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# Automation systems and integration — Industrial data — Visualization elements of digital twins



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# Foreword

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This document was prepared by Technical Committee ISO/TC 184, *Automation systems and integration*, Subcommittee SC 4, *Industrial data*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.



# Introduction

This document analyses visualization elements to be shared or integrated between an avatar (digital replica) and a physical asset. Three component models of the digital twin, which are physical asset, avatar, and realtime interface, are adopted and elaborated in this document. The fidelity measure of the interface between the avatar and the physical asset is discussed.

# Automation systems and integration — Industrial data — Visualization elements of digital twins

## 1 Scope

This document analyses visualization elements that are key components of the interface between the physical asset and the avatar (digital replica of the physical asset).

## 2 Normative references

There are no normative references in this document.

## 3 Terms, definitions and abbreviated terms

### 3.1 Terms and definitions

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

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

**3.1.1**
**administration shell**
bridge between a tangible asset and the IoT world

**3.1.2**
**asset**
economic resource, or something of value

**3.1.3**
**avatar**
digital replica of a physical asset

**3.1.4**
**digital twin**
compound model composed of a physical asset, an avatar and an interface

**3.1.5**
**fidelity**
level of accuracy whereby a copy reproduces its source

**3.1.6**
**level of detail**
decrease in complexity of a 3D model representation as it moves away from the viewer or according to other metrics such as object importance, viewpoint-relative speed or position

**3.1.7**
**physical asset**
asset which exist in the real world

**3.1.8**
**accuracy**
measurement deviation from true value and its scatter

Note 1 to entry: Accuracy consists of trueness (proximity of measurement results to the true value) and precision (repeatability or reproducibility of the measurement).

**3.1.9**
**reality**
sum or aggregate of all that is real or existent, as opposed to that which is only imaginary

**3.1.10**
**realtime**
guarantee response within specified time constraints

Note 1 to entry: Often referred to as "deadlines".

**3.1.11**
**shape**
form of an object or its external boundary, outline, or external surface, as opposed to other properties such as color, texture or material type

**3.1.12**
**STEP model**
product model which is described according to ISO 10303

**3.1.13**
**synchronization**
joining up of multiple processes at a certain point, in order to reach an agreement or commit to a certain sequence of action

**3.1.14**
**visualization**
technique for creating images, diagrams, or animations to communicate a message

## 3.2 Abbreviated terms

| | |
|---|---|
| AI | artificial intelligence |
| AR | augmented reality |
| CAD | computer aided design |
| CAE | computer aided engineering |
| CG | computer graphics |
| CPS | cyber physical system |
| DPI | dots per inch |
| DTw | digital twin |
| LoD | level of detail |
| MAR | mixed and augmented reality |
| MR | mixed reality |
| O&M | operation and maintenance |

P&ID piping and instrumentation diagram

RPM revolutions per minute

VR virtual reality

XR extended reality

## 4 Motivation

There is a need for standardization of visualization elements that should be shared or integrated between a physical asset and an avatar (or digital replica)[2]. As defined in this document, the digital twin is composed of a physical asset, an avatar, and an interface. Figure 1 shows this separation of the concept (three components model) and visualization elements of the digital twin.

