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Review Article

International Standards for Digital Twins

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ABSTRACT

Interest in digital twins has grown significantly due to the maturation of enabling technologies, including cloud computing, 5G, data storage, computing capabilities, the Internet of Things (IoT), Artificial Intelligence (AI), and machine learning. As these technologies have reached a sufficient maturity level and costs have decreased, the concept of digital twins has gained prominence. Given the growing interest in digital twins, which are widely acknowledged as a fundamental component in the digitalization of production underlying smart manufacturing, the absence of standards concerning digital twin terminology, architecture, and models during application development has resulted in divergent user interpretations. This lack of standardization leads to significant confusion regarding the concept of digital twins. To alleviate this confusion, establishing guidelines and developing unified terminology and implementation procedures are crucial steps to promote the widespread adoption of digital twins. This study aims to contribute to the development of digital twins by analyzing studies that present different technologies, procedures, and standards for implementing digital twins, with a particular focus on the ISO 23247 Digital Twin Framework for Manufacturing.

Keywords: Digital twin, Standards of digital twin, ISO 23247

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1. INTRODUCTION

The foremost pioneer of digital twins was NASA, which innovatively used simulators from 200,000 miles away in 1970 to diagnose and repair damage on the Apollo 13 spacecraft. While the concept of digital twins was initially proposed in 2002, the technologies required to make this concept widely accessible recently reached a turning point (Accenture, 2021). Grieves and Vickers initially defined a digital twin as "a digital information structure of a physical system as an entity in itself." In this context, the term "twin" implies that digital information is connected to a physical system throughout its lifecycle. The application of this concept to production enables manufacturers to create purposeful digital representations of production systems and processes using collected data (Shao & Helu, 2020).

Digital twins facilitate the modeling, analysis, and optimization of problems that are challenging in the physical world. By modeling the performance of humans, physical entities, and processes in a virtual environment, digital twins help us understand how humans behave under various conditions. By leveraging machine learning, digital twins can simulate complex scenarios in numerous new ways, capturing potentialities that might otherwise go unnoticed (Accenture, 2021). With the ability to work with real-time data from the physical world, digital twins can represent the physical world with unparalleled precision and accuracy and conduct mathematical modeling. This capability allows decision makers to conduct limitless "what-if" analyses by altering numerous variables to model potential outcomes.

Digital twins not only enable the real-time visual modeling of products and processes but also aid decision makers in understanding how productivity can be enhanced, risks mitigated, issues resolved, and potential future states of a product or system (Shao & Helu, 2020). Due to ttthesepromised benefits, the uuseof digital twins is increasingly expanding across various sectors, from manufacturing to energy, health care to defense, logistics to supply chains. However, the concept of digital twins leads to confusion and difficulty for practitioners because of its foundation in the convergence of new technologies and different disciplines, its nascent application, and the lack of sufficient practical examples. Overcoming these practical challenges requires the standardization of terms, concepts, and reference models to serve as guiding principles (Shao et al., 2023). This study aims to contribute to the development of digital twins and eliminate the conceptual confusion that arises in practice by examining works that define standards applicable to implementing digital twins, primarily the ISO 23247 Digital Twin Framework for Manufacturing. At the same time, a very limited amount of research exists on the standards of digital twins. Therefore, this study can serve as a guide for future research in this area.

2. LITERATURE REVIEW

The number of studies focusing on standards for implementing digital twins, particularly ISO 23247, remains limited. Although 96 articles concerning digital twins are accessible in national reference journals indexed in LUlabim, none specifically explore digital twin standards. Within the WoS and Scopus databases, 16 studies were documented

Notably, the initial publication dates vary, with one in 2020, two in 2021, four in 2022, six in 2023, and three in 2023.

Shao and Help, affiliated with the American National Institute of Standards and Technology (NIST), elucidated the foundational framework of the ISO 23247 standard in their 2020 study, "Framework for a digital twin in manufacturing: Scope and requirements." This research explored and categorized the diverse applications of digital twins in manufacturing, underscoring the necessity of standards to ensure interoperability among digital twins designed for distinct purposes and employing different technologies. This study emphasizes the potential of the ISO 23247 standard to bridge this gap.

