be a base for autonomous systems and artificial intelligence.

### 4.1.5 Further parts

Further parts of the AAS are currently proposed as New Work Item Proposals to the IEC. These parts are:

- IEC 63278-2: Information meta model

  By specifying such meta models, a syntactic interoperability and exchange of standardised information will be achieved.

- IEC 63278-3: Security provisions for Asset Administration Shells

  The purpose of this document is to add the security viewpoint to the IEC 63278 AAS series, including recommendations and requirements. This project is an essential element in achieving secure semantic interoperability for smart manufacturing applications.

The working plan also foresees parts covering the following sections:

- online interfaces to Asset Administration Shells;

- communication language among sets of Asset Administration Shells;

- specification of content of Asset Administration Shells for various domains e.g. digital nameplate IEC 63365 ED1 with IEC Common Data Dictionaries defined in https://cdd.iec.ch/

## 4.2 Approaches of Digital Twin

### 4.2.1 General

With the advance of technologies such as the Internet of Things and artificial intelligence, Digital Twin has been widely explored and applied in the fields of smart manufacturing, smart cities, smart buildings, smart medical care, smart energy and so on. The value of Digital Twin can be seen in several ways, from virtual testing and validation to speed up risk assessment, predictive maintenance to improve efficiency, real-time remote monitoring to reduce costs, etc. The overall concept, terminology, reference architecture and use cases of Digital Twin are studied in ISO/IEC JTC1/SC41/WG6 in separate standardisation projects, as follows:

- ISO/IEC DTR 30172 ED1: Digital Twin use cases;

- ISO/IEC CD 30173 ED1: Digital Twin concepts and terminology;

- ISO/IEC PWI JTC1-SC41-5: Digital Twin reference architecture;

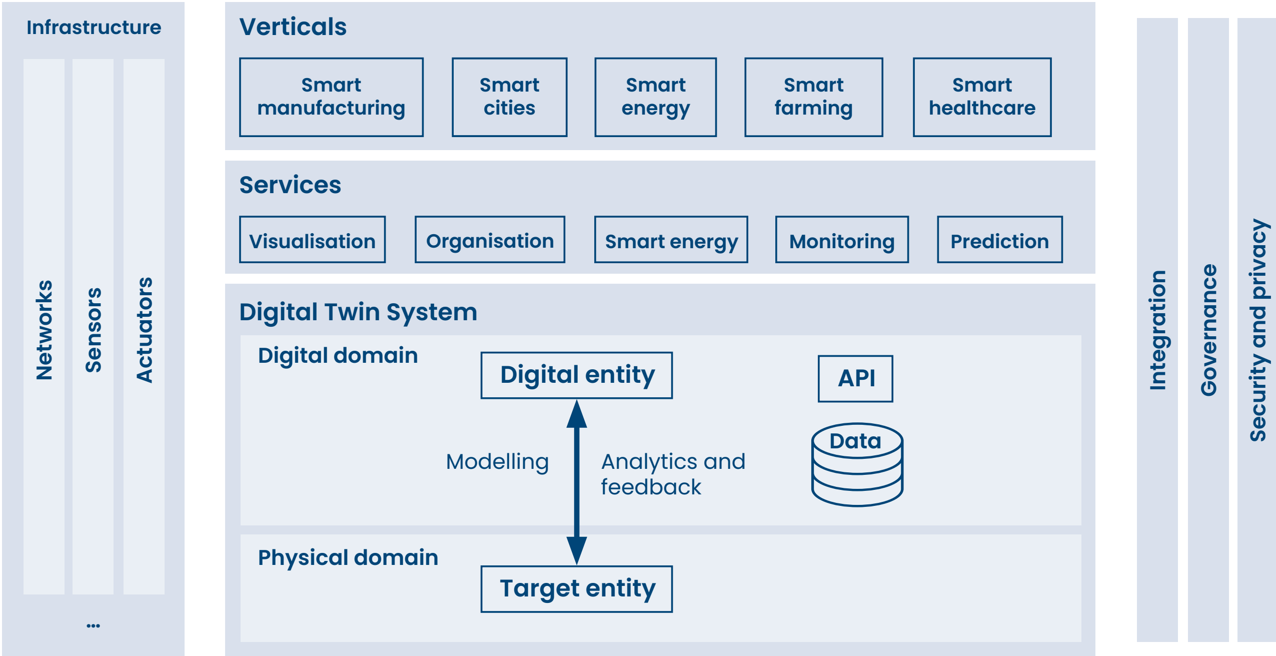
- ISO/IEC PWI JTC1-SC41-7: Digital Twin maturity model.

### 4.2.2 Ecosystem of Digital Twin

The ecosystem of Digital Twin includes five parts: Digital Twin system, infrastructure, services, verticals and integration, as shown in Figure 6.

The Digital Twin system is the core of the Digital Twin ecosystem. It consists of two portions, a digital domain and a physical domain. These two portions interact through a digital entity and a target entity. The target entity provides raw data for the modelling and operation of the digital entity. The digital entity analyses the data provided by the target entity and provides feedback to the target entity to improve performance of the target entity. The operation of a Digital Twin system requires support from infrastructure, including sensors, actuators and networks, etc. Infrastructure is an integral part of the Digital Twin ecosystem.

**Figure 5:** Ecosystem of Digital Twin




Digital Twin can provide visualisation, optimisation, simulation, monitoring, prediction and other services for stakeholders in the ecosystem. Digital Twin is used in multiple verticals, including smart manufacturing, smart cities, smart energy, smart farming, smart healthcare, etc. The normal operation of the Digital Twin system also needs to consider integration with other elements in the ecosystem, governance during operation, security and privacy, etc.

### 4.2.3 Framework of a Digital Twin

The framework of a Digital Twin is shown in Figure 7 (p 25). The basic support layer is the terminal of the Digital Twin and the Internet of Things, mainly including target physical entities, sensors, etc., which are used for data collection and transmission to the network.

- The data interaction layer provides support for the software tools and platforms required for modelling and simulation.
- The model sub-layer needs to provide data acquisition and build digital models. The content of modelling includes geometric modelling, meshing, system modelling, process modelling, organisation modelling, etc.
- The simulation sub-layer needs to integrate physical laws and mechanisms into digital models. It is not only to establish a digital model of physical objects, but also to calculate, analyse and predict the future state of physical objects through physical laws and mechanisms according to the current state.
- The function layer includes the main functions that Digital Twin may give based on the modelling and simulation and Digital Twin data.

