Available online at www.sciencedirect.com

ScienceDirect

IFAC PapersOnLine 53-5 (2020) 726–731

The development of standardized models of digital twin

Haibo Duan*, Feng Tian**

**PERA Corporation Ltd., Beijing, 100025, China (e-mail: hyman.duan@peraglobal.com)*
*** PERA Corporation Ltd., Beijing, 100025, China (e-mail: hill.tian@peraglobal.com)*

Abstract: Digital twin is becoming a General Purpose Technology of the coming fourth industrial revolution. However, there is no consistent set of definition, concept system, reference architecture (model), application framework (model), and maturity model of digital twin yet. This paper identifies the relationship among these models, proposes a universal architectural and ontological concept system of digital twin, and a set of unified above models to facilitate the standardization of digital twin.

Keywords: Digital Twin, standardization, concept system, reference architecture, application framework, maturity model.

1. INTRODUCTION

When an emerging technology or a new concept is introduced, the terminology work is the basis for all subsequent work. And a concept system is the basis of terminology work. A concept system is a set of concepts structured in one or more related domains according to the concept relations among its concepts. The analysis and definition of existing terms and the establishment of new terms should all be carried out under the guidance of a concept system.

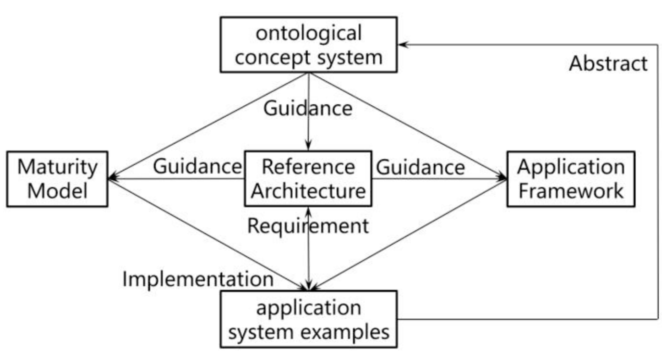

Fig. 1. The relationships between concept system, reference architecture, application framework, and maturity model.

Therefore, first of all, it is necessary to develop a model-based concept system from an both architectural and ontological view for all digital twin related concepts before we identify the meaning of each term and provide its natural language definition to obtain a consensus, and then formulate a glossary or terminology system of digital twin. The second step, the reference architecture, application framework and maturity model of digital twin need to be developed to guide the design, development and implementation of the specific application system of digital twin based on the concept system and application requirements. Meanwhile this is also a standardization process of formulating the underlying basic standards (terms, architecture, framework, maturity, etc.) in digital twin standards system. The relationships between the concept system, the reference architecture, the application framework, and the maturity model in the standardization process are shown in Fig. 1.

2. ARCHITECTURAL AND ONTOLOGICAL CONCEPT SYSTEM OF DIGITAL TWIN

Currently there are a dozen of definitions of digital twin. In order to unify and harmonize them, it is useless to provide a new one simply; instead, the essence of digital twin should be identified, and a universal concept system of digital twin should be developed. Digital twin builds bridges of communication between the physical world and the virtual world across system hierarchies and material scales. The essence and ultimate purpose of the technology and applications of digital twin is to eliminate the uncertainty of various systems, especially complex systems. It is with less energy, even with information instead of energy, i.e. digitalized and model-based means, that digital twins eliminate the uncertainty.

In order to model a concept system of digital twin, it is necessary to bear in mind the essence and ultimate purpose of digital twin, the expectations and objectives of the target users, and a set of unstructured but thematically digital twin related concepts. A universal architectural and ontological concept system of digital twin is proposed (Fig. 2) using STEP EXPRESS-G language. The ontology of *Entity* and the architecture of *Digital Twin System* act as the framework for modeling the concept system of digital twin.

The concept system of digital twin is based on the inheritance and generalization relationship and the attribute relationship. The thick solid line and the small circle in Fig. 2 represent the inheritance and generalization relationship, and the thick solid line marked with "1" represents the exclusive inheritance and generalization relationship constraint (all lower level specific concepts under a certain higher level generic concept are mutually exclusive relationships); thin solid lines with a small circle represents a necessary attribute relationship, the dotted line with a small circle represent an

10.1016/j.ifacol.2021.04.164

optional attribute relationship, (DER) means derived attribute, and "L" means List aggregation type; the solid line box represents a general entity, and the dashed box with the left vertical line represents a selected type entity.