Huiyue and Run (2021) conducted a case analysis leveraging edge computing advantages to access and analyze real-time data in digital twins. They outlined a general framework aligned with the ISO 23247 standard for the realization phase of this application.

Jacoby et al. (2021) developed integrated software for digital twins to enhance their business interoperability. This software adheres to the ISO 23247 reference architecture and can be seamlessly integrated with other open production standards.

Another 2022 literature study by Huile, Tang, and Xun surveyed digital twin platforms used in academia and industry, emphasizing the significance of delineating requirements and complying with the ISO 23247 standard during their development.

Eirinakis et al. (2022) proposed a digital twin focused on predicting and mitigating interruptions in production using the ISO 23247 reference architecture.

Lidell et al. (2022) discussed current and future challenges associated with digital twins, highlighting the imperative need for standards and the pivotal role of the ISO 23247 standard in addressing these challenges.

Kim et al. (2022) presented a digital twin application architecture tailored for additive manufacturing that was structured based on the ISO 23247 framework.

Huan et al. (2022) aimed to present a literature review of digital twin platforms in manufacturing. This study first proposes a generalized definition of a digital twin platform, and then, based on this definition, a literature review on the digital twin platform is conducted using the Web of Science database. The importance of ISO 23247 is also discussed to give an overview of the requirements for building a digital twin platform.

Kibira et al. (2023) analyzed existing standards, technologies, and methodologies to create a digital twin for a robot work cell and developed it in accordance with the ISO 23247 framework.

Ferko et al. (2023) scrutinized how existing digital twin architectures align with the ISO 23247 architecture, highlighting the incipient adoption of this standard by multinational companies and challenges in precisely measuring compliance due to differences between existing architectures and the recently proposed standard.

In their study, Ferrero et al. (2023) defined the functional requirements for adapting lean manufacturing to the digital twin model based on the ISO 23247 standard.

In their study, Spaney et al. (2023) created a digital twin of the milling process in manufacturing based on the ISO 23247 standard. This study presents a digital twin architecture framework that optimizes the manufacturing process.

Shao et al. (2023) reviewed the ISO 23247 set of standards to inform the manufacturing community in general and for applications in emerging industry sectors, such as bio-manufacturing, and new manufacturing technologies, such as 3D printers.

Cabral et al. (2023) devised a digital twin for implementation in a CNC machine tool by designing protocols for data acquisition, storage, visualization, simulation, and cloud-based transfer aligned with the ISO 23247 reference.

Triphati et al. (2024) interviewed experts on the digital twin ecosystem and conducted a systematic literature review. Based on these interviews and a literature review, the study identified various stakeholders and their roles in adding value to the digital twin ecosystem. The study also revealed the technical and nontechnical challenges faced by ecosystem-driven digital twins and highlighted the importance of standardization as a solution.

In their work, Caiza and Sanz (2024a) developed a digital twin to be implemented in the Industry 4.0 lab. The requirements for the design and implementation of the digital twin architecture are based on ISO 23247. The architecture includes 3D design and visualization, a communication entity through the OPC UA protocol for the collection of state changes of production elements, digital modeling and updating according to the collected data, and the use of AR and VR, all built according to the ISO 23247 standard. The results demonstrate that the proposed architecture provides interoperability between different platforms and control subsystems. The results demonstrate that the ISO 23247 standard makes an important contribution to interoperability, which is one of the most serious problems of digital twins.

In another study (2024b), Caiza and Sanz developed a digital twin architecture for flexible manufacturing systems based on the ISO 23247 standard. The proposed system is based on the integration of digital twin technologies together with augmented reality and motion tracking and aims to increase the interaction and flexibility between physical and virtual environments in real time. As a result of this study, it was stated that ISO 23247 facilitates the integration of different technologies, but its use with the ISO 16792 standard in the creation of the digital twin architecture allows for more detailed development of the 3D model.