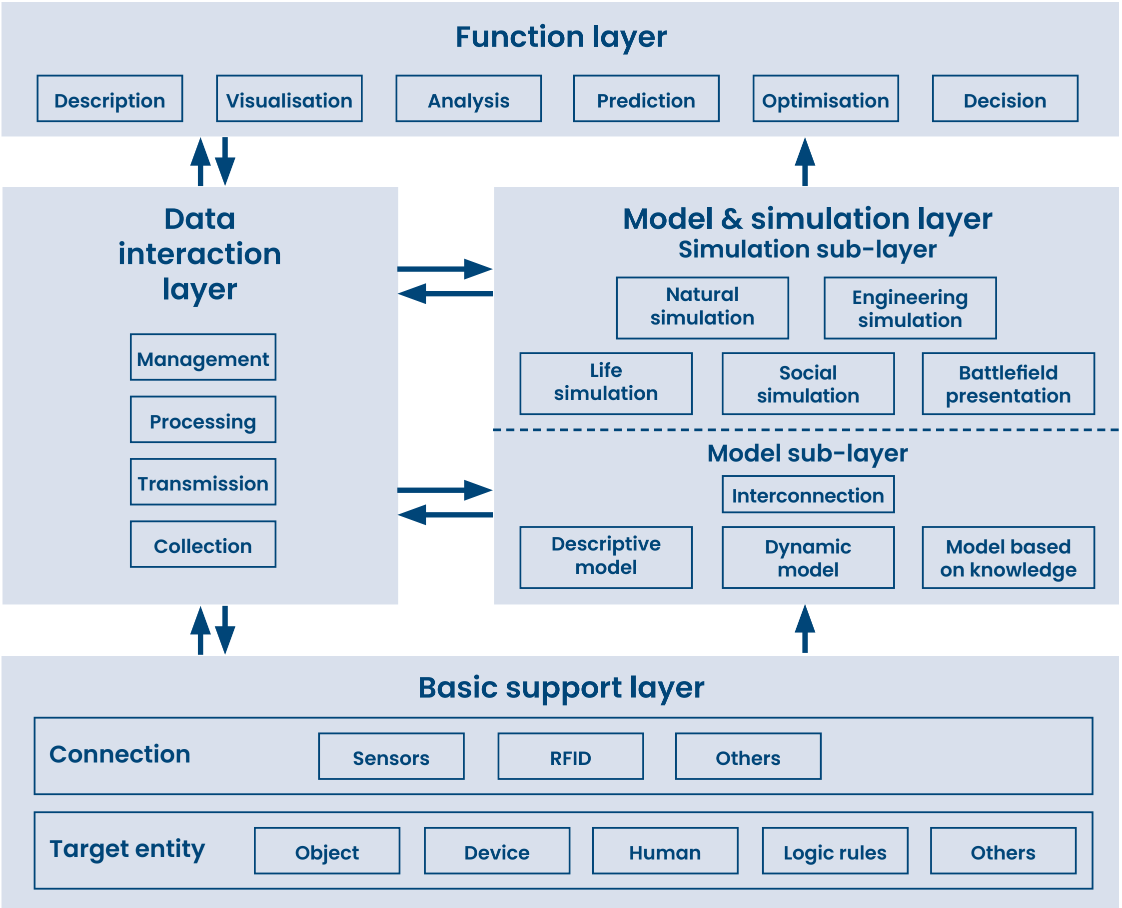
A system is recognised as a Digital Twin system if – and only if – it includes the basic support layer, model and simulation layer, data interaction layer, and implements one or more functions from the function layer.

### 4.2.4 Key objectives

Digital Twin focuses on the following key objectives:

- Digital Twin aims to establish digital representation of target entity and realise full-factor digitisation;
- Digital Twin applies to both physical and digital entities;

**Figure 7:** Framework of Digital Twin




- Digital Twin is designed to cover the full life cycle of the target entity;
- Digital Twin aims to empower entities with the ability to achieve intelligent management and scientific decision-making;
- Digital Twin aims to realise the optimal allocation of resources and energy.

### 4.2.5 Future standardisation works in Digital Twin

Future standardisation works in Digital Twin lie in the following four directions:

- **Basic standards:** terminology and concepts, reference architectures and frameworks, etc.;
- **Digital Twin technology implementation:** functionality, Digital Twin lifecycle, digital threads and interoperability;
- **Integration and collaboration between different Digital Twin systems:** resources, data, information models and interfaces, etc.;
- **Testing and evaluation:** performance evaluation, maturity and qualification testing, etc.;
- **Use cases and applications:** Digital Twin applications in different industries, such as smart manufacturing, smart cities, smart buildings, smart agriculture, smart healthcare, etc.

## 4.3 Digital Twin and the semiotic triangle

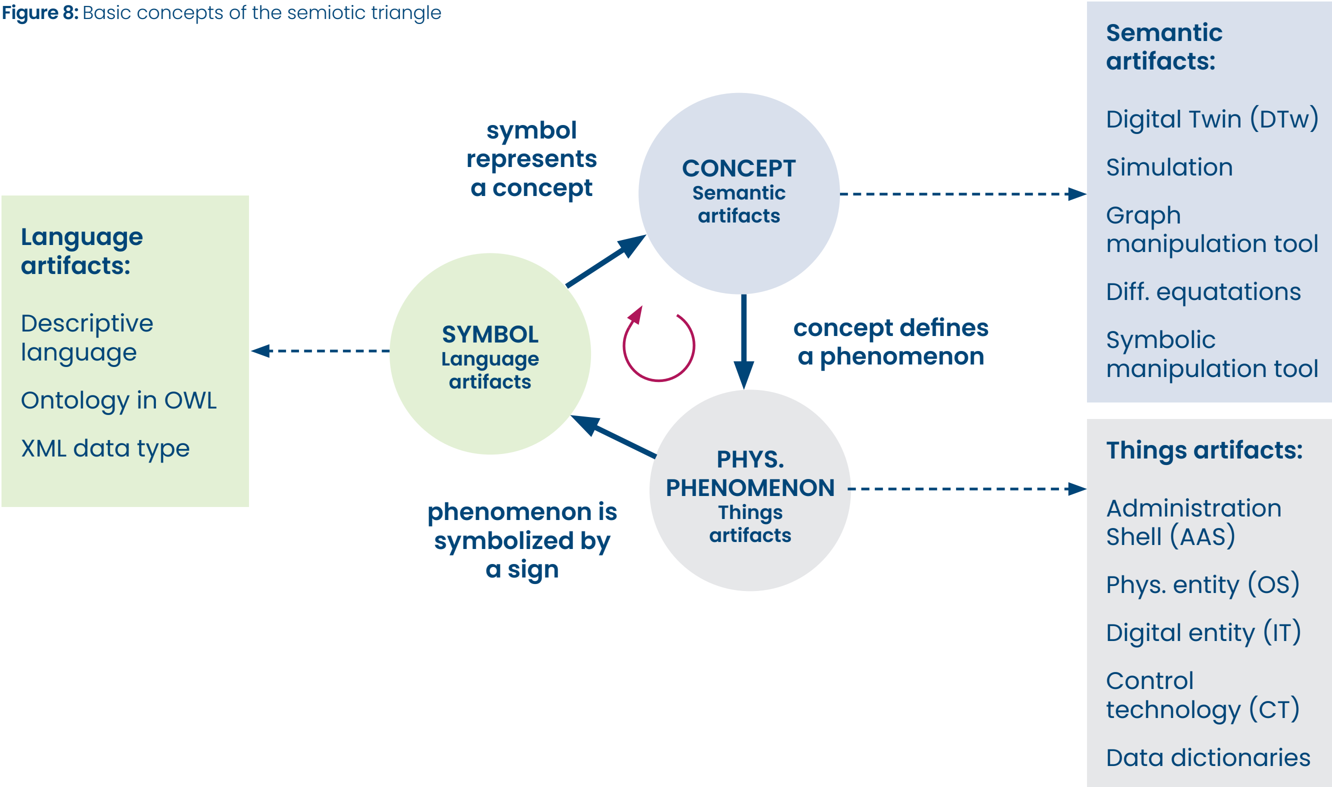
Specified knowledge and process graphs for Digital Twin express the semantics of system behaviour. More specifically, process and data type signatures specify the syntax and rules. Axioms specify the semantics of behavioural information gained from observations.[13]

The holistic view of the semiotic triangle comprises a descriptive ontology of the system under consideration, models for simulation, model checking, tests and analysis based on a common semantics execution platform, which is called operational semantics, and the anticipated lifecycle phases of the system under construction or system in operation. The holistic view is represented by the three semiotic corners and the three morphisms of the semiotic triangle. The semiotic corners of the triangle comprise artifacts of ontological language type, of the type of applied declarative and operational semantics representation, and of the construction and operation of the OT/IT machinery of the system under consideration (see information box below). A Digital Twin can help to support engineers, operators, users, designers and other stakeholders during their decision-making activities by analysing simulations, acquiring new knowledge, gaining information from observing system behaviour, and by providing feed-back signals to adjust the system input and, feed-forward data to adjust the system output such as an information model. A Digital Twin may use and modify the given associations between artifacts of different semiotic domains called morphisms as shown in Figure 8. By applying these relationships the Digital Twin captures knowledge about phenomena of system components that are embedded into control loops aiming at a certain behaviour.