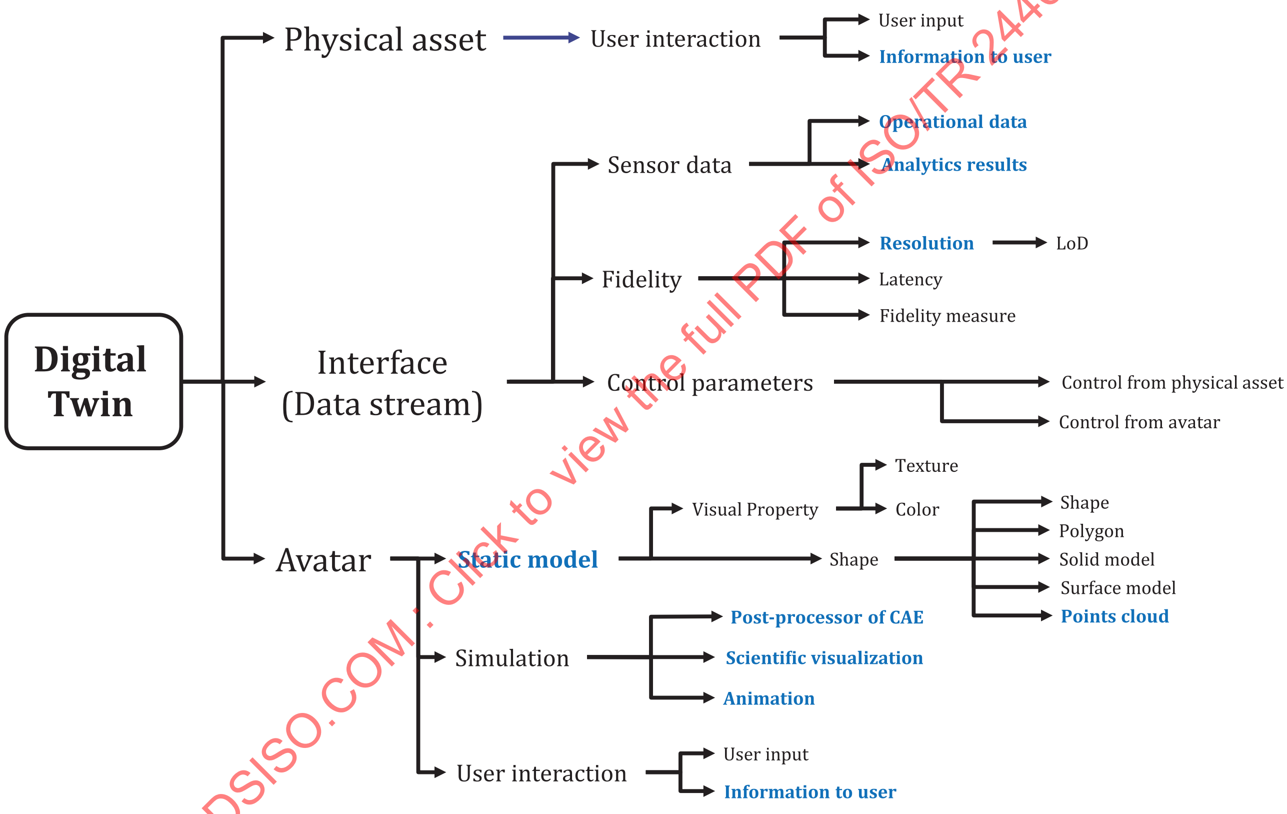



**Figure 1 — Classification of terminologies of digital twin visualization**



## 5 Digital twin visualization

### 5.1 Core technologies of digital twin

#### 5.1.1 General

Core technologies of the digital twin that Deloitte consulting introduced[3] are sensors, actuators, integration, data, analytics. More technologies can be defined for the visualization of digital twins.

#### 5.1.2 Sensor

Sensors that are attached to operating equipment can send the status (such as position, temperature, pressure, vibration, RPM) of the equipment to a user in near-realtime.

### 5.1.3 Data

Sensor data collected in near-realtime are generated continuously. The result can be a big data that is a collection of operating status information of the equipment.

### 5.1.4 Analytics

The technology which analyses big data is called analytics. As a bulk of digital sensor information is collected through the internet, the quantity of data exceeds the amount that human's analysing abilities. Consequently, data analysing technology using a computer with AI capability is being spotlighted.

### 5.1.5 Actuator

Once big data about the operating status is analysed by analytics, operating parameters of the product can be optimized and the operating status is adjusted based on the analysis result. The delivery device of modified parameters to drive the machine is an actuator.

### 5.1.6 Integration

The operating status information and the control information should be shared between the avatar and the physical asset for the integration of the digital twin. The interface component of a digital twin as is defined in this document enables the sharing and integration.

## 5.2 Visualization elements of digital twin

The relations between keywords which are being discussed among digital twin experts in Korea are shown in Figure 2. Data models or product models in the STEP standard (ISO 10303) which are being standardized can be regarded as elements of avatars. Not only design models, but also models for production or manufacturing are included in ISO 10303. There are also digital models for visualization that are specified in certain standards (see Annex A).

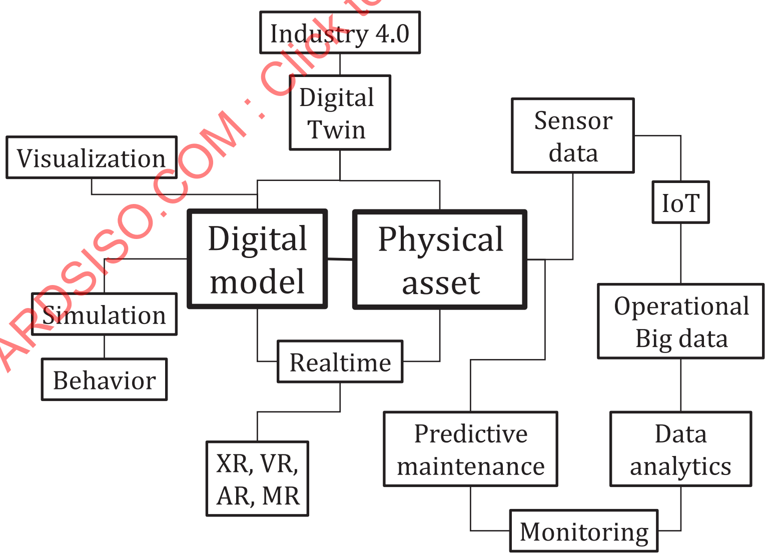



**Figure 2 — Sample relations among keywords of digital twins**

For the visualization of digital twins, most of the methods of virtual reality (VR) or augmented reality (AR) can be utilized. Visualizing properties such as shape, color, and texture of an avatar or a digital replica should be included, and animation also should be included.