Digital twins are among the most important technologies of Industry 4.0 and smart manufacturing, and their use in both academia and industry has recently become significantly widespread. It has a wide range of applications and research areas, from manufacturing to smart cities, to healthcare and accounting systems. However, the platforms used for digital twin architectures are also changing significantly. Although it is a new and developing field, the wide range of application areas and platforms and the fact that it is not yet fully mature have created some difficulties in the implementation of digital twins. Among the above-mentioned studies, it has been reported that digital twin architectures created with reference to the ISO 23247 standard facilitate the integration of different technologies. These studies emphasize the importance of the standards to be applied to digital twins and the potential of the ISO 23247 standard to overcome the difficulties encountered in the implementation of digital twins. However, studies and applications in academia and business are still not at a sufficient level.

3. DIGITAL TWIN STANDARDS

A standard can be delineated as a universally agreed-upon set of regulations and principles for interoperability (Türkiye Bilimler Akademisi, 2023). These standards serve to ensure the seamless operation of technology and foster trust to facilitate efficient market functionality.

Moreover, they establish a shared framework for assessing and appraising performance, thus allowing for the compatibility of components manufactured by diverse entities (Shao et al., 2023). Standardization denotes the process of instituting and implementing specific regulations, involving the cooperation of all stakeholders, aimed at yielding economic advantages in a particular sphere of activity. Essentially, standardization dictates the attributes to be pursued in the production of goods and services (Ministry of Industry and Technology, 2023).

Various organizations, such as the International Standards Organization (ISO), International Electrotechnical Commission (IEC), International Telecommunication Union (ITU), Institute of Electrical and Electronics Engineers (IEEE), American National Institute of Standards and Technology (NIST), and American National Standards Institute (ANSI), conduct standardization studies on digital twins or related technologies (ANSI, 2020; Wang et al., 2022).

Standards developed for digital twins encompass a spectrum of focal areas. Wang et al. (2022) categorized these standards based on physical assets, virtual assets, data, connectivity, and services, as illustrated in Figure 1.

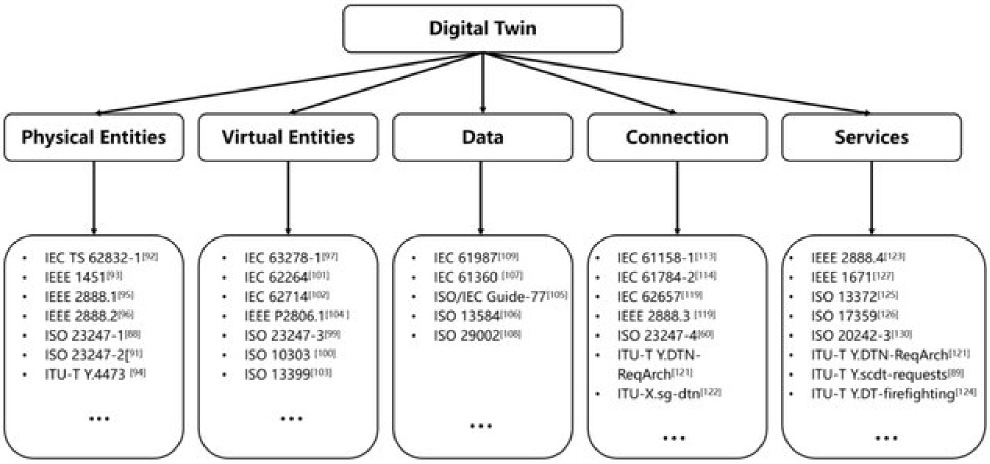

Figure 1. *Framework of digital twin standards (Wang vd., 2022)*

ISO functions as an international standardization body composed of representatives from national standard organizations. The ISO 23247 series defines a framework for the establishment of digital twins. Founded in 1906, the IEC is the foremost global organization for developing and disseminating international standards on electrical, electronics, and related technologies. Collaborative efforts focusing on digital twins are being undertaken by both the ISO and the IEC. ISO/IEC JTC 1/SC 41 strives to standardize aspects of the Internet of Things and Digital Twinning and offers guidance to other entities developing applications in this domain (International Electrotechnical Commission, 2023). Within ISO/IEC JTC 1/SC 41, the working group WG6 is presently engaged in five projects, two of which are dedicated to standard development: ISO/IEC 30172: This document outlines digital twin use cases across diverse sectors like autonomous mobility, energy, smart cities, buildings, manufacturing, business management, and healthcare. ISO/IEC 30173: Focused on digital twin concepts and terminology, this document delves into applications, ecosystems, life cycle processes, and the classification of digital twins (IEC, 2022).