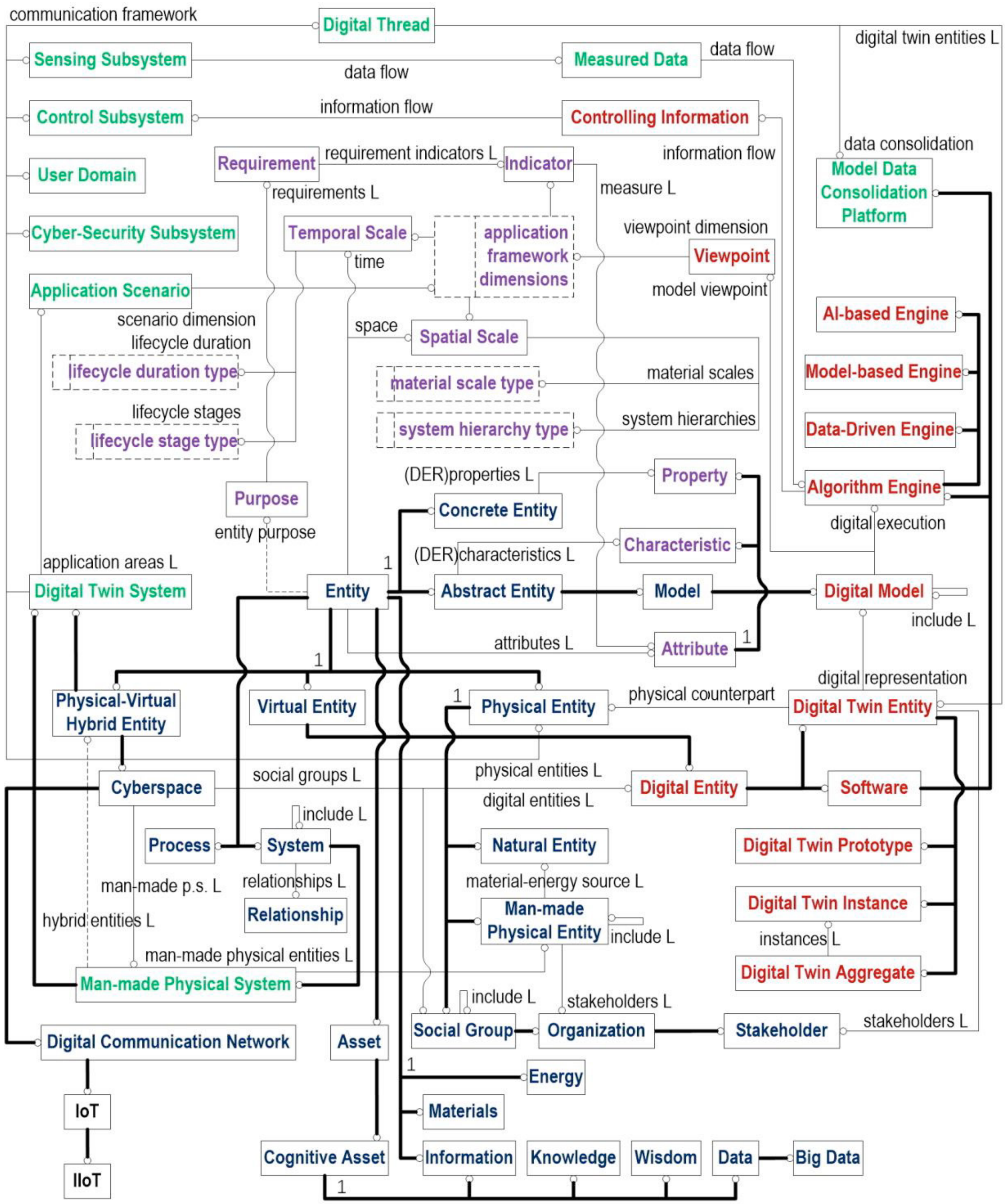

Fig. 2. The architectural and ontological concept system of digital twin.

According to the logical structure of *Digital Twin Entity* and *Digital Twin System*, the concept system of digital twin in Fig. 2 divides digital twin related concepts into the following four categories: *Entity*-related (the blue area in the middle and lower part) and *Digital Twin Entity*-related (the brown area on the right part), *Digital Twin System* (the green area on the left and top part), and *Application Framework Dimensions* (the purple area on top and in the middle).

The concept system of digital twin has following references and considerations:

- ✓ Basically, agree with Dr. Grieves' classification of digital twins.
- ✓ Agree with the industry's common view that digital twin and the Internet of Things are inseparable.