Visualization of sensor data which shows the operating status of a physical asset should also be added for the visualization of digital twins. It is similar to the visualization elements of a post-processor in numerical simulations.

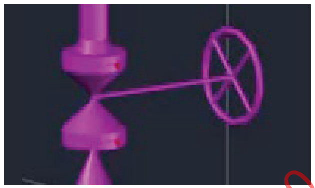
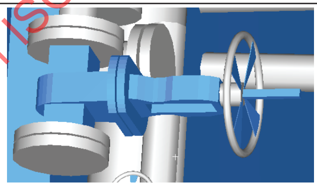
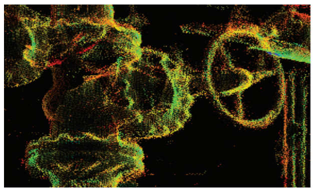
Additionally, visualization elements are dependent on the lifecycle of the product. The information that digital twins should share is changing along the lifecycle of a product which is usually made of plan, design, manufacturing, O&M, or discard, so that visualization elements change along the lifecycle of the product.

At the beginning of a product lifecycle, there is no physical asset. There is only the avatar or the digital replica. The conceptual product inside the mind of the designer is modeled as an avatar inside a computer at the beginning. The avatar is tested or simulated inside a virtual manufacturing system and the physical product then is realized into a physical asset through physical manufacturing. Only from this time both twins (avatar and physical asset) exist and can be integrated by sharing realtime status data from sensors and control parameters to actuators.

## 5.3 Detail elements of digital twin visualization

3D printing and 3D laser scanning, which have recently been under research and development also require a visualization model. In addition to the traditional CAD or mesh models, points cloud models are also being introduced. Depending on the fidelity of the avatar, different levels of detail (LoD) are being used as shown in Table 1.

**Table 1 — Classification of plant equipment models based on level of detail (LoD)**

| LoD | Type | Description | Example (Valve) |
|---|---|---|---|
| 1 | Symbol-level model (Basic design stage, send to equipment manufacturer) | — Simple model (3-dimensionalized symbol from P&ID)<br>— Model in default libraries (known as catalog model) provided by a plant CAD system. |  |
| 2 | Production model (Production design stage of plant) | — Model that plant manufacturer re-models based on vendor-package (ranges from collection of 2D drawings to detail 3D model) of equipment (LoD 5)<br>— The product model which is suitable for plant construction |  |
| 3 | Handover model (Reconstructed model from scanned data) | — Model that plant owner or operating company requests<br>— Has different LOD depending on the requests |  |
| 4 | Scanned model (during or after construction of plant) | — A points cloud model from 3D scanning during or after construction of the plant<br>— It shows additional material such as insulation material surrounding the equipment |  |
| 5 | Detailed model from equipment manufacturing (Vendor) | — Detail model of vendor for producing the equipment<br>— Contains detail (geometric, non-geometric) information about the equipment e.g. internal geometry as well as detailed surface information<br>— Due to security issues, only vendors have the model |  |

Visualization of the operational status of a product is a long-standing area in computer graphics (CG), which is known as scientific visualization. It is better to utilize existing technologies in the CG domain and to include CG technologies as the visualization elements of the digital twin.

Animation requires the use of motion texture which uses data obtained through a motion capturing sensors. Further development of technology is needed to apply the animation technology to the points cloud models in addition to the traditional animation of polygon meshes. Motion texture can play a role in complementing the weakness of kinematics-based animations, and similarly, the weakness of CAD models can be complemented by the laser-scanned models or points cloud. The merge of data from the avatar (polygons or motion from kinematics) with data from the physical asset (points cloud or motion texture) can enhance the fidelity of the digital twin.

## 6 Use cases

There are various use cases of digital twins and their visualizations. KAIST's wind power model[1)] (Figure 3) is shown as an example. It is necessary to define the concept of a digital twin, which is made of a physical asset, an avatar, and an interface. The avatar means the virtual or digital replica of the physical wind power system. The physical asset means the wind power system that physically exists in the physical world.