The International Telecommunication Union (ITU) functions as the specialized agency of the United Nations for telecommunications and information and communication technologies (ICTs). Within the ITU, the Telecommunications Standardization Sector (ITU-T) is a permanent body responsible for examining and issuing recommendations for standardizing global telecommunications (ITU, 2022). The ITU-T recommendation "Y.3090: Digital Twin Network" delineates the requirements and architecture of digital twin networks, encompassing functional requirements, service criteria, architectural aspects, and security concerns. Unlike ISO 23247 and ISO/IEC initiatives, ITU-T Y.3090 focuses primarily on network-oriented standards. The Institute of Electrical and Electronics Engineers Standards Association (IEEE-SA) is an integral part of IEEE, developing global standards spanning various industries. Within the IEEE-SA, the C/SM/DT_WG Digital Twin Working Group developed the P 3144 standard. This standard defines a digital twin maturity model catering to industry needs, encompassing digital twin capability areas, related sub-areas, and assessment methodologies comprising assessment content, processes, and maturity levels (IEEE-SA, 2022). The American National Standards Institute (ANSI) developed the IPC-2551 standard for digital twins. This standard allows any manufacturer, design organization, or solution provider to initiate the implementation of interoperability to create smart value chains and assess their current level of IPC Digital Twin readiness.

This standard provides the information and guidance necessary to understand the IPC Digital Twin, Digital Twin Product, Digital Twin Manufacturing, and Digital Twin Lifecycle. The standard also provides information and guidance on how organizations benefit from the IPC Digital Twin, how to assess readiness, and how an organization of any size can prepare to apply the IPC Digital Twin approach to itself and/or its products (ANSI, 2020).

The US National Institute of Standards and Technology (NIST) released draft report NISTIR 8356 titled "Digital

Twin Technology and Emerging Standards Considerations" in 2021. This report comprehensively details digital twins, elucidating their motivations, utility, common operational procedures, use cases, and illustrative examples. With a specific focus on technical facets pertinent to the cybersecurity of digital twins, this study scrutinizes both existing and emerging cybersecurity challenges stemming from the deployment of digital twin architectures. Moreover, it analyzed trust-related concerns, explored the ramifications of lacking standards on the functionality and quality of digital twins, and correlated these evaluations with existing NIST cybersecurity directives (Voas et al., 2021).

Within the purview of NIST, evaluations were conducted regarding ISO 23247 studies, generating scenarios aligned with the framework established by ISO 23247 (Shao, 2021). A summary of the above-mentioned and other standards for digital twins and their constituent technologies is presented in Table 1.

Table 1. Standards for digital twins and related technologies

Standard Name	*Full Name*	*Year*	*Purpose*	*Application Areas*	*Focus*
ISO 10303	Automation systems and integration — Product data representation and exchange	1994	Exchange of product data between computers.	CAD systems, industrial data management.	Data Representation & Exchange
IEEE 1451	Standard for a Smart Transducer Interface for Sensors and Actuators	1997	Network-based integration of smart sensors.	IoT, industrial automation, smart sensors.	Sensors & Actuators
ISO 13584	Industrial automation systems and integration — Parts library	1998	Representation and exchange of part libraries.	Digital manufacturing, data exchange.	Parts Library & Exchange
IEC 62264	Enterprise-control system integration	2003	Model for integration between manufacturing and business management.	Manufacturing management, Industry 4.0, business processes.	Enterprise Integration
ISO 29002	Industrial automation systems and integration — Exchange of characteristic data	2004	Use of metadata in product data management.	Product data management, industrial automation.	Metadata Exchange
ISO 13372	Condition monitoring and diagnostics of machines — Vocabulary	2004	Terminology and methodology for condition monitoring and diagnostics.	Maintenance management, industrial facilities.	Condition Monitoring
IEEE 1671	Standard for Test System Interface Architecture	2006	Information modeling standard for test systems.	Automated test systems, electronic testing.	Test Systems & Interfaces
ISO 13399	Cutting tool data representation and exchange	2006	Digital format representation of cutting tool data.	Cutting tools, digital manufacturing processes.	Data Representation
IEC TR 62541	Industrial communication protocol — OPC Unified Architecture	2006	Unified architecture for communication in automation systems.	Industrial automation, communication systems.	Industrial Communication
IEC 61987	Industrial-process measurement and control — Data structures and elements in process equipment catalogues	2007	Data structures for devices used in industrial processes.	Industrial automation, process control.	Data Structures