In Figure 8 below you will find the basic concepts of the semiotic triangle, which are semiotic domains and morphisms. The domains of the semiotic triangle comprise three classes of artifacts i.e. semantic, phenomenological and ontological ones and the morphisms relate instances of these artifacts to each other in order to achieve meaning of things.

For example, semantics of a phenomenon of a thing is represented by graph vertices and graph edges representing differential process variables

**Figure 8:** Basic concepts of the semiotic triangle



and events observable at the process interfaces respectively. Related morphisms then map the semantics represented by graphs to an (normative) expression of the describing ontology (contained by a standard) and another morhism maps the same semantics to a physical phenomenon of a real thing, e.g. to a component of an I4.0 production machinery.

For clarity, the following colour codes are used: blue for semantic conceptual artifacts of the concept domain; grey for technical ('real-world') artifacts of the phenomenon domain; green for descriptive and prescriptive ontological artifacts of the symbol domain. In figure 8 the morphisms are represented by arrows that symbolise pairs of artifacts from different coloured domains. For example, in the realm of autonomous cars a traffic sign (green symbol) may represents the concept of controlling the traffic in a city or on highways. In a city environment the controlling concept (blue semantics) is implemented by concrete means (grey things) such as traffic lights, stop sign etc. The morphisms are not fixed, instead they can learn additional knowledge about system behaviour during interoperation of a digital twin with physical system components.

Semantics is 'a real thing of real things'. One real thing is to express semantics in a concrete manner e.g. by differential equations which comprise differential variables that represent the behaviour of physical assets. Another example of a concrete format of semantics could be the choice of computational graph theoretical representations. Another real thing, however, is the expectation to perform exactly like the prescribed semantics.

Both, China and Germany are mutually driving forces in international standardisation activities in IEC and ISO for the implementation of concepts to represent semantics by means of algebraic knowledge and process graphs. For this purpose, both countries have initiated significant committees to include knowledge and process graph representations for the purposes of semantics analysis into their scope of work, i.e. ISO/IEC JTC 1/SC 41/WG 6, IEC/TC65/WG 23, IEC/TC 65/WG 24.

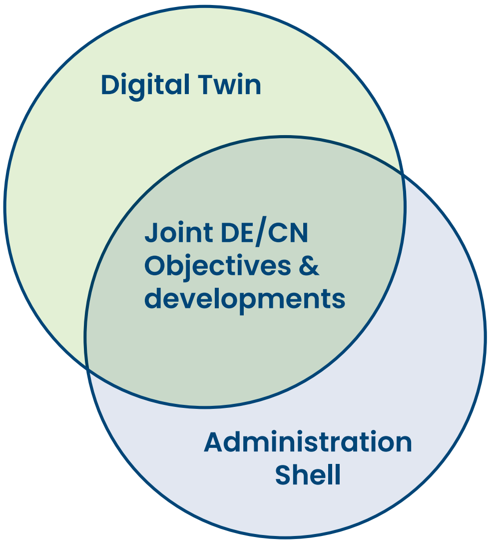
**Digital Twin and the Semiotic Morphisms**

Morphisms can be understood as a formal set of guidelines on how a Digital Twin or machine operators are enabled to gain knowledge from system observation. Hence a morphism represents a characteristic relationship between the corners of the semiotic triangle, i.e. it labels the edges of the triangle turning the edges into arrows that comprise pairs of artifacts from disjunct semiotic corners. For example, the ontological artifact of a 'traffic sign' is assigned to the semantic scenery artifact of 'a stop sign in front of a junction', which is assigned to the 'scenario of a self-driving autonomous car in smart city'. The self-driving car has built-in sensors with which it scans its environment and reads the next traffic sign scenario for which a new semantic pattern is looked for and so on. When moving in a continuously changing environment, the proper semantic patterns must be found and assigned, the semiotic triangle should be applied in a cyclical manner. This can be achieved by a Digital Twin operating in the semiotic corner of semantics encountering traffic scenarios, assigning semantic artifacts and making appropriate decisions which are fed back to the self-driving car in its permanently changing environment

# 5 Similarities between the mutual approaches of Digital Twin and Asset Administration Shell

## 5.1 Approach: emphasise similarities

**Figure 8:** Similarities between the mutual approaches of DTw and AAS




- **Assets**
- **Interoperability**
- **Benefits & added value**
- **Type of digital models**
- **Structure & information modelling**
- **Deployment scenarios**
- **Information security**
- **Connectivity & Open APIs**
- **Positioning in reference architecture**

## 5.2 Discussion of similarities

### 5.2.1 Assets

| Aspect | DE | CN |
|---|---|---|
| **Which assets are covered by DTw** | **Automation and manufacturing equipment (physical assets):** equipment from many different suppliers needs to be integrated and to be operated; digital models for engineering and operation of equipment; configuration and parameter optimisation; condition monitoring; quality control; maintenance and upgrade documentation | **Personnel:** human resources involved in manufacturing operations management. Some aspects to consider are temporary/permanent worker, availability, schedule, leadership, skills, emotional status, training, experiences, etc. |

| Aspect | DE | CN |
|---|---|---|
| **Which assets are covered by DTw** | **Software modules (logical assets):** manufacturing equipment uses more and more functional software modules; software configuration management; license management; integration with automation function; deployment into devices, edge or (private) cloud.<br><br>**Further logical entities:** such as licenses, patents and more need to be maintained as assets with particular value to the organisation; (data) integrity and (access) authorisation<br><br>**Produced products:** product variant management; lot size 1/customisation; quality data analysis; usage date from the field (as used by customers); declarable and hazardous substances<br><br>**Supplies, materials, parts:** all half-goods need to be tracked; quality and process data to be analysed; at least on batch level of materials; supply-chain management important<br><br>**Waste management:** regulatory requirements<br><br>**Production and business processes:** process definitions; software and algorithms; specification and documentation; process and quality data; version management | **Physical asset:** equipment or hardware involved in manufacturing operations management. Some aspects to consider are equipment manufacturer, progress status, schedule, performance parameter, operating technique, training/skills needed, etc.<br><br>**Material:** A physical object acts as an ingredient in production to be a part or whole of a product. Some aspects to consider are quantity, size, expiration date, storage and handling method, safety measures, etc.<br><br>**Process:** identification of personnel, physical assets, and material resources with specific capabilities needed for a segment of production, independent of any product at the level of detail required to support business processes that may also be independent of any particular product. Some aspects to consider are instruction, specification, supervisory framework, testing, tolerance, etc.<br><br>**Product:** physical output within the manufacturing process which includes in-work and final product. Some aspects to consider are production status, location, quality, quantity, size, model, storage and handling method, etc. |

**Similarities:** There is a large degree of similarity in the understanding of assets of Digital Twins. Both sides adhere to the concept that technical equipment including tools, processed materials and required parts need to be covered. Both sides want to provide Digital Twins also for the products being produced by manufacturing processes, including final products. Both sides want also manufacturing and business processes to be covered by Digital Twins.

## 5.2.2 Interoperability

| Aspect | DE | CN |
|---|---|---|
| **Degree of interoperability** | • Dynamic behaviour<br>• Application functionality<br>• Parameter semantics<br>• Data types and access<br>• Communication interface and protocol | • Dynamic behaviour<br>• Application functionality<br>• Parameter semantics<br>• Data types and accessibility<br>• Communication interface and protocol<br><br>... |

**Similarities:** Both sides recognise that interoperability can be progressively established on different degrees or levels. For interoperable Digital Twins, it is not enough to establish interoperability on communication and data types. Interoperability needs also to be accomplished for parameter semantics, functionality of mutually used applications and the joint understanding of dynamic behaviour of processes.