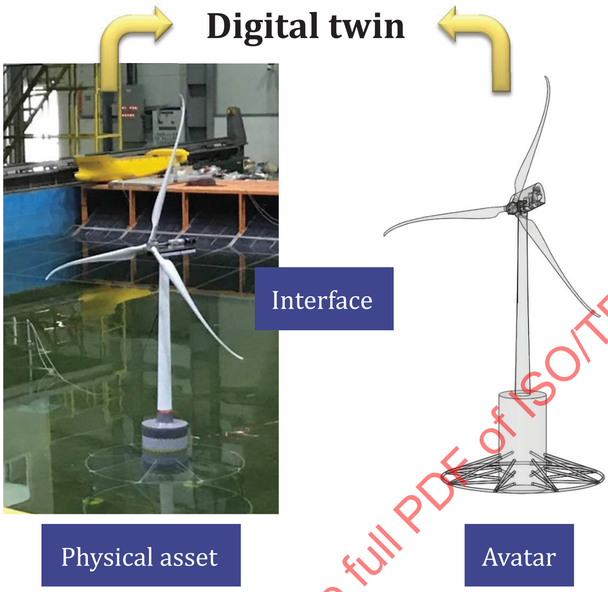


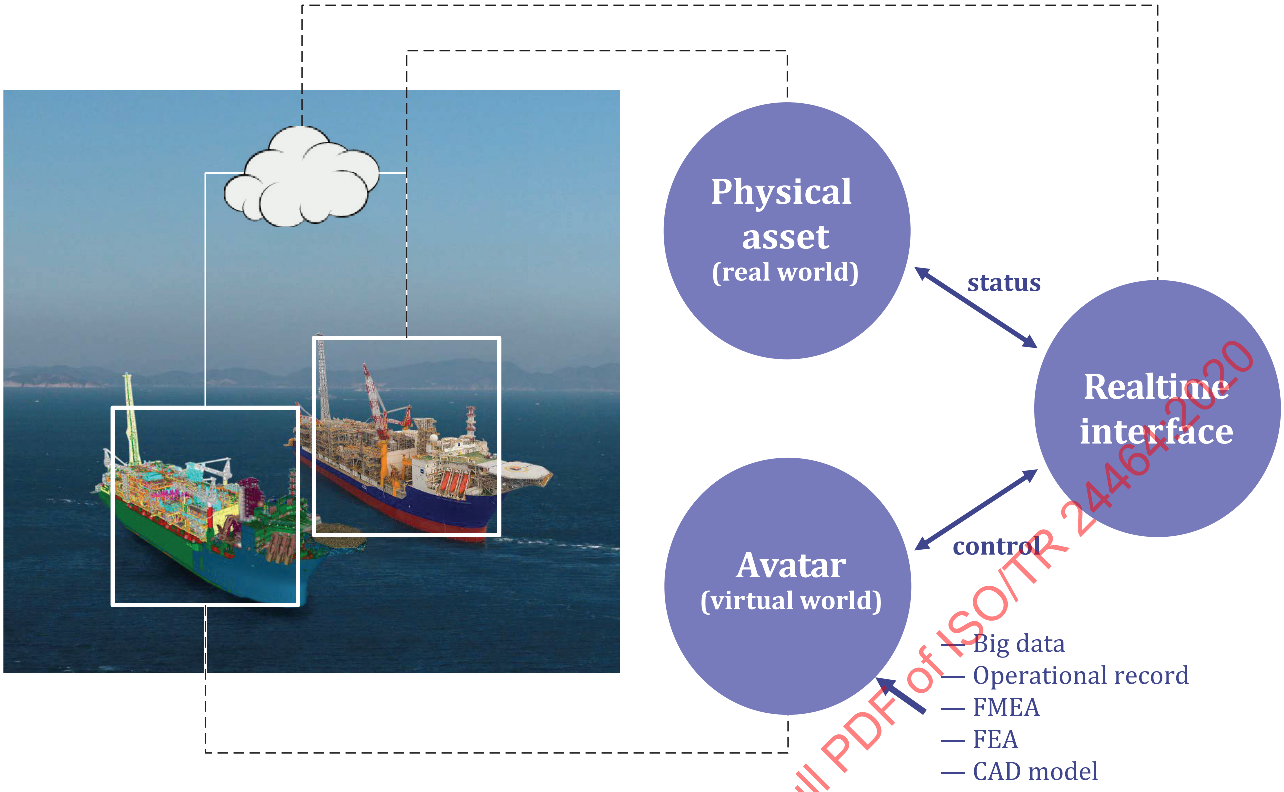

**Figure 3 — Use case of digital twin of KAIST wind power system**

The ocean plant sector is also an area in which the need for digital twins is high due to the complexities of products and the operating location is far from the land. It is an area where complex and huge digital twin models are needed as the ocean plants must be operated in near-realtime while it is in a remote place. The physical asset and the avatar operate in a remote state but are integrated through the near-realtime data communicated between them, which enables operations just as it is at the nearly same time and close by.



1) KAIST wind power system is a wind generator model researched by KAIST. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO or IEC.