Table 1. Continued

ISO/IEC Guide-77	Guide for description of reference models and general requirements for classification of products	2008	Provides a guide for product classification and data management.	Product lifecycle, supply chain management.	Product Classification
IEC 61360	Standard data element types with associated classification scheme for electric components	2010	Methodology for product classification and data elements.	Product lifecycle management, data classification.	Data Classification
IEC 61784	Industrial communication networks – Profiles	2010	Standards for industrial communication profiles.	Industrial automation, factory communication systems.	Communication Profiles
ISO 17359	Condition monitoring and diagnostics of machines — General guidelines	2011	Procedures for monitoring the condition of industrial machinery.	Industrial maintenance, equipment management.	Condition Monitoring
ISO/IEC 27001:2013	Information security management systems — Requirements	2013	Requirements for information security management systems.	Information security, risk management.	Information Security
IEC 62714	Engineering data exchange format for use in industrial automation systems engineering	2014	Exchange and integration of engineering data.	Industrial engineering, data exchange.	Data Exchange
ITU-T Y.DTN-ReqArch	Requirements and architecture for delay-tolerant networking (DTN)	2016	Architecture and requirements for delay-tolerant networks.	Space, defense, large data transmission.	Delay-Tolerant Networking
IEC 62657	Industrial communication networks – Wireless communication networks	2017	Spectrum management for industrial wireless communication systems.	Wireless communication, industrial automation.	Wireless Communication
ISO/IEC 38505-1:2017	Information governance — Framework for information and records management	2017	Governance standards for information management.	Information management, governance.	Information Governance
ISO 20242	Industrial automation systems and integration — Distributed application protocol	2018	Interface structures for distributed systems.	Automation systems, distributed networks.	Distributed Systems

Table 1. Continued

ITU-T Y.DT-firefighting	Digital twin standard for firefighting applications	2018	Requirements for digital firefighting systems.	Fire safety, digital monitoring.	Digital Twin for Safety
IEC 62443	Cybersecurity for industrial automation systems	2018	Cybersecurity framework for industrial systems.	Cybersecurity, industrial automation, digital twins.	Cybersecurity for Industrial Systems
ISO/IEC 20889:2018	Privacy enhancing technologies — Data deletion and destruction techniques	2018	Standards for data deletion and destruction techniques.	Data security, privacy management.	Data Privacy & Security
IEC 61158	Industrial communication networks – Fieldbus specifications	2019	Communication protocols for industrial networks.	Industrial networks, automation.	Industrial Communication
IEC TS 62832	Industrial-process measurement, control and automation – Digital factory framework	2020	Provides a reference model for digital factory systems.	Industrial automation, digital factories.	Digital Factory
IEEE P.2806	Standard for Digital Reality — Reference Architecture	2020	Provides a reference architecture for digital reality technologies.	Digital reality, augmented reality, virtual reality.	Digital Reality
ITU-X.sg.dtn	Delay-Tolerant Networking (DTN) standardization efforts	2020	Standardization efforts for delay-tolerant networks.	Space and defense, large data transmission.	Delay-Tolerant Networking
IEEE P2048	Standard for Digital Reality — Framework for interaction	2020	Interaction framework for digital reality applications.	Digital reality, virtual and augmented reality.	Digital Reality
IEEE 2888	Standard for Sensory and Exchanged Information in the Internet of Things	2021	Standards for human sensory and experience sharing over the internet.	Multimedia systems, virtual reality, IoT.	IoT & Sensory Systems
ISO 23247	Automation systems and integration — Digital twin framework for manufacturing	2021	Creation of digital twins for smart manufacturing.	Digital twins, Industry 4.0, smart manufacturing.	Digital Twin
ITU-T Y.4473	Requirements and capabilities for IoT data sharing framework	2021	Technical requirements for data sharing in IoT.	IoT, data sharing, network management.	Data Sharing & IoT