## 5.2.3 Benefits and added value

| Aspect | DE | CN |
|---|---|---|
| **Benefits** | **Marketing:**<br>• Increase market attention<br>• Reduce operational costs in marketing<br>• Increase addressable market on digital platforms<br>• Extend product portfolio (esp. in terms of software)<br><br>**Engineering:**<br>• Reduce lead time<br>• Increase engineering quality<br>• Improve collaboration between roles and partners<br>• Include new partners, skills, capabilities, technologies, processes<br>• Optimisation of product and engineering based on digital Operation | • Increase visibility<br>• Reduce time to market<br>• Keep optimal operation<br>• Reduce energy consumption<br>• Reduce maintenance cost<br>• Increase user engagement<br>• More convenient and more suitable for innovation<br>• Measurement in a more comprehensive manner<br>• More comprehensive analysis and prediction capabilities<br>• Process optimisation based on Manufacturing Process Simulation |

| Aspect | DE | CN |
|---|---|---|
| **Benefits** | **Maintenance:**<br>• Increase agility of manufacturing<br>• Increase product quality<br>• Reduce manufacturing costs, operational costs<br>• Reduce downtime, expenses on maintenance<br>• Reduce energy consumption, hazardous materials<br>• Optimisation of manufacturing operation based on digital insights<br><br>**Other:**<br>• Increase awareness, digital competences<br>• Include new market players, expertise into business operation | |
| **Added value sustainability, human-centric and resilience** | **Sustainability:**<br>For monitoring the product carbon footprint (PCF), information models in line with ISO14067 along the supply chain are found important.<br><br>**Dependability:**<br>Dependability is a technical discipline that is important in quality management, asset management risk management and financial decision-making. It is managed through life-cycle processes involving availability and its core performance attributes of reliability, maintainability and supportability, as well as application-specific performance attributes such as recoverability, survivability, integrity and security for products and service dependability evaluation.<br><br>• IEC 60300-1 Dependability management – Part 1: Managing dependability<br><br>• IEC 60300-3-4 Dependability management – Part 3-4: Application guide – Specification of dependability requirements<br><br>• IEC 60300-3-10 Dependability management – Part 3-10: Application guide –Maintainability and maintenance | **Sustainability:**<br>Promote economic development, cultivate new markets and achieve inclusive and sustainable growth<br><br>**Human-oriented**<br>Continuous labour training; improve people's living standards by solving problems such as unemployment, traffic congestion, increased crime, environmental degradation, and resource shortages |

| Aspect | DE | CN |
|---|---|---|
| **Added value sustainability, human-centric and resilience** | **Reliability:**<br>IEC TS 63164-1<br>Reliability of Industrial Automation Devices and Systems – Part 1: Assurance of automation devices reliability data and specification of their source<br><br>IEC TR 63164-2<br>Reliability of Industrial Automation Devices and Systems – Part 2: System reliability | |

**Identified similarities:** Both sides want to increase market share, productivity and product quality using Digital Twins. Lead times, overall time to market, downtimes and use of energy will be reduced. Efforts for maintenance will be manageable. Operation will be optimised, e.g. by more comprehensive analysis and prediction capabilities and the means of simulation.

Both sides adhere to the fact that sustainability and human-centric approaches are important for future production. For sustainability, both reduction of environmental impacts as well as sustainable growth are seen as important.

### 5.2.4 Types of digital models

| Aspect | DE | CN |
|---|---|---|
| **Types of digital models** | • **Documentation and media:** to bring about knowledge-complex data models: e.g. CAD, electric plans<br>• **Descriptive models:** e.g. device descriptions, recipe management<br>• **Declarations:** e.g. provided by the manufacturer<br>• **Digital nameplate:** information on machines and components that is required by law, other regulations<br>• **Functional models:** such as software applications, function block libraries, flow charts<br>• **Interface models:** for functions in IT systems and cloud<br>• **Dynamic models:** simulation, virtual commissioning, virtual sensors, quality models<br>• **Statistical models:** for artificial intelligence, classification and more<br>• **Semantic models:** explicit knowledge representation | • **Descriptive model:** connected and multi-dimensioned structure and function of object, which could be divided into different sub-systems, components and parts.<br>• **Dynamic model:** certain working conditions of object comprise kinematics, dynamics, and thermodynamics parameters according to different subjects. To make the descriptive model come alive, the running data from various sensors and CNC controller should be uploaded to digital space in real time.<br>• **Loop model based on knowledge:** this mainly contains the expert system for the Digital Twin with input from history maintenance data and fault information, as well as fault solutions output.<br>• Physical and chemical reactions model in process industry |

**Identified similarities:** Both sides want to provide descriptive and executable models as part of the Digital Twin; these descriptive models reflect the composition of assets out of sub-systems, components and parts.

Both sides want to provide functional and dynamic models within the Digital Twin, which allow the understanding, behaviour, prediction and simulation of the described assets in state space and near real time. Both sides want to extensively use semantic models, statistical models and knowledge of assets via Digital Twin to facilitate expert system functionalities, artificial intelligence, advanced analysis and more.

### 5.2.5 Structure and information modelling

| Aspect | DE | CN |
|---|---|---|
| **Structure and information modelling** | • Portfolio definitions<br>• Use cases<br>• Requirements and test cases<br>• Concept level and system engineering/breakdown<br>• Bills of materials (BOMs)<br>• Engineering (CAD, plans)<br>• Programming and implementation<br>• Network definitions<br>• Documentation<br>• Operation procedures<br>• Maintenance and service records | • Concepts and terms<br>• Use cases<br>• Reference architecture<br>• Physical and virtual entity<br>• Digital Twin data<br>• Connection and integration<br>• Services |

**Identified similarities:** Both sides agree on the importance of well-recognised use cases for production engineering and software development for smart manufacturing. Additionally, unified sources for terms and definitions of all sorts of concepts are required. Technical development will follow agreed reference architectures.

### 5.2.6 Deployment scenarios

| Aspect | DE | CN |
|---|---|---|
| **Deployment scenarios** | • On device<br>• On automation system (PLC…)<br>• On edge<br>• Private clouds<br>• Public clouds | • On the device<br>• On the edge<br>• In an open-source platform<br>• In the cloud |

**Identified similarities:** Both sides share the vision that the Digital Twin models provide knowledge that will be available on all levels of ICT networks even between organisations and including public clouds. As particular types of Digital Twin may be required to closely follow production processes in near real time, a deployment close to manufacturing processes will be possible.

### 5.2.7 Information security

| Aspect | DE | CN |
|---|---|---|
| **Information security** | • Physical security<br>• Functional safety<br>• Information security (authorisation, integrity, authenticity, confidentiality and more)<br>• Identity management | • Physical system security requirements<br>• Functional security requirements<br>• Information security requirements |

**Identified similarities:** Both sides agree that comprehensive measures are required to achieve information security, e.g. described in ISO 27001, IEC 62443. Additionally, both sides recognise that functional safety will also be one aspect of Digital Twin.

### 5.2.8 Connectivity and Open APIs

| Aspect | DE | CN |
|---|---|---|
| **Connectivity and Open APIs** | • Field bus connectivity<br>• OPC UA<br>• Message protocols and brokers<br>• File interface<br>• REST and Open APIs | • Remote Procedure Call Protocol<br>• Message Protocol<br>• File Interface<br>• Data Communication Interface<br>• Data Query Interface |

**Identified similarities:** Both sides share the insight that Digital Twins provide connectivity and interfaces by supporting a set of different computer interface approaches and well-accepted standards. Both sides agree also on file interfaces as a required, minimal level for information exchange. For all approaches, openness is found to be key.