- ✓ Agree with the US DoD's definition of digital thread.
- ✓ Agree with the industry's view that the digital thread is the key enabling technology for digital twin and incorporate digital thread into the concept system of digital twin.

According to the concept system of digital twin, a new definition of *Digital Twin Entity* is proposed: Based on the *Digital Model*(s) of one or more *Viewpoint*(s) of the existing or future *Physical Entity*, the *Measured Data* from the *Physical Entity* is analyzed and processed through one or more *Algorithm Engine*(s) to perceive, diagnose or predict the state of the *Physical Entity*, and then to synchronize the states between the *Digital model*(s) and the physical counterpart, eventually to generate *Controlling Information* that optimizes the behavior of the *Physical Entity*.

The *Algorithm Engine* in the concept system of digital twin means the *Software* tool or platform that implement the *digital representation* and *execution* of the *Digital Model* of the *Digital Twin Entity* and synchronizes the state between the *Digital Model* and its *Physical Entity*.

With reference to the DoD's definition, an updated definition of *Digital Thread* is also proposed: An extensible, configurable and componentized enterprise-level analytical *communication framework*, that construct the integrated view of multi-viewpoints of *Digital Twin Entity* across the *Life Cycle* and value chain, *Temporal Scales* and *Spatial Scales*, of its counterpart *Physical Entity*, furthermore drive the *Life Cycle* activities of the *Physical Entity* with a unified model in order to provide support for *Stakeholders*. Therefore, the goal of *Digital Thread* is to deliver the correct *Information* to the correct *Social Group* or *Digital Entities* at the correct time and place within the *Physical Entity Life Cycle*.

Besides identifying the relationship among *Digital Twin Entity*, *Digital Twin System* and *Digital Thread*, the concept system of digital twin provides a grand perspective of the fourth industrial revolution, therefore *Digital Twin Entity* is not limited to the *Application Scenario* of *Man-Made Physical Entities* (such as intelligent products, digital workshops), but extended to all *Physical Entities* including *Social Groups*. With considering various scales from micro to macro and various hierarchical levels from system elements to system of systems, taking various needs and application scenarios of industrialization, urbanization and globalization into consideration, the concept system of digital twin provides a basis for *Digital Twin System* reference architectures development and *Application Scenarios* expansion.

3. REFERENCE ARCHITECTURE OF DIGITAL TWIN SYSTEM

Based on the concept system of digital twin (Fig. 2), and refer to the two IoT reference architecture standards GB/T 33474-2016 and ISO/IEC 30141:2018 and the draft standard ISO/DIS 23247 standard, Fig. 3 provides the general reference architecture of digital twin system. A typical digital twin system includes five domains: user domain, digital twin domain, sensing and controlling domain, physical domain and cross-domain functionalities.