Table 1. Continued

ISO/IEC TS 27110:2021	Internet of Things (IoT) — Reference architecture	2021	General framework for IoT architectures.	IoT architecture, digital systems.	IoT Reference Architecture
ISO/IEC 21823-3:2021	Internet of Things (IoT) — Interoperability for IoT systems	2021	Interoperability for the Internet of Things.	IoT, integration, cyber-physical systems.	IoT Interoperability
ISO/IEC 30147:2021	Internet of Things (IoT) — Bridging IoT protocols	2021	Bridging protocols and architectures for IoT.	IoT, communication protocols.	IoT Communication
IEC 63278	Industrial-process measurement, control, and automation — Digital factory framework for system configuration	2022	Guidelines for configuring and managing digital factory systems.	Digital factories, industrial automation.	Digital Factory
ISO/IEC DIS 23894	Cybersecurity — Data security and privacy framework	2022	Framework for data security and privacy.	Data management, privacy and security.	Cybersecurity Framework
IPC-2551	Generic Standard for Smart Manufacturing Systems	2022	Provides guidelines for smart manufacturing systems integration.	Manufacturing, smart systems, automation.	Smart Manufacturing
ITU-T Y.3090	Framework for AI-Based Network Management and Control	2022	Provides a framework for managing and controlling networks using AI.	Network management, artificial intelligence, telecommunications.	AI in Network Management
ISO/IEC DIS 23894	Cybersecurity — Data security and privacy framework	2022	Framework for data security and privacy.	Data management, privacy and security.	Cybersecurity Framework
ISO/IEC DIS 27400	Cybersecurity and IoT — Security and privacy management guidelines	2023	IoT security risk management standard.	IoT, cybersecurity, risk management.	Cybersecurity & IoT
ISO/IEC AWI 30172	Internet of Things (IoT) — Bridging mechanisms in IoT devices	In Progress	Standards for bridging mechanisms in IoT devices.	IoT, network management.	IoT Mechanisms
ISO/IEC AWI 30173	Internet of Things (IoT) — Bridging protocols in IoT devices	In Progress	Development of standards for bridging protocols in IoT devices.	IoT, network protocols.	IoT Protocols

Table 1. Continued

ISO/IEC AWI 5339	Internet of Things (IoT) — Open data sharing framework	In Progress	Standards for open data sharing in IoT.	IoT, data sharing, open networks.	IoT & Data Sharing
ISO/IEC AWI 5339	Internet of Things (IoT) — Open data sharing framework	In Progress	Standards for open data sharing in IoT.	IoT, data sharing, open networks.	IoT & Data Sharing
ISO/IEC AWI 5392	Internet of Things (IoT) — IoT device lifecycle management	In Progress	Standards for managing IoT device lifecycle.	IoT, device management, lifecycle systems.	IoT Device Management
ISO/IEC AWI TR 5469	Information security — Privacy impact assessment	In Progress	Guidelines for conducting privacy impact assessments.	Data security, privacy management, risk assessment.	Privacy & Risk Assessment
ISO/IEC FDIS 22989	Artificial intelligence — Artificial Intelligence concepts and terminology	In Progress	Standardizing terminology and concepts for AI.	AI, data science, digital systems.	AI & Terminology
ISO/IEC FDIS 38507	Information governance — Governance implications of the use of AI	In Progress	Governance of AI in information systems.	AI governance, information management.	AI Governance
P 3144	Standard for Digital Twins for Industrial Systems	In Progress	Guidelines for implementing digital twins in industrial systems.	Industrial systems, digital twins, manufacturing.	Digital Twin

3.1. ISO 23247

To facilitate the creation of ISO digital twins, the concept of "observable production elements" was identified. These elements include personnel, equipment, materials, production processes, facilities, the environment, products and supporting documentation. The primary objective of the ISO 23247 series is to establish a framework that offers comprehensive guidelines, reference architectures, methods, and approaches for developing digital twins by monitoring these "observable production elements" within production contexts (ISO, 2021).