### 5.2.9 Positioning in reference architecture

| Aspect | DE | CN |
|---|---|---|
| **Positioning in reference architecture** | • RAMI4.0<br>• ISO/IEC JTC 1/SC 41/ WG 6 Digital Twin – Reference Architecture<br>• ISO/IEC JWG 21: Unified reference model for smart manufacturing | • IMSA v2[14] (Intelligent Manufacturing System Framework),<br>• ISO/IEC JTC 1/SC 41/ WG 6 Digital Twin – Reference Architecture |

**Identified similarities:** Both sides recognise the fact that multiple organisations are working on standards with respect to the Digital Twin. These standardisation activities cover different verticals and industrial segments and therefore both have their own good motivation. Both sides are engaging in different working groups to foster a set of common guiding principles and concepts for the large variety of Digital Twin. Both sides agree on the importance of interoperability between partners in the supply chain, along the life cycle and across hierarchy levels. Reference architectures are found to have the correct approach to promote these goals. Both sides propose to develop a mapping of standards in the respective reference architectures (RAMI 4.0 and IMSA v2)

# 6. Summary and outlook

## 6.1 Summary

### Summary of the approaches

During the application of Digital Twin technology, the necessity of modelling and simulation of certain entities must be considered, which means partial entities can be ignored as long as they don't influence the stakeholders, functions or benefits. Asset Administration Shell is to support interoperations from the perspective of management; as a result, all contents with the characteristics of smart manufacturing and Industry 4.0 should be regarded as assets.

Since DTw is an asset, it is managed by the AAS. However, DTw is not part of the targeted entities since the latter are made available as engineered (physical) entities. Compared to RAMI4.0, DTw models the value streams of a system of interest for the purpose of analysis and the hierarchical system levels of the RAMI4.0 axis are implemented by physical and digital entities. Finally, the RAMI4.0 layers are described by the layer ontologies of the green semiotic domain, comprising symbols and languages.

In general, standardisation activity for DTw is still in the exploratory stage. Important standards, e.g., reference architecture, integration and collaboration requirements need to be reformulated. As the top-level architecture and foundation, RAMI 4.0 is able to support AAS as an implementation of DTw. In the progress of building RAMI 4.0, many standards relating to AAS have made great progress. For example, the standardisation work of OPC UA and TSN can be used directly to solve the problem of communication interface.

### Summary of identification of similarities:

A significant effort was spent on identifying similarities in the fields of work of Germany and China. These similarities are found to be an important factor for future activities:

- The scoping of Digital Twin activities for manufacturing, namely the respective assets to be covered, is nearly identical for both sides. The challenge of fostering innovations is similar in structure on both sides and will involve both technical advancements and business processes.

- A key aspect of joint Digital Twin and AAS activities will lie in increased interoperability on multiple levels.

- Both sides identify a wealth of different benefits and impacts, spanning all life-cycle phases of the sustainable supply chain, including the environmental, human-centric and social impact.

- Both sides agree that future efforts must be dedicated to establishing descriptive, executable, functional and dynamic models for Digital Twin and AAS. These models need to be developed to be quite specific and effective for multiple industrial sectors and asset types. A use-case orientation for such models is found beneficial.

- With respect to deployment, progress is required at all levels; this includes device, edge and cloud deployments. Therefore, the group recommends continuing activities both in OT and IT fields, i.e. IEC TC65 and ISO/IEC/JTC1 fields of activity.

- Both China and Germany are mutually driving forces in the international standardisation of IEC/ISO for implementing concepts for representing semantics by means of algebraic knowledge and process graphs. For that purpose, both countries have initiated significant committees to include knowledge and process graph representations for the purpose of semantics analysis into their scope of work i.e. ISO/IEC JTC 1/SC 41/WG 6, IEC/TC65/WG 23, IEC/TC 65/WG 24.

- Industrial security has been found to be crucial by both sides. International standards such as ISO 27001, IEC 62443 are found crucial.
- Both sides agree that open connectivity and APIs will be an import enabler for future fields of business.
- Both sides see a high potential in establishing well-accepted reference architecture models, as these can foster a large spectrum for developing technology building blocks which fit with each other. (JTC SC41 & JWG 21).

## 6.2 Outlook

Discussions in IEC on the topic of Smart Manufacturing and Industry 4.0 were started in about 2014. The first working groups in TC65 for Smart Manufacturing (SM) in IEC were set up at the beginning of 2016. The main objective was to create a foundation for future standards development. IEC TC 65/WG 23 has developed for SM an extensive terminology base, a holistic use

**Strategy for a consistent set of standards for Smart Manufacturing**

- Smart Manufacturing Base standards are in development of WG23 and JWG21 (figure bottom): RAMI 4.0, IEC 63283 Smart Manufacturing standards (terminology, use cases, security etc.)
- Framework of standards (figure middle) are standard that are commonly use, some of them needs to be updated to make the Smart Manufacturing aware
- Smart Manufacturing standard (figure top) are e.g. the Asset Administration Shell. These standards are using SM Base and Framework standards as normative base

**Figure 9:** Smart Manufacturing Standards layer model

### SM Standards
(new) specific SM standards

| | |
|---|---|
| **IEC 63278 Asset Administration Shell for Industrial Applications** | **IEC 6zzzz SM** |

### SM Framework Standards
Standards proposed to be used in SM architecture (existing standards may need to be enhanced to fully support SM)

| | | | |
|---|---|---|---|
| **IEC 62443 Security**<br>**ISO 270xx Security**<br>**IEC 61508 Functional Safety**<br>**IEC 61511 Functional Safety**<br>**IEC 63164 Reliability**<br>**IEC 62890 Lifecycle M.**<br>**...** | **IEC 62832 Digital Factory**<br>**ISO 62264 MOM (MES)**<br>**IEC 61424 P&ID**<br>**IEC 62714 AutomationMl.**<br>**IEC 63280 MTP**<br>**IEC 62541 OPC UA**<br>**...** | **IEC 61360 CDD**<br>**ISO 62270 Units**<br>**IEC 61987 List of Properties**<br>**IEC 63365 Digital Nameplate**<br>**IEC 61406 Identification Link**<br>**ISO 13584-42**<br>**ISO 22400 MOM KPIs**<br>**ISO 20140-5 Enviroment Data** | **IEC 61131 PLC**<br>**IEC 61499 Function Block**<br>**IEC 61512 Batch**<br>**IEC 62682 Alarm Mgmt.**<br>**IEC 63303 HMI**<br>**...** |

### SM Base Standards
Standards especial supporting and used as bas for SM architectures

| | |
|---|---|
| **IEC PAS 63088 RAM 4.0 (NP for IS in prep.)**<br>**IEC TR 63319 SM Meta Reference Model**<br>**IEC 63339 Unified Reference Model SM** | **IEC 63283-1 SM Terms & Definitions**<br>**IEC 63283-2 SM Use Cases**<br>**IEC 63283-3 SM recommendations for cybersecurity**<br>**SM recommendations for safety**<br>**SM Framework and Concepts** |

case collection, security requirements and IEC TC 65/JWG 21 is developing reference model standards. The basic standards will be further extended to include safety, market and innovation trends, gap analyses, etc. Based on these, existing standards areas and standards will be further developed e.g. Identification Link, digital nameplate, list of properties, etc. to build a SM framework. On top of this, standards such as the Asset Administration Shell IEC 63278 series will use this base for future SM applications that are able to meet the large range of use cases.
Figure 9 shows the 3-layer Smart Manufacturing Standards layer model, from SM base standards to the SM Framework and SM Standards.

This base is still partly under development and will be the base for further development and collaborations. This base is mostly domain independent and can be used in a wide range of applications.