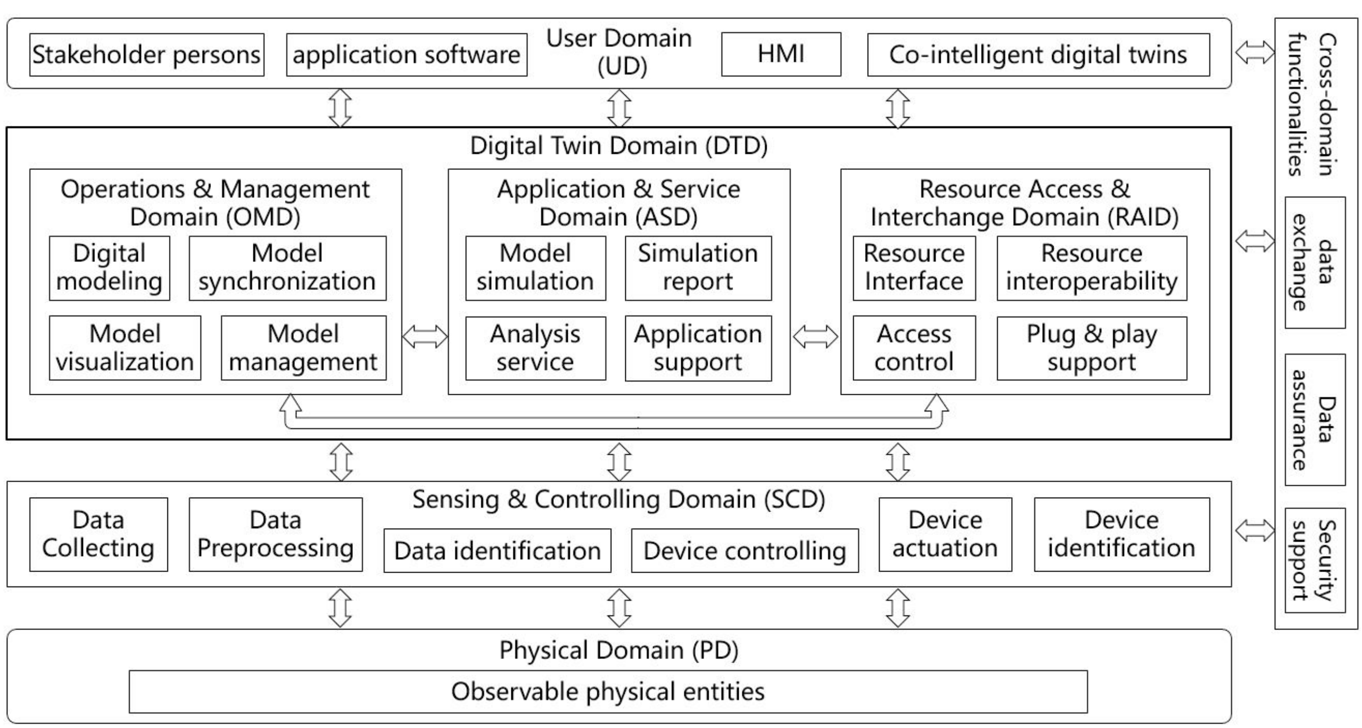

Fig. 3. General reference architecture of digital twin system.

The first layer (the uppermost layer) is the user domain that uses digital twins, including humans, human-machine interfaces, application software, and other related co-intelligence digital twins.

The second layer is digital twin corresponding to the target object of the physical entities. It is a digital model that reflects the characteristics of a certain perspective of physical objects, and provides three subdomains: Operation and Management, Application and Services, and Resource Access and Interchange. Operation and Management involves digital modeling and display of physical objects, synchronization and operation management with physical object models. Application and Services include model simulation, analysis services, report generation, and platform support. Resource Access and Interchange involves the interface, interoperability, online insertion and removal, and secure access of resources such as the co-intelligence digital twins. The three subdomains transfer the information needed to realize the state awareness, diagnosis, and prediction of physical objects.

The third layer is the sensing and controlling entities that is in the sensing and controlling domain, connecting digital twin and the physical entities, and realizes the state awareness and control function of the physical object.

The fourth layer is the physical domain where the physical entities corresponding to digital twin is located. The measurement data flow and control information flow are transmitted between the measurement and control entities and the real physical domain.

The flow of data and information between measurement and control entities, digital twins, and user domains requires the support of cross-domain functional entities such as information exchange, data assurance, and security assurance. Information exchange realizes the exchange of information between digital twins through appropriate protocols. The security guarantee is responsible for the authentication, authorization, confidentiality and integrity related to the security of digital twin system. Data assurance is responsible for the accuracy and completeness of digital twin system data together with security assurance.

4. APPLICATION FRAMEWORK OF DIGITAL TWIN

Based on digital twin concept system (Fig. 2) and digital twin system reference architecture (Fig. 3), this white paper uses the three-dimensional space of the system purpose, system hierarchy/material scale and system lifetime as digital twin application scenario. Reference frame (Fig. 4). For example, the creation of digital twins, fault diagnosis of object systems and health management are all extended applications in the dimension of system lifetime. Table 1 provides some examples of digital twin application scenarios based on the two dimensions of system purpose and spatial scale.