Digital twins play a crucial role in identifying anomalies in production processes, and they are aligned with functional goals such as real-time control, predictive maintenance, in-process adaptation, big data analytics, and machine learning. They achieve this by continuously updating pertinent operational and environmental data, thus enabling the monitoring of these 'observable production elements'. Transparency in processes and execution provided by digital twins contributes to optimizing manufacturing operations (ISO, 2021).

The applicability of the ISO 23247 framework to supporting production types hinges on the standards and technologies available for modeling "observable production elements." Different data standards might be employed across diverse production domains.

The scopes of the four parts within this series are as follows:

ISO 23247-1: Overview and principles

ISO 23247-2: Reference architecture,

ISO 23247-3: Digital representation of production elements,

ISO 23247-4: Information exchange

Figure 2 illustrates the interrelations among the four parts of this series.

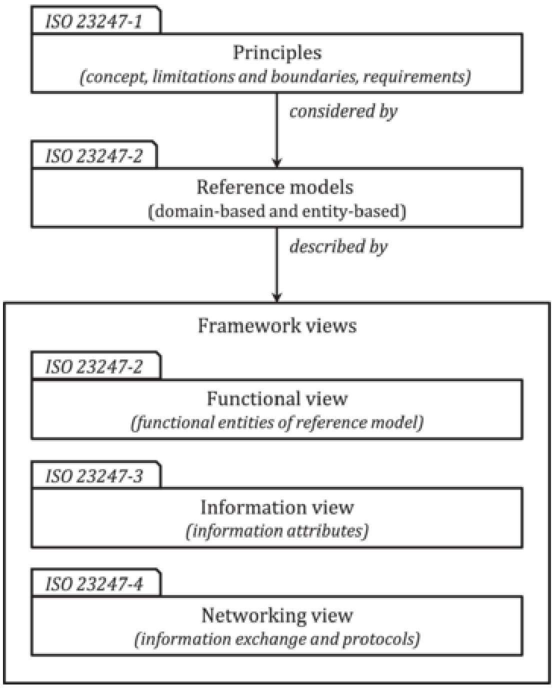

Figure 2. *ISO 23247 series structure (ISO, 2021)*

ISO 23247 Part 1: Overview and General Principles

This section outlines the general principles and requirements governing the development of digital twins in production environments. It establishes terminologies for each segment of the standard and delineates synchronization and communication protocols between digital twins and observable production elements, ensuring the optimization and real-time status of data sourced from these elements.

ISO 23247 Part 2: Reference Architecture

Part 2 covers the reference architecture for digital twins in manufacturing, considering perspectives from both domain and entity perspectives. The architecture comprises four domains: the observable production domain, data collection and device control domain, core domain, and user domain. Each domain delineates a logical array of tasks and functions executed by functional entities. Figure 3 illustrates the functional entity view of the reference architecture model.