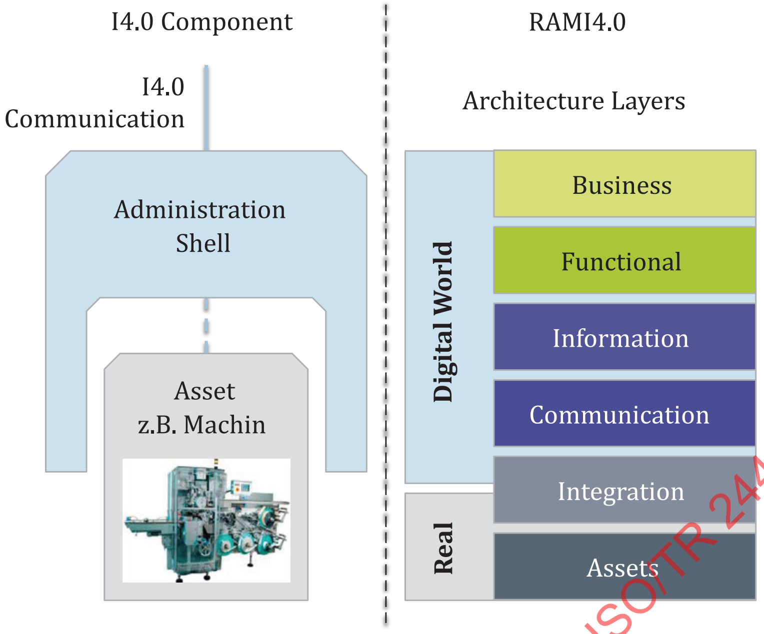
 




Source: Daewoo Shipbuilding & Marine Engineering

**Figure 4 — Digital twin of ocean plant and core technologies**

In the Industries 4.0 program of Germany, which is spearheading the fourth industrial revolution initiatives, the digital twin of smart manufacturing is also present[4]. The concept of administration shell is proposed as shown in Figure 5. By converting real-world physical equipment (asset) into an avatar the administration shell can realize the digital twin.




Source: ZVEI and Plattform Industries 4.0

**Figure 5 — Administration shell for digitalization of a factory**

Similar to ocean plants, big cities need digital twin technology. Smart cities, such as Figure 6, have expanded the concept of the smart home up to the urban scale. In smart homes, the operational information and control information of the equipment in the home can be monitored and controlled using smartphones. The concept can be expanded to the urban scale and develops as a huge digital twin where the visualization function is indispensable. If further expanded, the implementation of the digital twin of the Earth is possible. A satellite image mapping program like Google Earth[2)] can become the avatar of the physical Earth, and if the satellite image mapping program adds sensor information and control functions as the smart home, the near-realtime operational information of the Earth can be integrated with the avatar Earth.

**Figure 6 — Concept of smart city**

2) Google Earth is an example of suitable satellite image map program available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO or IEC. Equivalent products may be used if they can be shown to lead to the same results.

To automate the modeling process of a digital model of the KAIST campus, technologies have evolved from an old way of manual modeling, where modeling of small items (usually as meshes) is time-consuming. The technology for automatic reconstruction of buildings has been developed based on the video stream, images, or point clouds with depth information which is obtained using a Lidar sensor. Figure 7 shows the results of the automatically reconstructed KAIST campus using the above methods.


**Key**

1 result of automatic reconstruction research

2 original commercial satellite image map program(1)

3 original commercial satellite image map program(2)

4 original commercial satellite image map program(3)

**Figure 7 — Automatic reconstruction of the KAIST campus**

Figure 8 shows the differences between a design model and the manufactured product. The left side of Figure 8 is a photograph of the finished product, the middle is the CAD model of the designed product, and the right is the laser-scanned points cloud which is used for the verification of manufacturing. Although it is required to produce products according to the design, the details of the CAD model are often simplified in a complex engineering plant because the CAD is modeled barely to the required degree of detail. The manufacturing process also produces small differences or errors in the final product. There is a difference between the design model and the manufactured product. To identify and verify these differences, the finished product is checked and verified through laser scanning.