The TEG 'Digital Twin and AAS' considers future activities in three dimensions:

### Further collaboration on standardisation activities

The standardisation activities with respect to Digital Twin (ISO/IEC JTC 1/SC 41 …) and Asset Administration Shell (IEC 61406, IEC 63278 …) will receive mutual attention in the future. Such activities might cover jointly defined use cases, working groups on standards and specifications, activities in consortia, joint specification of information models for Digital Twin and AAS, implementation of industrial security.

The TEG 'Digital Twin and AAS' recommends continuing the existing activities (see related standardisation committees).

### First industrial implementations

First industrial implementations provide Asset Administration Shells, e.g. to be downloaded in company data portals.[15] The availability of this AAS data is expected to kick-start further activities, including (automatic) proliferation of such data along the value chain; usage of such data in engineering, planning and operation software; availability of simulation and comprehensive analysis and prediction capabilities. A further next step for industrial implementation might be the availability dedicated software, provided by and to companies, to handle such applications. The empowerment of such software providers might be a future task.

### Joint testbeds

In parallel with first industrial implementations with respect to the customer base (see 2), the same developments can be used to demonstrate further far-reaching scenarios. Such scenarios could involve multiple partners in added-value networks to demonstrate the full impact of Digital Twin technologies. These testbeds would ideally be executed cross-border and across industrial sectors, to demonstrate the potential impact and benefits for both sides.

The TEG 'Digital Twin and AAS' recommends investigating the possibility of utilising existing structures for testbeds.

# 7. List of abbreviations

| | |
|---|---|
| AA | Arbeitsausschuss (equivalent Working Group) |
| AAS | Asset Administration Shell |
| AI | Artificial Intelligence |
| AutoID | Automated identification |
| API | Application Programming Interface |
| AR | Augmented Reality |
| CAD | Computer-aided design |
| CCM | Collaborative Condition monitoring |
| CD | Committee draft |
| CDD | Common data dictionary |
| DIN SPEC | DIN Specification |
| DTw | Digital Twin |
| FOL | First Order Logic |
| IEC | International Electrotechnical Commission |
| IMSA v2 | Intelligent Manufacturing System Architecture |
| IMSG | Intelligent Manufacturing Standardization Administration Group |
| ISO | International Organization for Standardization |
| JTC 1 | Joint Technical Committee 1 |
| JWG | Joint Working Group |
| NA | Normungsausschuss (equivalent Standardisation Committee) |
| NIST | National Institute of Standards and Technology |
| OCR | Optical character recognition |
| OT/IT | Operational technology/ Information technology |
| RFID | Radio-frequency identification |
| PAS | Publicly available specification |
| PLC | Programmable logic controller |
| PMI | Power Management Interface |
| PNW | New work item proposal |
| RAMI 4.0 | Reference Architecture Model Industrie 4.0 |
| SAC | Standardization Administration of the People's Republic of China |

| | |
|---|---|
| SC | Sub-committee |
| SDG | Sustainable Development Goals |
| SGSCC | Sino-German Standardization Cooperation Commission |
| SMB | IEC Standardization Management Board |
| SMCC | ISO Smart Manufacturing Coordinating Committee |
| SM2TF | IEC Smart Manufacturing Standards Map Task Force |
| SWG I4.0/IM | Sub-working group Industrie4.0/Intelligent Manufacturing (as a sub-working group of SGSCC) |
| SyC SM | System committee Smart Manufacturing |
| TC | Technical Committee |
| TEG | Technical Expert Group |
| TMBG | Technical Management Board - groups |
| TR | Technical report |
| TS | Technical specification |
| TSN | Time Sensitive Networking |
| UCA | Use cases and applications |
| URMSM | Unified reference model for smart manufacturing |
| VR | Virtual Reality |
| WG | Working Group |

# 8 Annexes

## 8.1 Annex 1: Relevant standards in the context of Digital Twin and Asset Administration Shell

| Standard | TC/SC | Scope |
|---|---|---|
| **IEC-lead** | | |
| IEC 61406 ED1<br>**Identification Link – Unambiguous biunique Machine-Readable Identification** | IEC/SC65E/WG 2<br>Product properties & classification | This activity defines minimum requirements for globally unambiguous identification of physical devices using a globally unique, machine-readable identification to be attached to the physical device in the data-format of a link (URL/URI). This link serves as biunique identification for both the physical device and its related digital information. This standardisation was initiated by the process manufacturing industry and its suppliers of technical equipment, but it is so generically formulated that it can be applied to various industries. This New Proposal defines the properties of a globally biunique ID for physical devices as well as the methods and technologies to be used for machine- readable representation of the ID in the identifier on the physical device. |
| IEC TS 63164-1<br>**Reliability of Industrial Automation Devices and Systems – Part 1: Assurance of automation devices reliability data and specification of their source**<br><br>IEC TR 63164-2<br>**Reliability of Industrial Automation Devices and Systems – Part 2: System reliability** | IEC/TC65/WG 22<br>Reliability of Industrial Automation Devices and Systems | This part provides guidance on the assurance of reliability data of automation devices. If the source of this data is calculation, guidance is given on how to specify the methods used for this calculation. If the source is from observations, guidance is given on how to describe these observations and their evaluations. If the source is the outcome of laboratory tests, guidance is given on how to specify these tests and the conditions under which they have been carried out. This part defines the form to present the data. The components considered in this document are assumed not to need any preparation before usage, either because they never needed to be prepared for usage or because the preparation was accomplished before the usage. If devices are used for functional safety application, the requirements of IEC 61508 and related standards should be considered |

| Standard | TC/SC | Scope |
|---|---|---|
| **IEC-lead** | | |
| IEC 63365 ED1 **Digital nameplate – Digital Product Marking** | IEC/SC65E/WG 2 Product properties & classification | The objective of this proposal is to provide electronically readable digital information (e.g. 2D Barcode, RFID, firmware) as an alternative to conventional plain text marking on the nameplate. The digital nameplate contains the manufacturer and product identification, the basic technical product specifications, approvals and legally required markings. Legally required information (e.g. manufacturer name, product name), conformity marks and logos shall stay human-readable on the nameplate, independently of the digital information. A semantic data description, making the digital nameplate internationally readable based on IEC 61360, IEC Common Data Dictionary (CDD) and/or eCl@ss properties, is specified as an option. The product marking is completely stored in the digital code and directly and sustainably affixed to the product. Hence, it is readable using a standard scanning device (e.g. a smartphone) without any internet connection and during the complete lifecycle of a product. |
| IEC 63278-1 **Asset Administration Shell for industrial applications – Part 1: Administration Shell structure** | | This standard specifies the structure of the Asset Administration Shell in the scope of Smart Manufacturing and defines how to represent an asset of the real world in the information world by the Administration Shell containing structures, properties and services. The purpose of the standard is to provide common structures for information and services. The term 'Asset Administration Shell' is seen as the specific concept of a Digital Twin for Smart Manufacturing applications. This project is an essential element to achieve semantic interoperability for Smart Manufacturing applications. |
| IEC 63278-2 **Asset Administration Shell for Industrial Applications – Part 2: Information meta model** | IEC/TC65/WG 24 Asset Administration Shell for Industrial Applications | This document focuses on the access of information of an Asset Administration Shell and its sub-models including sub-model elements among two or more AAS user applications, potentially between different organisations, including enterprises. It defines an information meta model, including references and handling of identifiers, in an unambiguous way that is neutral to specific technologies or implementations. The reference mechanisms will allow referencing entries (entities) in dictionaries and ontologies as well as asset-related services. |
| IEC 63278-3 **Asset Administration Shell for Industrial Applications – Part 3: Security provisions for Asset Administration Shells** | | |