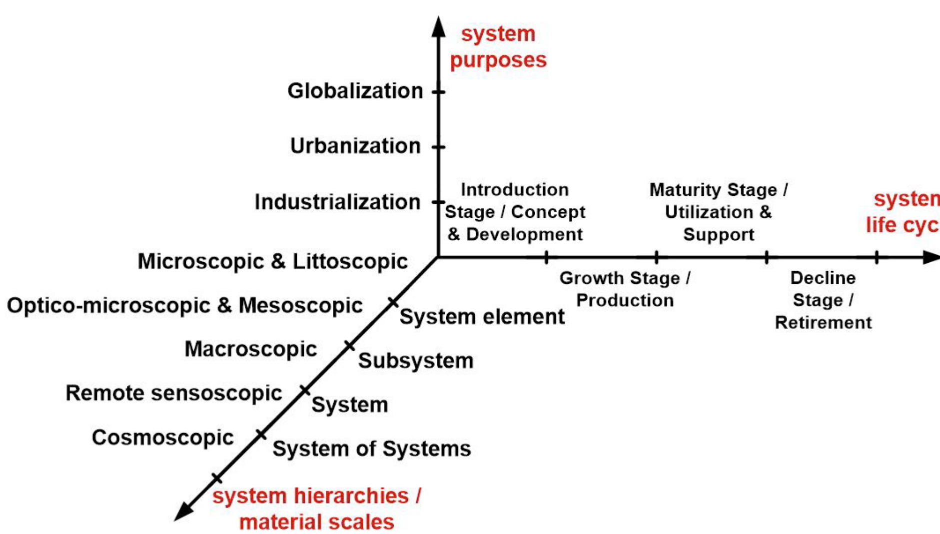

Fig. 4. Reference framework for digital twin application scenarios.

Table 1. Examples of digital twin application scenarios based on system purpose and spatial scale

material scale/system hierarchy	industrialization	urbanization	globalization
optico-microscopic & mesoscopic / system element	ICME, micro-nano manufacturing, additive manufacturing process simulation		
macroscopic/subsystem	intelligent manufacturing unit	intelligent home	
macroscopic/system	R&D, intelligent workshop/factory	intelligent building	supply chain of an industry

macroscopic/ system of system	distributed cloud manufacturing, digital agriculture	digital twin city, smart grid, intelligent transportation	global supply chain network of a group of industries, digital twin government

5. THE MATURITY MODEL OF DIGITAL TWIN

Digital twin is not only a mirror image of the physical world, but also receives real-time information from the physical world, and in turn drives the physical world in real time, and has evolved into a prophet, or even a superbody in the physical world. This evolution process is called maturity evolution, that is, the growth and development of a digital twin will go through five maturity levels: modeling, interaction, foreknowing, prediction, and co-intelligence (Fig. 5).

(1) Modeling

The first level, modelling, is the process of digitalization the physical world. This process requires physical objects to be expressed as digital models that computers and networks can recognize. Modeling technology is one of the core technologies of digitalization, such as surveying and scanning, geometric modeling, grid modeling, system modeling, process modeling, organization modeling and other technologies. The Internet of Things is another core technology of the level of modeling, which changes the state of the physical world itself to be perceivable, recognized and analyzed by computers and networks.

(2) Interaction

The level of interaction mainly refers to the real-time dynamic interaction between digital objects and their physical objects. The Internet of Things is the core technology for realizing the interaction between virtual and real. One of the responsibilities of the digital world is prediction and optimization, and at the same time intervene in the physical world based on the results of optimization, so instructions need to be passed to the physical world. The new state of the physical world needs to be transmitted to the digital world in real time as the new initial value and new boundary conditions of the digital world. In addition, this interaction includes interaction between digital objects, relying on digital threads to achieve.

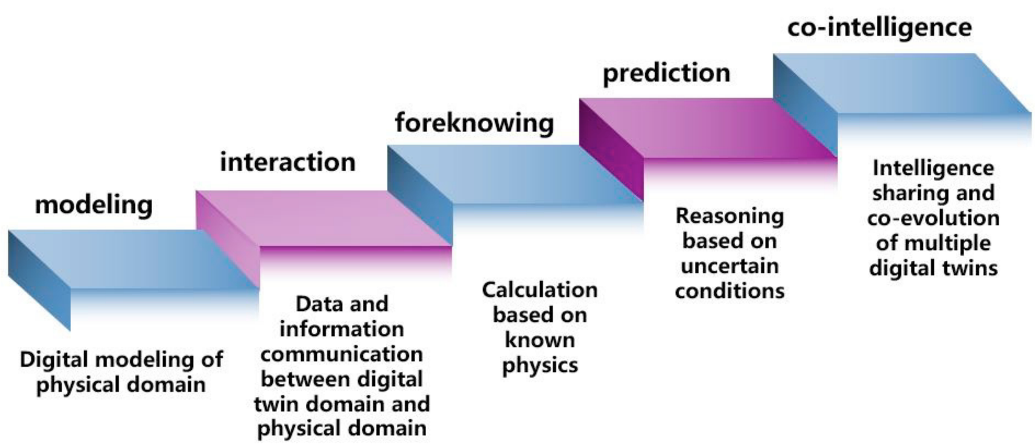

Fig. 5. The maturity model of digital twin.