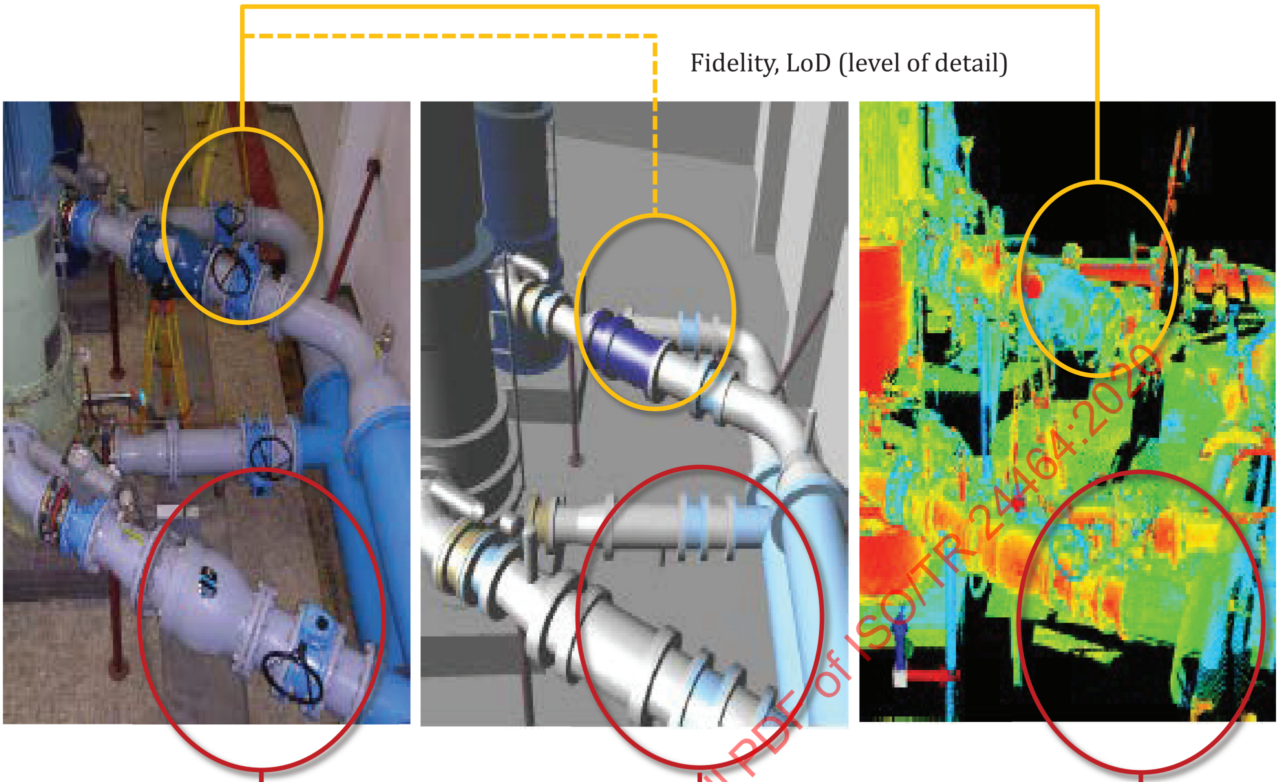



**Figure 8 — Laser-scanned points cloud for verifying design model against manufactured product**



## 7 Differences compared with augmented reality (AR) and cyber physical system (CPS)

The differences between the digital twin and the AR need to be analysed. AR, where the real-world information is added to the pure virtual models, resembles the digital twin, which is made of a physical asset, an avatar, and an interface. Differences between the AR and the digital twin can be the integration of the near-realtime operational big data in the digital twin. Further analysis is needed because AR also allows integration with the realtime operational data. The operational big data in the digital twin can complement the avatar into a higher level of operational efficiency and accuracy.

Additional differences are simulation intensity in the digital twin and special visualization functions of AR. Simulation is used to predict the performance of a product or a system. Since a digital twin is often used for the preventive maintenance of plants, the simulation function which is to predict the future performance or problems using the operational big data is essential. However, the simulation function can also be implemented in AR.

The visualization function is a core technology for both digital twin and AR since it is difficult to implement digital twin or AR without visualization capability. Since AR relies more on visualization capabilities, a variety of visualization techniques or elements of AR can also be used for DTw.

CPS is made of cyber portion and physical portion and their integration (or digital thread). The construction is very similar to that of the digital twin. Although current speculation says that DTw is a part or an implementation of CPS, this document finds out that two (DTw and CPS) are similar and be a candidate to replace each other.

# Annex A
(informative)

# Analysis of international standards for the digital twin visualization

## A.1 Visual presentation (ISO 10303-46)

Presentation data as described in ISO 10303-46 are combined with the product data and are exchanged together between systems. Examples of presentation data are; presentation styles, occlusion and invisibility, marker, font, fill-style, shading, rendering, invisibility, colour[1].

## A.2 Data Architecture of the Digital Twin

The ISO/TC 184 Ad Hoc Group report on Data Architecture of the Digital Twin[5] provides two definitions of DTw and five examples of the definitions. Although the original definition by Michael Grieves is introduced at the beginning of the ISO/TC 184 Ad Hoc Group report, the definition of Michael Grieves is not included in the selected two definitions. This report of DTw visualization adopted the three components (or parts) model of Michael Grieves. The ISO/TC 184 Ad Hoc Group report also mentions about resolution, latency, and fidelity which are further elaborated in Annex B of this document.

The phrase Digital Twin was first coined by John Vickers of NASA in 2002 and later used by Michael Grieves in 2003. While Grieves' thinking was grounded in the field of product lifecycle management, NASA's interest in the Digital Twin was motivated by its requirement to operate, maintain and repair physical systems that are in space[6].