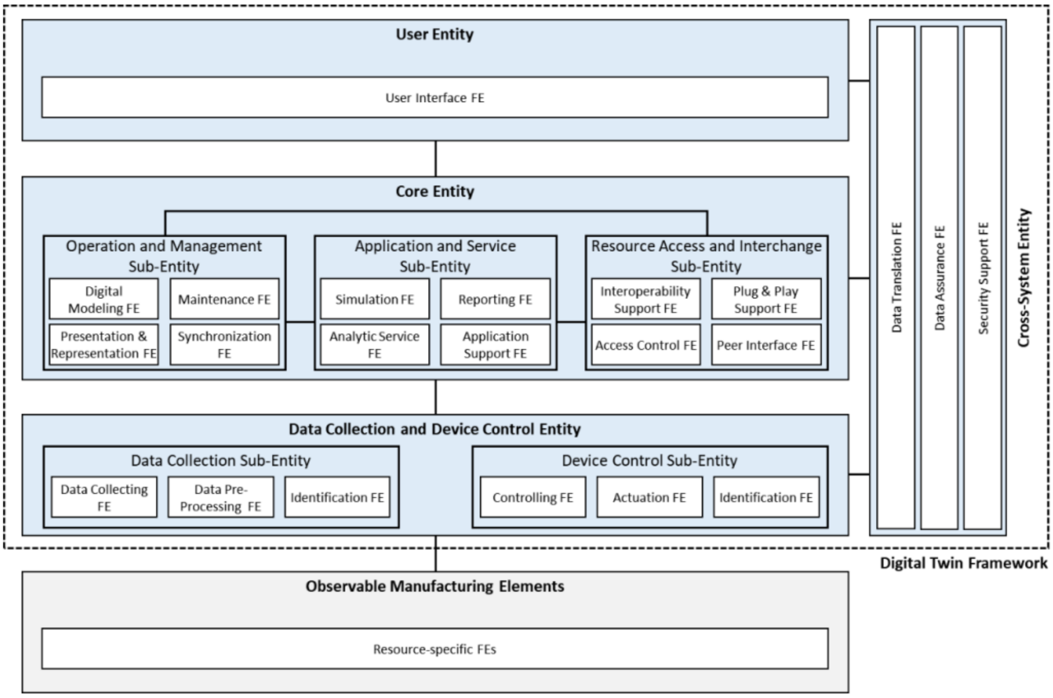

Figure 3. Digital twin manufacturing framework *(Shao, 2021)*

ISO 23247 Part 3: Digital Representation

Part 3 details the digital representation aspect and elucidates the fundamental information attributes—both static and dynamic—pertaining to observable production elements.

ISO 23247 Part 4: Information Exchange

This section outlines the technical requirements for information exchange among entities in the reference architecture. It defines the user network, service network, access network, and proximity network. Furthermore, it provides illustrative use cases illustrating the framework and presents a selection of standards and technologies applicable to information exchange.

4. DISCUSSION and CONCLUSION

Manufacturing is undergoing a digital transformation dubbed Industry 4.0. As a key technology to enable this digital transformation, digital twins enable manufacturers to digitally represent their assets, diagnose problems in advance, collect and manage relevant data, predict and optimize the response of their assets under different conditions. Recently, there has been a growing interest from both academia and industry in the potential benefits of digital twins. As an emerging technology, the digital twin creates a virtual representation of physical objects and develops predictive strategies. Digital twins are virtual representations of resources that organize and manage knowledge and are tightly integrated with AI, machine learning and IoT to further optimize and automate production. All these technologies and models that make up the digital twin are not new. They have been around for some time and have reached a level of maturity to prove their effectiveness. So the power of the digital twin, but also its complexity and difficulty, is not that it is a new technology, but that it brings together many new but mature disruptive technologies. Its power comes when the digital twin brings all these technologies and applications together, and this integration needs standards and common concepts. The Internet of Things, which makes it possible to collect a wide variety of types of data from a variety of objects, advances in powerful but low-cost processing and storage, artificial intelligence applications to help model and optimize the acquired data, and advances in virtual and augmented reality that enable cost-effective visual viewing of digital representations have been important building blocks for the expected benefits of digital twin applications. While the standards established for all these applications are important building blocks for the standards to be established for the digital twin, they are also important challenges for integration.

The potential applications and benefits of digital twins have been demonstrated in both academic and industry applications. The next step is to develop standards and harmonize existing standards to make these applications widespread. While individual companies are starting to use digital twins, there are significant challenges for manufacturers, especially small and medium-sized enterprises, to implement digital twin applications correctly and effectively. The lack of relevant standards for digital twins is a barrier to wider adoption. Because digital twins involve highly complex data collections and functional subsystems, many manufacturers struggle to know where to start when implementing digital twins. While standards are often controversial and seen as premature at first when a new technology emerges, the widespread adoption of digital twin technology depends on standards development efforts.

This study focuses on the digital twin standards developed to broaden and facilitate the usage of digital twins. Digital twins are a significant component for the realization of smart manufacturing. However, due to their multidisciplinary nature, scarcity of applications, and the necessity of integrating emerging technologies, they possess a complex and at times challenging structure. Reducing this complexity, establishing standardized terminology, and having a common architectural framework that promotes interoperability will enhance the application success of digital twins. In this regard, the existence of the ISO 23247 standard, put forward by the International Standards Organization, fills a crucial gap for practitioners. The number of studies related to digital twins in the literature, especially concerning the ISO 23247 standard, is quite limited. This study aims to examine these standards to fill this gap in the literature and contribute significantly to the field for both practitioners and researchers. Additionally, given the scarce number of studies aligned with this standard, there is a need to identify aspects of the standard that are open to improvement.

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