(3) Foreknowing

The level of foreknowing refers to the dynamic prediction of the physical world using simulation technology. This requires that digital objects not only express the geometry of the physical world, but also need to incorporate physical laws and mechanisms into the digital model. The simulation technology not only establishes the digital model of the physical object, but also calculates, analyzes and predicts the future state of the physical object based on the current state and through the laws and mechanisms of physics. This kind of simulation is not a simulation of a stage or a phenomenon, but a dynamic simulation of the whole cycle and the whole field.

(4) Prediction

If the level of foreknowing predicts the future of digital twin based on the definite laws of physical objects and the complete mechanism, then the level of prediction is based on incomplete information and unclear mechanisms to predict the future through industrial big data and machine learning technology. If digital twins are required to become more intelligent and intelligent, they should not be limited to humans' deterministic knowledge of the physical world. In fact, human beings do not fully rely on deterministic knowledge to understand the world.

(5) Co-intelligence

The highest fifth level, co-intelligence, is to realize the exchange and sharing of wisdom between different digital twins through cloud computing technology. The implicit premise is that the intelligence of each component within a single digital twin is first shared. The so-called "single" digital twins are artificially defined ranges. Multiple digital twins can form larger and higher-level digital twins through co-intelligence. The number and level can be unlimited. Many digital twins must have a large number of digital asset transactions in the process of co-intelligence, and the blockchain provides the best transaction mechanism.

6. CONCLUSIONS

This paper identifies the relationship among the concept system, the reference architecture (model), the application framework (model), and the maturity model of digital twin, and proposes a set of unified these models to facilitate the standardization of digital twin. Digital twin bridges the communication between the real world and the virtual world across system layers and material scales. It is becoming one of the General Purpose Technologies and core technology systems of the coming fourth industrial revolution, a comprehensive technology system supporting the interconnection of all things, a fundamental cornerstone of digital economy, and the basis of the information infrastructure in the future smart era. The next decade will become the "digital twin era". In the process of the fourth industrial revolution, digital twin will permeate all aspects of urbanization, globalization and industrialization and become ubiquitous digital twin systems.

REFERENCES

Duan Haibo. (2019-11). Why do we need to add the Chinese character "entity" to digital twin? (in Chinese). Digital Twin Lab, https://mp.weixin.qq.com/s/R4TlaD1dxd9n2pyeu90oMg

Duan Haibo. (2020-1). The standardization roadmap of digital twin. (in Chinese). Digital Twin Lab, https://mp.weixin.qq.com/s/lPzW1BOFptlKjz1zQ6qA5Q

Duan Haibo. (2020-3). Digital twin from the perspective of the coming industrial revolution. (in Chinese). PERA, https://mp.weixin.qq.com/s/r9hLxDUXiMzUms9BAXTaTA

Grieves M, Vickers J. (2016). Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems. // Kahlen, Flumerfelt, Alves (Eds). Trans-Disciplinary Perspectives on System Complexity. Switzerland: Springer

Piascik R, Vickers J, Lowry D, Scotti S, Stewart J, Calomino A. (2010). Technology Area 12: Materials, Structures, Mechanical Systems, and Manufacturing Road Map. NASA Office of Chief Technologist

Shafto M, Conroy M, Doyle R, Glaessgen E, Kemp C, LeMoigne J, Wang L. (2010). Technology Area 11: Modeling, Simulation, Information Technology and Processing Roadmap. NASA Office of Chief Technologist

Tuegel E J, Ingraffea A R, Eason T J, Spottswood S M. (2011). Reengineering Aircraft Structural Life Prediction Using a Digital Twin. International Journal of Aerospace Engineering. http://dx.doi.org/10.1155/2011/154798

ISO 1087:2019 Terminology work and terminology science — Vocabulary

ISO 704:2009 Terminology work — Principles and methods

ISO 860:2007 Terminology work — Harmonization of concepts and terms

ISO 10303-11:2004 Industrial automation systems and integration — Product data representation and exchange — Part 11: Description methods: The EXPRESS language reference manual

ISO/IEC 30141:2018 Information technology - Internet of Things Reference Architecture

ISO/DIS 23247-1 Digital Twin manufacturing framework - Part 1: Overview and general principles. (2020-9-4). https://www.iso.org/standard/75066.html

ISO/DIS 23247-2 Digital Twin manufacturing framework - Part 2: Reference architecture. (2020-9-4). https://www.iso.org/standard/78743.html