The Digital Twin concept model is shown in Figure A.1. It contains three main parts: a) physical products in Real Space, b) virtual products in Virtual Space, and c) the connections of data and information that ties the virtual and real products together[7].

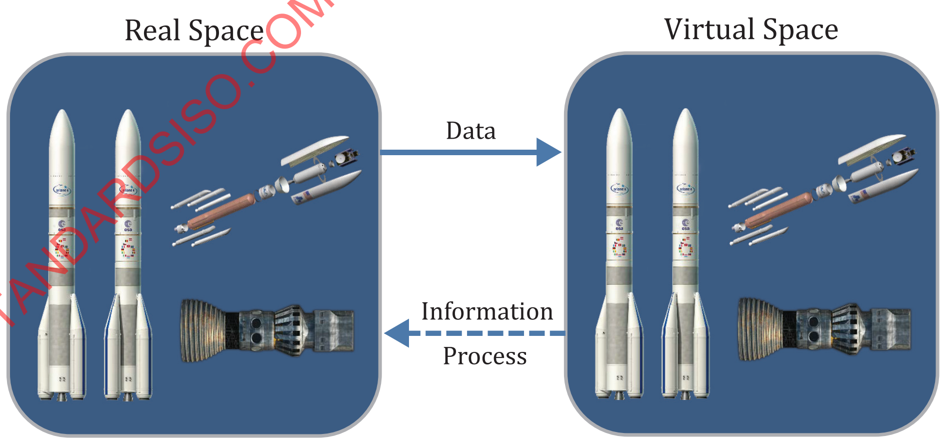



**Figure A.1 — Information mirroring model**

## A.3 Technology Trend Report

The ISO/IEC JTC 1 Technology Trend Report on Digital Twin[8] is similar to the ISO/TC 184 Ad Hoc Group report in that it introduces the three components model of DTw of Michael Grieves, but also introduces seven other definitions (Wikipedia, Deloitte, JST of Japan, GE, SAP, IBM, SIEMENS) which mostly refer DTw as a digital replica of a physical asset that corresponds to the avatar of this document.

## A.4 Cyber Physical System

The term Cyber-Physical System (CPS) was first coined by Helen Gill at the National Science Foundation in the U.S. for systems combining computation, networking and physical processes in 2006. Since then the research of CPS has received increasingly more attention from both academia and industry[9]. Figure A.2 shows a typical CPS configuration. It is similar to the digital twin with the three components of physical asset, avatar, and interface.