| Standard | TC/SC | Scope |
|---|---|---|
| **IEC-lead** | | |
| IEC TR 63283-1 ED1<br>**Industrial-process measurement, control and automation – Smart Manufacturing – Part 1: Terms and definitions** | IEC/TC65/WG 23<br>Smart Manufacturing Framework and Concepts for industrial-process measurement, control and automation | This document presents a vocabulary for terms that are relevant within the scope of Smart Manufacturing. This vocabulary therefore not only includes the terms from the following parts of this series, but also a comprehensive collection of base terminology with compatible terms. Most terms refer to existing definitions in the domain of industrial-process measurement, control and automation and its sub-domains. This document contains only the preferred definition in the context of Smart Manufacturing, when multiple definitions exist for the same term in different standards. New or modified definitions are given, whenever the existing terms are not compatible to other terms in this document or when the definition does not fit into the broader scope of Smart Manufacturing, with the challenge of accommodating the coexistence of several intersecting and contributing domains. Hence, it is readable using a standard scanning device (e.g. a smartphone) without any internet connection and during the complete lifecycle of a product. |
| IEC TR 63283-2 ED1<br>**Industrial-process measurement, control and automation – Smart Manufacturing – Part 2: Use cases** | IEC/TC65/WG 23<br>Smart Manufacturing Framework and Concepts for industrial-process measurement, control and automation | This Technical Report has the goal of analysing the impact of Smart Manufacturing on the everyday running of an industrial facility. It focuses on the requirements of automation and control of the production system, but also on the support processes of ordering, supply chain management, design, engineering and commissioning, operational technology, life-cycle management and resource management. It does this based on several carefully selected use cases that are familiar to manufacturing industry. Each use case is described, the possible influence of Smart Manufacturing on it analysed and the impact on existing and future standardisation assessed. |
| IEC 63339 ED1<br>**Unified reference model for Smart Manufacturing** | ISO/IEC/JWG 21<br>Smart Manufacturing Reference Model(s) | This document specifies a unified reference model for Smart Manufacturing (URMSM). This model comprises a set of common Smart Manufacturing modelling elements, their associations and relationship criteria. This model establishes a reference model for documenting relationships among entities involved in Smart Manufacturing. The reference model accommodates systems consisting of equipment, products and services within the domain of manufacturing. The reference model is suitable for use in new manufacturing opportunities and challenges and will support the development of industry-specific and country-specific standards and specifications. |

| Standard | TC/SC | Scope |
|---|---|---|
| **ISO-lead** | | |
| ISO 23247-1-2021 **Automation systems and integration — Digital Twin framework for manufacturing — Part 1: Overview and general principles** | | The ISO 23247 series defines a framework to support the creation of Digital Twins of observable manufacturing elements, including personnel, equipment, materials, manufacturing processes, facilities, environment, products and supporting documents. This part of ISO 23247 provides an overview and general principles of a Digital Twin for manufacturing. |
| ISO 23247-2-2021 **Automation systems and integration — Digital Twin framework for manufacturing — Part 2: Reference architecture** | | This part of ISO 23247 provides a reference architecture for the Digital Twin in manufacturing. The following are included within the scope of this part of ISO 23247: reference architecture goals and objectives; reference model; functional view |
| IEC 63339 ED1 **Unified reference model for Smart Manufacturing** | ISO/TC 184/SC 4 Industrial data | This part of ISO 23247 provides a list of basic information attributes for the observable manufacturing elements. The following are included within the scope of this part of ISO 23247: digital representation of observable manufacturing elements. |
| ISO 23247-4-2021 **Automation systems and integration — Digital Twin framework for manufacturing — Part 4: Information exchange** | | This part of ISO 23247 identifies technical requirements for information exchange between entities within the reference architecture. The following requirements for information exchange in the following networks are within the scope of this part of ISO 23247: user network, which connects the user entity and core entity; service network, which connects sub-entities within the core entity; access network, which connects the data collection and device control entity to the core entity and to the user entity; proximity network, which connects the data collection and device control entity to the observable manufacturing elements. |

| Standard | TC/SC | Scope |
|---|---|---|
| **ISO/IEC JTC 1-lead** | | |
| ISO/IEC 21823<br>**Internet of things (IoT) — Interoperability for IoT systems — Part 1: Framework** | ISO/IEC JTC 1/SC 41/WG 4<br>IoT Interoperability | ISO/IEC 21823-1:2019(E) provides an overview of interoperability as it applies to IoT systems and a framework for interoperability for IoT systems. This document enables IoT systems to be built in such a way that the entities of the IoT system can exchange information and mutually use the information in an efficient way. This document enables peer-to-peer interoperability between separate IoT systems. This document provides a common understanding of interoperability as it applies to IoT systems and the various entities within them. |
| ISO/IEC DTR 30172 ED1<br>**Digital Twin – use cases** | | This standardisation activity aims to provide a collection of representative use cases of DTw applications in a variety of domains. To collect use cases, the first step is to identify application domains of DTw systems and to provide a use case template. Contributors were requested to submit use cases using the template provided. Guidance is provided for contributors to improve the quality of use case description. The guidance includes DTw concepts and reference models for preparing use cases. |
| ISO/IEC CD 30173 ED1<br>**Digital Twin – concepts and terminology** | ISO/IEC JTC 1/SC 41/WG 6<br>Digital Twin | This document provides a standardised generic Digital Twin (DTw) reference architecture using a common vocabulary, reusable designs and industry best practices. It uses a top-down approach, beginning with collecting the most important characteristics of DTw along its life cycle, abstracting those into a generic DTw conceptual model, deriving a high-level system-based reference with subsequent dissection of that model into five architecture views from different perspectives. |
| ISO/IEC PWI JTC1-SC41-6<br>**Guidance for IoT and Digital Twin use cases** | | Define a conceptual model for the building of use cases; specify a use case template ontology, i.e. vocabulary as well as conventions for describing and representing use case contents; provide guidance on building use case templates and on extending a use case ontology to cover the targeted standard; provide examples of use case templates and use cases; and specify an implementation scheme that will allow use cases to be stored and shared in a repository. |
| ISO/IEC PWI JTC1-SC41-7<br>**Digital Twin – maturity model** | | This document provides a generic Digital Twin maturity model, definition of assessment indicators and guidance for a maturity assessment. |

## 8.2 Annex 2: List of standardisation committees relating to Digital Twin and Asset Administration Shell

| International committees | Scope | DE Mirror committee | CN Mirror committee |
|---|---|---|---|
| **IEC-lead** | | | |
| IEC/SyC SM<br>**System Committee Smart Manufacturing** | The IEC/SyC 'System Committee Smart Manufacturing' is directly answerable to the Standardization Management Board (SMB) of IEC and started its work in 2018. The tasks of the IEC/SyC are, in addition to coordination of standardisation activities, to identify gaps and overlaps, especially in the cooperation of relevant standards organisations and consortia. Systems Committees (SyC) aim to extend the use of strategic or other horizontal groups to bridge areas covered by more than one or two TC/SCs. | DKE K/931<br>System aspects of automation | SAC/TC124<br>Industrial Process Measurement, Control and Automation of SAC |
| IEC/SyC SM/SM2TF<br>**Smart Manufacturing Standards Map (SM2)** | Create an initial compilation of terms and definitions for Smart Manufacturing; generate and organise a definitive list of Smart Manufacturing-relevant standards from committees participating in ISO SMCC and IEC, taking into consideration the work done to date | DKE K/931<br>System aspects of automation | SAC/TC124<br>Industrial Process Measurement, Control and Automation of SAC |
| IEC/TC 65<br>**Industrial-process measurement, control and automation** | | DKE K/931<br>System aspects of automation | SAC/TC124<br>Industrial Process Measurement, Control and Automation of SAC<br><br>SAC/TC 28/SC 41<br>IoT |
| IEC/TC 65/WG 16<br>**Digital Factory** | | DKE AK/931.0.14<br>Smart Manufacturing and Industrie 4.0 | SAC/TC124<br>Industrial Process Measurement, Control and Automation of SAC |