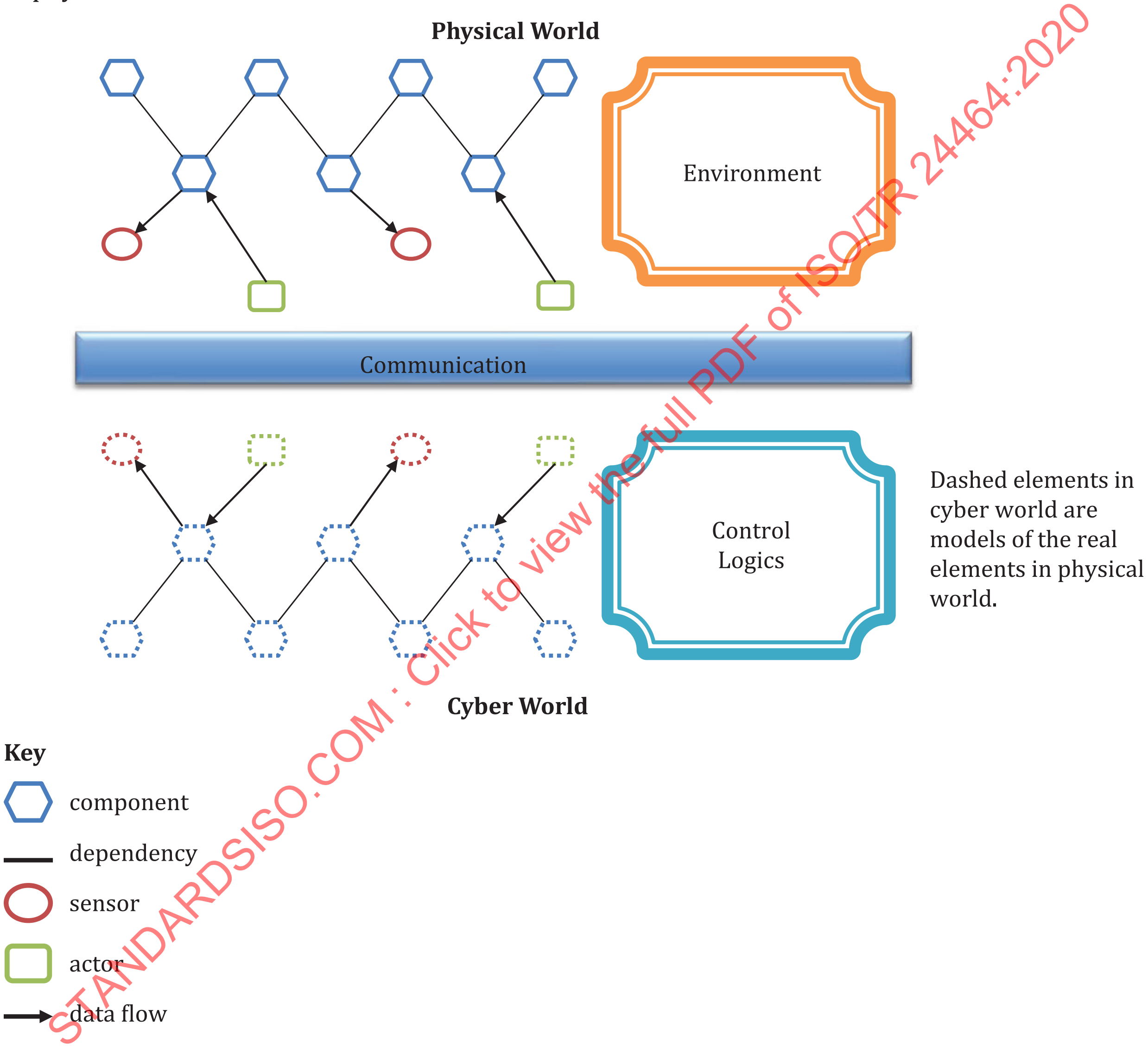
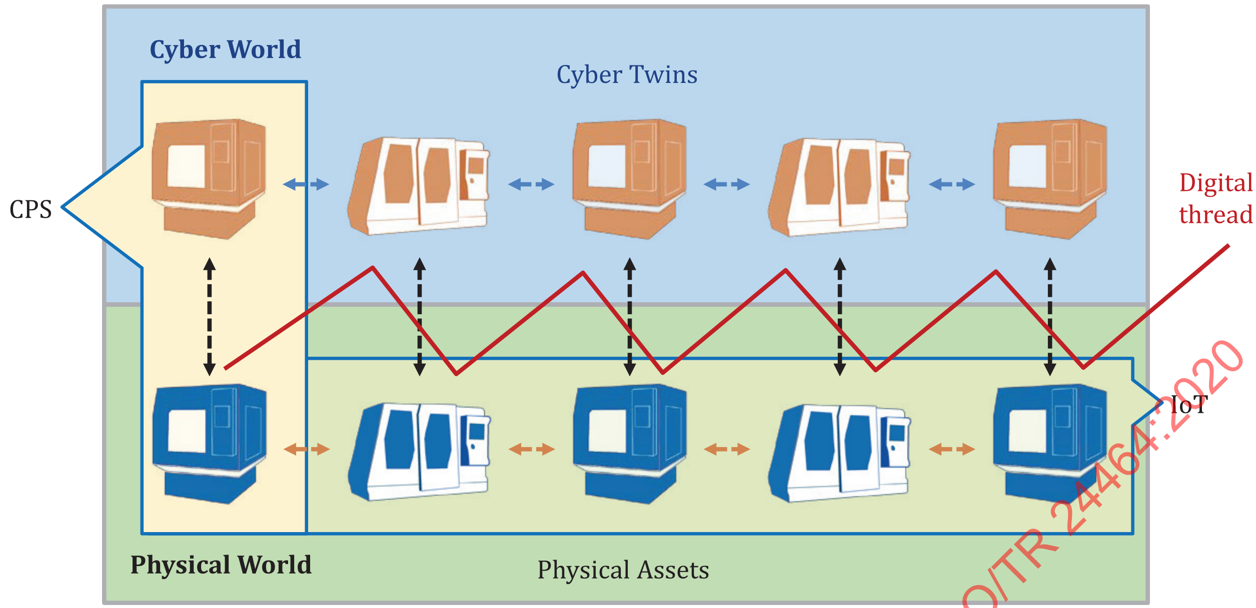





**Figure A.2 — A typical CPS**

Figure A.3 shows a cyber-physical manufacturing system which is also made of three components of physical assets, cyber twins, and communications between them. A cyber-physical system is characterized by a physical asset, such as a machine, and its digital replica; basically, a software model that mimics the behavior of the physical asset. In contrast, the IoT in common parlance is generally limited to the physical assets, not their digital models[10].




Source: Behrad, Bagheri. Jay, Lee. (2015, September 23) [10].
*Big future for cyber-physical manufacturing systems*. Design World.
https://www.designworldonline.com/big-future-for-cyber-physical-manufacturing-systems/

**Figure A.3 — A cyber-physical manufacturing system**

## A.5 Mixed and augmented reality

ISO/IEC 21858[3)] was intended to standardize the mixed and augmented reality (MAR). Figure A.4 shows two components of MAR as the real root and the virtual root.



3) Deleted.