| International committees | Scope | DE Mirror committee | CN Mirror committee |
|---|---|---|---|
| **IEC-lead** | | | |
| IEC/TC65/WG 22 **Reliability of Industrial Automation Devices and Systems** | Part 1: Assurance of automation devices reliability data and specification of their source. The project will develop a technical specification (TS).<br><br>This part will provide guidance on the assurance of reliability data of automation devices. If the source of this data is calculation, guidance will be given on how to specify the methods used for this calculation.<br><br>If the source is made of observations, guidance will be given on how to describe these observations and their evaluations. If the source is the outcome of laboratory tests, guidance will be given on how to specify these tests and the conditions under which they have been carried out. | | |
| IEC/TC 65/WG 23 **Smart Manufacturing Framework and Concepts for industrial-process measurement, control and automation** | Create an initial compilation of terms and definitions for Smart Manufacturing; generate and organise a definitive list of Smart Manufacturing-relevant standards from committees participating in ISO SMCC and IEC, taking into consideration the work done to date | DKE AK/931.0.14 Smart Manufacturing and Industrie 4.0 | SAC/TC124 Industrial Process Measurement, Control and Automation of SAC<br><br>SAC/TC 28/SC 41 IoT |
| IEC/TC 65/WG 24 **Asset Administration Shell for Industrial Applications** | | DKE AK/931.0.16 Asset Administration Shell for Industrial Applications | SAC/TC124 Industrial Process Measurement, Control and Automation of SAC |
| IEC/SC65E/WG 2 **Product properties and classification** | | DKE K/931 System aspects of automation | |
| Joint ISO/TC 184 - IEC/TC 65/JWG 21 **Smart Manufacturing Reference Model(s)** | | DKE K/931 System aspects of automation | SAC/TC 124 Industrial Process Measurement, Control and Automation of SAC<br><br>SAC/TC 28/SC 41 IoT |

| International committees | Scope | DE Mirror committee | CN Mirror committee |
|---|---|---|---|
| **ISO-lead** | | | |
| ISO/TC 184<br>**Automation systems and integration** | | DIN NA 060-30-04 AA<br>Transfer and archiving of product definition data | TC 159/SC 4<br>Industrial Automation Systems and Integration/ Industrial Data |
| ISO/TC 184/SC 4<br>**Industrial data** | Create an initial compilation of terms and definitions for Smart Manufacturing; generate and organise a definitive list of Smart Manufacturing-relevant standards from committees participating in ISO SMCC and IEC, taking into consideration the work done to date | DIN NA 060-30-04 AA<br>Transfer and archiving of product definition data | TC 159/SC 4<br>Industrial Automation Systems and Integration/ Industrial Data |
| ISO/TC 184/SC 4/WG 13<br>**Industrial Data Quality** | | DIN NA 060-30-04-01 AK<br>Industrial data quality | TC 159/SC 4<br>Industrial Automation Systems and Integration/ Industrial Data |
| ISO/TC 184/SC 4/WG 15<br>**Digital manufacturing** | | DIN NA 060-30-04 AA<br>Transfer and archiving of product definition data | TC 159/SC 4<br>Industrial Automation Systems and Integration/ Industrial Data |
| ISO/TC 184/SC 4/AG 2<br>**Implementation Group** | | DIN NA 060-30-04 AA<br>Transfer and archiving of product definition data | TC 159/SC 4<br>Industrial Automation Systems and Integration/ Industrial Data |

| International committees | Scope | DE Mirror committee | CN Mirror committee |
|---|---|---|---|
| **ISO/IEC JTC 1-lead** | | | |
| ISO/IEC JTC 1/SC 41/ AG 6 **Advisory Group** | ISO/IEC JTC 1/SC 41/AG 6 aims to facilitate SC 41 management and business and strategic planning. In that context it coordinates the focus of SC 41 to establish a standardisation programme and provide guidance to JTC 1, IEC, ISO and other entities developing IoT-related applications. | DIN NA 043-01-41 AA Internet of Things | SAC/TC 28/SC 41 IoT |
| ISO/IEC JTC 1/SC 41/ AG 27 **Digital Twin strategy** | Both JTC1 and SC41 have agreed to assign the new standardisation project on Digital Twin to SC41, whereby the technical work on a DTw is assigned to WG6 and the strategic work to develop DTw standards is assigned to AG 27. Both groups have started their work since end of 2020. The approach of a Digital Twin (DTw) is understood as a 'digital representation of a real-world entity mirroring a unique physical object based on massive, cumulative, real-time and real-world data measurements'. Mirroring is done through synchronisation using data streams. | DIN NA 043-01-41 AA Internet of Things | SAC/TC 28/SC 41 IoT |
| ISO/IEC JTC 1/SC 41 **Internet of Things and Digital Twin** | | DIN NA 043-01-41 AA Internet of Things | SAC/TC 28/SC 41 IoT |
| ISO/IEC JTC 1/SC 41/ AG6 **Internet of Things and Digital Twin** | | DIN NA 043-01-41 AA Internet of Things | SAC/TC 28/SC 41 IoT |
| ISO/IEC JTC 1/SC 41/ WG 6 **Internet of Things and Digital Twin** | | DIN NA 043-01-41 AA Internet of Things | SAC/TC 28/SC 41 IoT |

## 8.3 Annex 3: Examples of testbeds related to DTw/AAS

| Testbed name | Initiating institute | Partners | Functions |
|---|---|---|---|
| **Adaptive Modular Manufacturing Verification Platform for Customisation** | Shenyang Institute of Automation (SIA), Chinese Academy of Sciences | China Academy of Information and Communications Technology Sunny Intelligent Technology Co., Ltd. | • Interconnection technologies for industrial devices and device-level security protection<br>• Technologies for planning modular reconfigurable unit system structures and building mechanical structures<br>• Technologies for building adaptive wireless and reconfigurable industrial networks<br>• Semantic digital factory modelling technology |
| **Industrial robot edge computing controller testbed** | SIASUN Robot & Automation Co., Ltd. | | • Robots access automatic production lines more easily, reducing cost and time of system integration.<br>• Upper-level applications support real-time detection of lower-level devices' status and data, device fault reports, and statistical analysis and visualised management of device data, helping reduce the cost of data monitoring and collection for device providers. |
| **Digital Twin and big data optimisation testbeds based on unified information model** | Alliance of Industrial Internet | | • Uses a unified information model to provide a unified description of product drawing numbers, engineering technology, process development, business management, production planning, product manufacturing, warehousing and logistics.<br>• Uses a unified data platform to decouple the functions of enterprise resource management and control software and production process software, develop general and customised functional modules. |

# 9. Footnotes

[1] COVID-19 impact on sustainable production and operations management, Aalok Kumara Sunil Luthrab Sachin Kumar Manglac Yiğit Kazançoğlud

[2] Social responsibility – Discovering ISO 26000.

[3] Can Digital Twins model the post-pandemic recovery? 3 November 2020

[4] ISO 23247-1:2021: Automation systems and integration — Digital Twin framework for manufacturing —Part 1: Overview and general principles.

[5] ISO/IEC JTC1/WC41/WG6 ISO/IEC CD 30173 ED1: Digital Twin – Concepts and terminology.

[6]

[7]

[8] German standardisation roadmap Industrie 4.0:

[9] Common perspectives on Germany and China described in guidance on use cases and applications scenarios.

[10]

[11] ISO/IEC JTC1/WC41/WG6 ISO/IEC CD 30173 ED1: Digital Twin – Concepts and Terminology.

[12] 65/867/CD Page 8 of 58

[13] The content of this section is related to the ISO/IEC 30173 ED1: Digital Twin – Concepts and Terminology

[14] National Intelligent Manufacturing Standard System Construction Guidelines (Version 2021)

[15] Confer for example first downloads of AAS: