CHANGE2TWIN

FIRST REPORT ON STANDARDS RELEVANT FOR DIGITAL TWINS

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EXECUTIVE SUMMARY

The implementation and use of digital twins in Small and Medium-sized Enterprises (SME) is much facilitated by deploying standards. This document is the first in a series of three to highlight the role of standards in digital twins and to contribute to good practice for digital twin implementations.

This first document identifies relevant standardisation bodies and organizations that work on digital twin standards in domains like communication, data interoperability, security, quality, user interaction / ergonomics, engineering domains and many more. The wealth of standards that they are producing has been surveyed by several projects and organizations already. Such surveys were evaluated by the team and presented to the Change2Twin pilot owners and enabling technology providers. Change2Twin partners have selected standards of their interest, described the role of these in the Change2Twin platform and indicated their type of involvement with these standards and standardisation bodies.

Future standards related activities in Change2Twin will be guided by this analysis and will include, among others:

- Validation of the selected standards in the pilots for their benefits in digital twin solutions,
- Contributions to standards bodies to cope with deficiencies of these standards, and
- Evaluation of the compatibility of these standards with SME requirements.

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1 DOCUMENT SCOPE

The use of standards is essential for digital twins. Standards help to overcome digital twin barriers, like the one called “[BAR-T5] Bringing it all together” in Change2Twin D1.1 “Digital Twin Barriers”. Interoperability of hardware, software and data from a heterogeneous environment is one important example that requires widely accepted and validated agreements. Especially small and medium-sized enterprises (SME), due to their limited resources, greatly benefit from the existence of standards. The pure existence of the documents, however, is not sufficient and needs to be coupled with best practice guides and support of the standards in the market.

Change2Twin considers standards as an enabling technology. This is why Task 1.5, “Link between the different standards” is part of Work package 1, “Enabling technologies for digital twins”, along with other technologies for digital twins, such as communication, security, quality, user interaction / ergonomics or engineering. Standards facilitate the use of enabling technologies in digital twins. Like other technologies, standards need to be developed, validated and maintained; this is in scope of Task 1.5 . Our activities include reviews of standards, recommendations to users and feedback to standardisation bodies. Our results will support, among others, enabling technology vendors in Task 1.3 “Adapt solution provider technologies for more general approach”, to improve their competitiveness in the market.

This deliverable D1.2, “First report on standards relevant for digital twins”, presents an initial analysis of relevant standards based on publicly available surveys from other projects and organizations as well as on input by Change2Twin (C2T) partners. The editor team has collected standards that may be relevant to Change2Twin solutions with the purpose of presenting the wealth of standards to the project. Project partners have identified standards of importance to their contributions to digital twin solutions. They have indicated how they will address the development of those standards during the project period.

This document addresses a public audience of the following types of readers:

- Developers of digital twin standards,
- Developers of digital twin solutions, and
- People with working knowledge of complex system architectures and information and communication technology solutions.

Chapter 3 gives an overview of standardisation bodies that are developing standards for digital twins and smart manufacturing.
Chapter 4 introduces surveys that other projects and organizations have conducted to identify such standards and that were considered as a useful input to this report.
In Chapter 5 the C2T partners commit to standards for the aspects of digital twins that they support. The roles of the standards in achieving C2T objectives are highlighted.
Chapter 6 concludes this report and provides an outlook of the planned activities up to the second standards related report in May 2022.
Appendix A presents the most comprehensive list of relevant standards that the project could find supplemented by standards that the C2T consortium considers important beyond those. The list also identifies the types of involvement by the C2T partners in the listed items, that is, whether they use, monitor or develop these standards.

2 ACRONYMS

Table 1 lists the most used acronyms in this document. Acronyms that only appear in the listings of standards are not included here.

TABLE 1: ACRONYMS

Acronym	Definition
3D	Three-dimensional
3MF	3D Manufacturing Format
AI	Artificial Intelligence
AP	Application Protocol
AP209	ISO 10303-209, Multidisciplinary analysis and design
AP239	ISO 10303-239, Product Lifecycle Support (PLCS)
AP242	ISO 10303-242, Managed model based 3D engineering
API	Application Programming Interface
ASTM	American Society for Testing and Materials
C2T	Change2Twin, EU-project
CAD	Computer-Aided Design
CEN	European Committee for Standardization
CENELEC	
DDS	Data Distribution Service
DIN	Deutsche Industrienorm
DMP	Digital Manufacturing Platforms
ECSS	European Cooperation on Space Standardisation
EFFRA	European Factories of the Future Research Association
EFPF	European Connected Factory Platform for Agile Manufacturing
EFTA	European Free Trade Association
ESA	European Space Agency
ETSI	European Telecommunications Standards Institute
EU	European Union
HPC	High Performance Computing
ICT	Information and Communications Technology
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
ISO	International Organization for Standardization

Acronym	Definition
JTC	Joint technical committee
JWG	Joint working group
ML	Machine Learning
MQTT	Message Queuing Telemetry Transport
NIST	National Institute of Standards and Technology (USA)
OASIS	Organization for the Advancement of Structured Information Standards
OCC	Open Cloud Consortium
OCF	Open Connectivity Foundation
OMG	Object Management Group
OPC	Open Platform Communication
R&D	Research and Development
RAMI	Reference Architectural Model for Industrie 4.0
RD	Reference Document
SBS	Small Business Standards
SC	Sub-commitee
SME	Small and Medium-sized Enterprises
SPEC	Standard Performance Evaluation Corporation
STEP	STandard for the Exchange of Product model data
TC	Technical committee
TR	Technical Report
TS	Technical Specification
VDMA	Verband Deutscher Maschinen- und Anlagenbau
W3C	World Wide Web Consortium
WP	Work Package

3 STANDARDISATION BODIES FOR DIGITAL TWINS

Some standards for digital twins support the infrastructure of a digital twin implementation; they may be categorized as generally applicable. They concern matters of reference architectures, the Internet of Things, hardware interfaces, low level network protocols including cloud communication, data interoperability (low level), data archival, data security including blockchain, data quality, sensors, big data, artificial intelligence and machine learning, and many more.
Other standards are domain specific. Their applicability depends on the purpose of a digital twin, which may be manufacturing or predictive maintenance for example. Such domain specific standards address processes, process specific hardware and software (such as manufacturing machines or robots), the data semantics of the application (for example manufacturing data or maintenance data), messaging, key performance indicators, and more.
Due to this large scope of two major categories – generally and domain specific – and many sub-categories, standards with relevance for digital twins stem from many standardisation bodies. There is not one standard for digital twin, there are rather hundreds, and there is not one responsible standardisation body, rather ten. Therefore, it is difficult to find one's way through the huge amount of standard related information. Below, we introduce some major standardisation bodies – we focus on the international ones, although also some national ones are listed; most of the standards mentioned in this document originate from the organizations listed below.

Key standardisation bodies or organizations with relevance to digital twins:

- **International Organization for Standardization** (ISO) is an independent, non-governmental international organization consisting of 165 national standards bodies. It unites experts for the sake of sharing knowledge and to develop voluntary, consensus-based, market relevant standards to support innovation and provide solutions to global challenges, like using digital twins to ensure smart production and system operation in smart industry context. ISO is developing standards in all domains that are not covered by IEC. ISO and IEC harmonize their activities closely, currently especially in the areas of smart manufacturing and digital twins.
- **International Electrotechnical Commission** (IEC) is similarly structured and also a well-attended international standardisation organization as ISO. IEC publishes international standards for all electrical, electronic and related technologies. IEC standards include energy production and distribution, electronics, magnetics and electromagnetics, electroacoustics, multimedia, telecommunication and medical technology, as well as associated general disciplines such as terminology and symbols, electromagnetic compatibility, measurement and performance, dependability, design and development, safety and the environment.
- **European Committee for Standardization (CEN)** and **European Committee for Electrotechnical Standardization (CENELEC)** are private international non-profit standardisation organizations controlled by 34 national members. They consider themselves as "business catalysts in Europe, removing trade barriers for European industry and consumers. Their mission is to foster the European economy in global trading, the welfare of European citizens and the environment. Through their services they provide platforms for the development of European Standards and other technical specs." CEN and CENELEC cooperate with their international "sister" organizations ISO and IEC for global standards to facilitate international trade. In distinction from ISO and IEC, CEN and CENELEC work closely with the European Commission to develop standards that correspond with relevant EU legislation ("Harmonised Standards"). Digital twin related contributions seem to be focused on product maintenance processes.
- **European Telecommunications Standards Institute** (ETSI) is the third European Standards Organization that is officially recognized by the EU and may, thus, provide "Harmonised Standards". ETSI supports else the development and testing of global information and

communications technology (ICT) standards across all sectors of industry and society. ETSI is an independent, not-for-profit, membership-based standardisation organization. In this survey, we have not met specifically digital twin related material by ETSI.

- **European Space Agency** (ESA) "has a strong commitment to support the European Cooperation for Space Standardisation (ECSS), an initiative established to develop a coherent, single set of user-friendly standards for all European space activities"[2]. ECSS documents have controlled the lifecycle of space systems for a long time, and they are involved in one of the Change2Twin pilots. Thus, digital twin solutions will need to take those standards into account, and ECSS standards will change to accommodate digital twins for the space industry.
- **American Society for Testing and Materials** (ASTM) is an international standards organization consisting of individual and organizational members that publishes standards for a wide range of materials, products, processes and services. ASTM operates over 12,000 voluntary consensus standards globally. In relation to digital twins, ASTM standards may provide the semantics of aspects of a product, such as geometric dimensions and tolerances.
- **World Wide Web Consortium** (W3C) is an international membership organization of individuals and organizations that "develops open standards to ensure the long-term growth of the Web"[3]. Examples of W3C standards include HTML, XML, URI, RDF, OWL, SOAP and SPARQL. Several W3C standards are also published as ISO standards. W3C standards play an important role in digital twin solutions.
- **Object Management Group** (OMG) is a not-for-profit standards consortium founded in 1989. Vendors, end-users, academic institutions and government agencies develop internationally enterprise integration standards for a wide range of technologies and industries. For digital twins highly relevant consortia currently include the Industrial Internet Consortium (IIC), with over 250 members and formed to accelerate development, adoption and widespread use of interconnected machines and devices and intelligent analytics. More recently, a sister consortium of the IIC, called the Digital Twin Consortium (DTC), coalesces industry, government and academia to drive towards consistent vocabulary, architecture, security, and interoperability of digital twin technology. Key industries of theirs include manufacturing, and aerospace & defense.
- **Organization for the Advancement of Structured Information Standards** (OASIS) is a global not-for-profit membership-based consortium that works on the development, convergence and adoption of open standards for cybersecurity, blockchain, Internet of Things (IoT), emergency management, cloud computing, legal data exchange, energy, content technologies, and other areas. Although the topics sound relevant for the context at hand, this survey could not identify a specific interest in OASIS deliverables.
- **Institute of Electrical and Electronics Engineers** (IEEE) is a professional association dedicated to advancing technology for the benefit of humanity. With nearly 1300 standards and projects under development, IEEE develops industry standards in a broad range of technologies that drive functionality, capabilities, and interoperability of products and services, transforming industries, like smart industry, and are critical to advanced digitization trends like the digital twin.
- **Standard Performance Evaluation Corporation** (SPEC): SPEC is a non-profit corporation that aims to establish, maintain and endorse standardized benchmarks and tools that evaluate performance and energy efficiency for the newest generation of computing systems. This is essential, especially for the storage, processing and transportation of data using systems like cloud computing, edge computing, and High Performance Computing (HPC) used by smart industry digital twin solutions.

[2] http://www.esa.int/Enabling_Support/Space_Engineering_Technology/Requirements_and_standards
[3] https://www.w3.org/?p=2335: About W3C

- **Verband Deutscher Maschinen- und Anlagenbau** (VDMA) is the German Mechanical Engineering Industrial Association. VDMA is one of the key association service providers in Europe and offers the largest engineering industry network in Europe. VDMA represents the entire process - from the component to the system, to the system suppliers on the system integrator and to service providers. VDMA integrates sector-specific developments around Industry 4.0 and has an active role in the development of Industry 4.0 standards under the umbrella of the NAM (DIN department for mechanical engineering).
- **3D Manufacturing Format** (3MF) is a consortium of industrial partners working to define a 3D printing format that "will allow design applications to send full-fidelity 3D models to a mix of other applications, platforms, services and printers"[4]. The consortium consists of partners representing CAD industry as well as 3D printing vendors and technology companies. 3MF, thus, provides one of the many interoperability formats that are so important in cost-efficient digital twin solutions.

4 RELATED STANDARDS SURVEYS

Many resources are available to express the digital twin example studies or implementations, tools, or views of academics and companies [RD7], like Deloitte [RD8]. Particularly, a standardized framework would provide a means to manage the large and quite complex set of standards, technologies, and processes involved in such an implementation. Although the importance of standards for data and connectivity are highlighted in Deloitte's conceptual architecture, no explicit reference is provided. However, they do form a fundamental part of the manufacturing digital twin.
Especially ISO and IEC have recognized the need of frameworks of standards, not only to help those who want to apply standards, but also to better coordinate the work of the many standards committees. Standards that serve a common industrial purpose are collected and their contributions categorized. A terminology is established to make this possible. Current focus is manufacturing under the headings of "Smart manufacturing" and "Digital twins for manufacturing" and the most prominent representatives of this class of standards are the following ones that are listed with increasing applicability to Change2Twin:

- ISO/TR 23087:2018 - Automation systems and integration — The Big Picture of standards
  - Aims at monitoring the consistency of published standards and current or future standardisation projects for manufacturing in general.
- ISO/IEC 63306 - Smart manufacturing standards map
  - Part 1 - Framework (2020): Describes the framework and the vocabulary that are used for the development of entries in the Smart Manufacturing Standards Map Catalogue. These enable the mapping and linking of standards and standard projects related to various aspects of smart manufacturing (product, production, supply chain, industrial services ...).
  - Part 2 - Catalogue (under development)
- ISO 23247 Digital Twin manufacturing framework
  - Part 1 to Part 4 (under development): 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.

Whereas it is good news that existing and future manufacturing standards will be better harmonized and accessible, the work is tedious and time consuming. Of the three initiatives listed above, we

[4] https://3mf.io/

consider ISO 23247 to be the most supportive one for immediate implementations and the Change2Twin platform.

Besides these overviews that are initiated by standardisation bodies themselves, standards surveys have been published or are still in work by industrial groups and projects. We have studied a selection of those driven by the wish to reuse relevant results. Thus, we were able to start our survey of standards that Change2Twin partners consider relevant, which is summarized in Chapter 5, with an existing list of applicable standards. As a result of this survey, we want to extend the most comprehensive survey by Change2Twin identified standards; see Appendix A.

The following Table 2 includes the sources that we have consulted. Each source references many standards and is further discussed in the chapter reference in the rightmost column.

TABLE 2: LIST OF SOURCES OF EVALUATED STANDARDS SURVEYS

Id	Source	Details	See
1	ECSEL JU - Productive 4.0 - Electronics and ICT as enabler for digital industry and optimized supply chain management covering the entire product lifecycle	Productive40_D6.1_Standards_Guide_version_1_final.pdf	Ch 4.1
2	European Connected Factory Platform for Agile Manufacturing	www.efpf.org	Ch 4.2
3	Zero Defects Manufacturing Platform	www.zdmp.eu	Ch 4.3
4	Industry 4.0 by Fraunhofer IAIS (2017/18)	http://i40.semantic-interoperability.org/	Ch 4.4
5	Digital Manufacturing Platforms (DMP) cluster	https://www.efpf.org/event/DMP-Cluster-Meeting	Ch 4.5

4.1 PRODUCTIVE 4.0 STANDARDS

Productive 4.0 is a recently completed innovation project in the field of the Digitising Industry, which involved 109 partners around Europe. Its focus is to develop a framework to efficiently design and integrate hardware and software solutions of the IoT within the entire value chain. In 2018 the project partners released a document about their standardisation activities, see [RD5], which have been classified into six major categories. The following list assigns the committees and the standards that were considered relevant for the implementation of the project, to these categories.

Functional safety, reliability, (cyber-) security and co-engineering:

- IEC TC65 SC65A - IEC 61508[5]
- IEC TC65 WG10 - IEC 62443
- IEC TC65 WG20, WG22 - IEC 63069, IEC 63164
- IEC TC56 Dependability - IEC 62853
- IEC TC56 - IEC 62741
- IEC SC65E - Function Blocks
- Ind. Control, safety performance levels EN/ISO 13849
- ISO/IEC JTC1 SC27 Security - ISO 27000-series
- NIST (Guide to Ind. Control Systems, event recovery) - NIST Special Publ. 800-82, 800-184

Security (authentication, internet) and communication (wireless, bus systems):

- ISO/IEC JTC1 SC27 - ISO/IEC 15408
- BSI (HW security elements for I40) BSI 314
- CENELEC WG 26 CENELEC IT Security
- FIDO Alliance FIDO2.0
- ETSI ISG-QKD ETSI QKD (Quantum Key Distrib.)
- ETSI Smart M2M/IoT, oneM2M
- ETSI ITS
- TG41 ETSI Wireless
- WG 802.11, .15 - IEEE Wireless
- IEC SC65C IEC 62948 etc. Wireless
- IEC SC65C ProfiBus
- VDMA Fieldbus
- TTEthernet SAE AS6802
- Deterministic Ethernet IEEE 802.1

Smart manufacturing, enterprise architectures:

- OPC Foundation - OPC-UA, DA, HDA IEC SC65E
- IEC AHG3, ISO/IEC TC65 JWG21, SC65E - Smart Manuf. AHG3, Modeling AHG1
- DKE WG Ind. 4.0 - RAMI40
- IEC TC65 SC65B - IEC 62453 (Field device tool interface)
- VDI/VDE GMA FA6.23 - Plant Asset Mgmnt.

Semiconductors and computing platforms:

- SEMI TF - SEMI-series
- TCG - TPM2.0
- IEEE WG (VHDL mixed signal ext.) - IEEE 1076.1-2017

[5] see: https://www.iec.ch/dyn/www/f?p=103:23:22514154717794::::FSP_ORG_ID,FSP_LANG_ID:1369,25

- Accellera - SCV, UVM-SystemC group
- IRDS - Wafer environmental Contamination control

Domain-specific standards such as automotive, railways, building and home automation, machinery and robotics, etc.:

- ISO TC2 SC32 WG08 ISO 26262, ISO PAS 21488
- ISO/SAE JWG1, ISO TC22 SC32 WG11 - ISO 21434
- ISO TC22 SC31 - Extended Vehicles Stds.
- ISO TC 110 SC2 - Industrial Trucks Safety
- ISO TC 299 - Robotics
- IEC TC44, ISO TC184 - Safety of Machinery
- DIN (UAS) - DIN 5452-1
- VDI (Planning of electrical systems in buildings) - VDI 2166
- CEN, ISO - (Security)Cards and Ticketing Systems
- VDI Driverless transport systems - VDI 2510, 4451
- Financial services ISO 20022
- Railway Stds. Bodies (ÖVE, TSK, TMA) - EN 50126, 50128, 50129
- CENELEC TC205, 59 - Home-und Building electronics
- RTCA/EUROCAE - DO 178C, 254

Simulation, modelling, AI and machine learning, Big Data, data exchange formats, service ontologies:

- VDI 3633.x - Simulation Stds.
- SISO (Core manufacturing simulation data) - SISO 008-01-2012
- ISO/IEC JTC1 SC41; IIC - IoT, sensor networks
- ISO/IEC JTC1 SC42 - AI, Machine Learning
- CENELEC TC 106X - EMC, EMF
- IEC (Data Exchange Format) - IEC 62714
- ISO (High level Petri Nets) - ISO 15909-2:2011
- Modellica Ass. - Modelica
- OMG, IEC TC 211 - UML, IEC 19505
- OMG - SysML
- OMG - CVL
- IIB - IIB-Standards
- ISO/IEC JTC1 Big Data - ISO/IEC 20546, 20547
- ISO TC211 - Service Ontologies
- Topology/Orchestration for the Cloud - OASIS TOSCA
- 3D Modeling, Open Geodata - OGC
- ISO 10303, 18876, 15531 - STEP, IIDEAS, MANDATE
- MAP - FMI2.0, SSP1.0
- Google, many open-source tools - Trip planning, Google GTFS

4.2 EFPF STANDARDS

The European Connected Factory Platform for Agile Manufacturing (EFPF) is an EU H2020 funded Factory of the Future project. Its goal is to grow an ecosystem that enables the transition from "analog" mass production to "digital twins" and "lot-size-one" manufacturing using solutions from Industry 4.0, IoT, AI, Big Data and Digital Manufacturing domains. In 2019, they published a standardisation plan [RD1] that assigns relevant standardisation bodies and standards to categories of industrial use. The following bulleted lists are abbreviated citations from Chapter 3 of [RD1].

Digital / Smart Manufacturing:

- ISO/TC 184/ IEC/TC 65/JWG 21
- IEC/TC 65/WG 23
- IEC System Committee SyC Smart Manufacturing
- OPC (https://opcfoundation.org/)
- IIC for Reference Architecture Model Industry 4.0/Smart manufacturing (https://www.iiconsortium.org/)
- OASIS activities for the Production Planning & Scheduling (https://www.oasis-open.org/)

Digital Twins:

- ISO/TC 184/SC 4 and ISO/IEC JTC 1/SC 27 for Digital Twin Manufacturing Framework

Integration and Interoperability:

- ISO/TC 184/SC 5 for Interoperability, integration, and architectures for enterprise systems and automation applications
- ISO/IEC JTC 1 /SC 41
- ETSI TC smartM2M
- oneM2M (http://www.onem2m.org/)
- IEEE (https://www.ieee.org/)
- W3C (http://www.w3.org/)
- AIOTI https://aioti.eu/ Initiatives for Internet of Things and related technologies

Blockchain:

- ISO/TC 307
- IEEE (https://www.ieee.org/)
- W3C (http://www.w3.org/) for Blockchain and distributed ledger technologies

Cloud Computing:

- ISO/IEC JTC 1 /SC 38
- OASIS (https://www.oasis-open.org/)
- Open Cloud Consortium (OCC) (http://opencloudconsortium.org/) for activities on Cloud Computing and Distributed Platforms

Chapter 4.3 of [RD1] includes a table of standards – which are authored by the above-mentioned standardisation bodies - that EFPF considers important for an open ecosystem. Although EFPF contributes to the efforts of the Digital Manufacturing Platforms (DMP) cluster (see Chapter 4.5, below), Table 3 is inserted below because not all of the standards are part of the DMP cluster listing that can be found in Appendix A.

TABLE 3: EFPF CATEGORIZATION OF STANDARDS FOR AN INTEROPERABLE PLATFORM

Category	Standard Acronym and Title
Industry 4.0 Standards	• AIOTI (Alliance for IoT Innovation) WG3 on IoT Standardisation & WG11 on Smart Manufacturing • oneM2M standards for M2M and the IoT covering many different industries • IEEE P2413 standard for an IoT Architectural Framework (based in ISO/IEC/IEEE 42010 Systems and software engineering – Architecture description) • RAMI 4.0, IEC PAS 63088:2017, Smart Manufacturing Reference Model(s); (drafted in JWG 21 between IEC/TC 65 and ISO/TC 184) • Special attention shall be given to IEC/TC 65/WG 23 dealing with Smart Manufacturing Framework and System Architecture having the potential to become an overlap with the work in JWG 21 • OCF (Open Connectivity Foundation) and ISO/IEC 30118, Information technology and OCF specification • OPC (Open Platform Communication) Unified Architecture for M2M Communication in Automation; OPC-UA • OASIS MQTT (Message Queuing Telemetry Transport); OASIS AMQP (Advanced Message Queuing Protocol) • ISO 11354, Advanced automation technologies and their applications -- Requirements for establishing manufacturing enterprise process interoperability (multipart standard) • ISO 15745, Industrial automation systems and integration -- Open systems application integration framework (multipart standard) • ISO 20534 Industrial automation systems and integration, Formal semantic models for the configuration of global production networks • ISO 22549 Assessment on convergence of informatisation and industrialisation for industrial enterprises (draft) • ISO 23247 Digital Twin manufacturing framework
Cybersecurity Standards	• IEC 62443 Industrial communication networks – Network and system security • ISO/IEC JTC 1/SC 27, IT Security techniques • ISO 13849 safety requirements and guidance • ISO/IEC TS 33052:2016 - Information technology -- Process reference model (PRM) for information security management • ISO/IEC 27017:2015 – Security Techniques – Code of Practice for Information Security Controls Based on ISO/IEC 27002 for Cloud Services • NIST SP 800-82 – Guide to Industrial Control Systems (ICS) Security • NIST Cybersecurity Framework – CSF • ENISA - Information Security and Privacy standards for Small and Medium Enterprises (SMEs) • ENISA - Procure Secure - A guide to monitoring of security service levels in cloud contracts • ISO/IEC TS 33052:2016 - Information technology -- Process reference model (PRM) for information security management

Category	Standard Acronym and Title
	• ETSI TS 103 457 CYBER; Trusted Cross-Domain Interface: Interface to offload sensitive functions to a trusted domain
Cloud Computing and Distributed Platforms Standards	• ISO/IEC TR 22678:2019 Information technology - Cloud computing - Guidance for policy development • ISO/IEC TR 23186:2018 Information technology - Cloud computing - Framework of trust for processing of multi-sourced data • ISO/IEC 19086-2:2018 Cloud computing - Service level agreement (SLA) framework - Part 2: Metric model • ISO/IEC 19941:2017 Information technology - Cloud computing - Interoperability and portability • ISO/IEC 19944:2017 Information technology - Cloud computing - Cloud services and devices: Data flow, data categories and data use • ISO/IEC 19086-3:2017 Information technology - Cloud computing - Service level agreement (SLA) framework -- Part 3: Core conformance requirements

4.3 ZERO DEFECTS MANUFACTURING PLATFORM (ZDMP)

The EU H2020 Factory of the Future project Zero Defects Manufacturing Platform (ZDMP) aims to establish and develop by the end of 2022 a digital platform for connected smart factories for achieving excellence in manufacturing through zero-defect processes and products.
Mid 2020 the project prepared an overview of standardisation bodies and standards with relevance for, among others, smart manufacturing and predictive maintenance, see [RD2]. Change2Twin enabling technologies and pilots focus mainly on these two use cases. Therefore, we below summarize the overviews of Chapters 1.2.3 and 1.2.5 of [RD2].

[RD2] Chapter 1.2.3:
“One of the most important aspects in smart manufacturing is the interoperability between the various types of machines, sensors, and devices. Unified connections between them and the overall semantics can be seen as enabler for smart manufacturing and as one of the main tasks of standardisation.
The most important standards to ensure interoperability are perceived to be:

- OPC UA (IEC 62541 series) – OPC Unified Architectures OPC UA Open Platform Communications United Architecture Series of standards, developed by the OPC foundation
- W3C World Wide Web Consortium standards HTML, XHTML, XML, RDF, OWL, CSS, SVG
- MQTT (ISO/IEC 20922:2016) – Information technology – Message Queuing Telemetry Transport (MQTT) v3.1.1 Message Queuing Telemetry Transport is a publish-subscribe-based messaging protocol. It works on top of the TCP/IP protocol
- ETSI TS 118112 V 2.0.0:2016 – oneM2M – Base Ontology Contains the specification of the oneM2M base ontology”

[RD2] Chapter 1.2.5:
“Maintenance is a topic which is well established in standardisation. Nevertheless, maintenance is experiencing substantial changes in connection with smart manufacturing. Reactive and periodic preventative maintenance strategies are increasingly being replaced by predictive ones. In the future, smart, interconnected factories will identify a large proportion of their faults before they occur. This will be enabled by different condition monitoring technologies so that a wide range of data related to a plant will be captured and analysed.

Most relevant basic standards are:

- EN 13306:2017 – Maintenance – Maintenance terminology Uniform definitions of the concepts underlying all types of maintenance and maintenance management have already been formulated in EN 13306:2018-02, irrespective of the objects or maintenance stakeholders involved.
- EN 17007:2017 – Maintenance process and associated indicators A detailed specification of the essential processes that form part of an overarching maintenance organisation and the associated reciprocal relationships can be found in EN 17007:2017, thereby ensuring that all entities involved in maintenance share the same understanding of the process."

[RD2] includes also, in its Figure 6, "Most important standards in ZDMP", a top 20 list of standards that resulted from a survey among project partners responsible for architecture components. This list is not included here because, ZDMP contributes to the more comprehensive efforts of the Digital Manufacturing Platforms (DMP) cluster (see Chapter 4.5, below). Thus, the ZDMP identified standards are included in the listing of Appendix A.

4.4 INDUSTRY 4.0 STANDARDS OVERVIEW BY FRAUNHOFER IAIS

[RD4] provides a webpage that classifies a set of standards by topics and relates them to the Industry 4.0 framework RAMI 4.0 by an interactive graphical representation. This representation is not as complete as some of the other standards surveys in this document, but the way of presenting the standards is user-friendly and may be considered for future Change2Twin T1.5 deliverables; see Figure 1, below.
Updated information and alternative ways of representation are available from the following GitHub page that is referenced by [RD4]:

https://i40-tools.github.io/StandardOntologyVisualization/

This updated web presentation is a valuable source of information and a good entry point to the standards listed. The presented information, however, needs a thorough quality review.
Therefore, this source of input has not been and will not be further pursued by T1.5 except for its user-friendly layout.

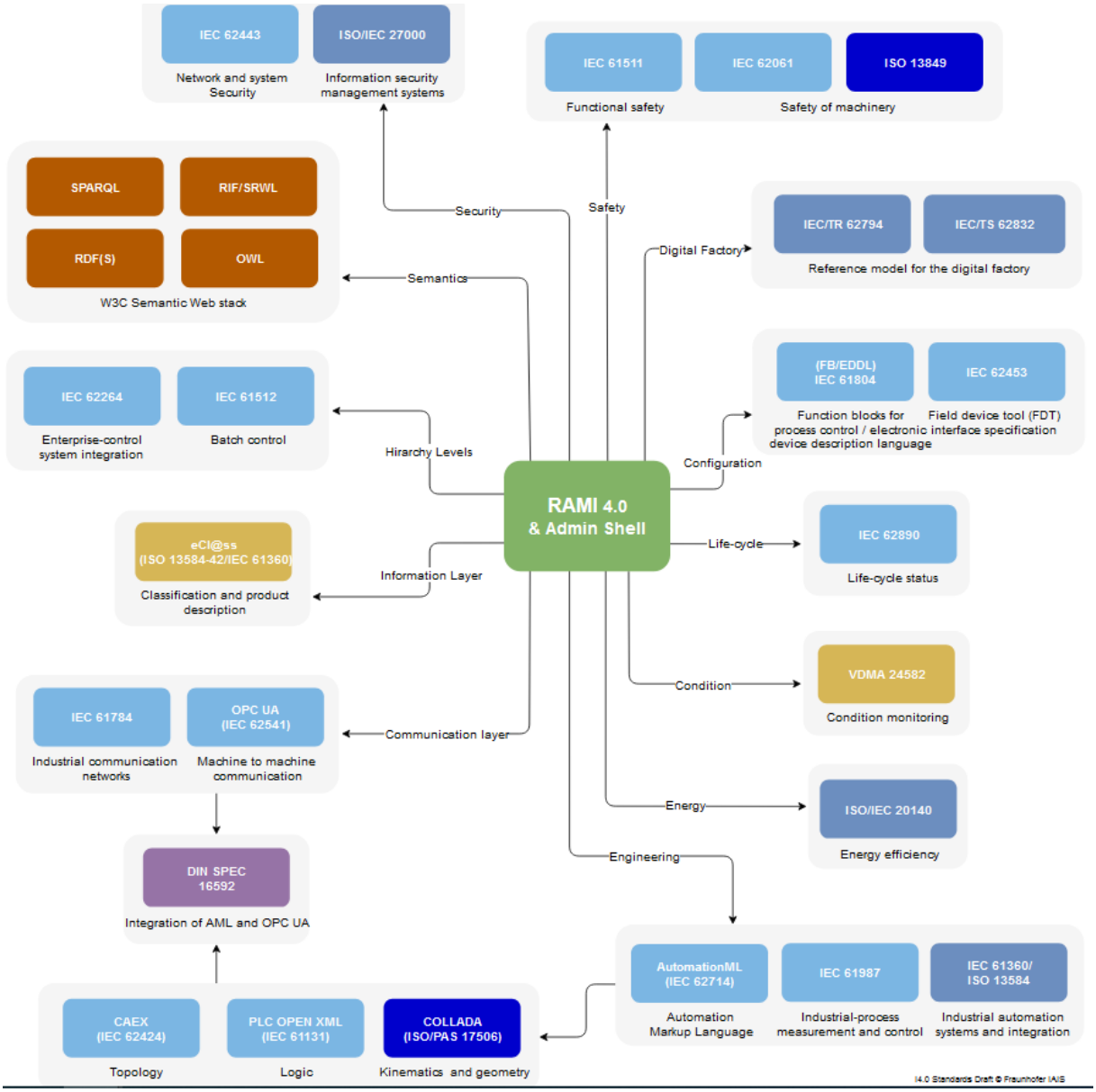

FIGURE 1: FRAUNHOFER IAIS OVERVIEW OF INDUSTRY 4.0 RELATED STANDARDS

4.5 DIGITAL MANUFACTURING PLATFORMS CLUSTER

The DMP cluster [RD6] is composed of six projects funded by EU R&D funds through the DT-ICT-07 calls in 2018 and 2019. The DMP cluster is pursuing joint activities in several areas (platform interoperability, dissemination, business models, standardisation, etc.) to synchronise related activities that take place in the different projects. For details, see https://www.efpf.org/event/DMP-Cluster-Meeting .

The European Factories of the Future Research Association (EFFRA) is a non-for-profit, industry-driven association promoting the development of new and innovative production technologies. It is the official representative of the private side in the 'Factories of the Future' public-private partnership. For details, see https://www.effra.eu/ .

With contributions by various organizations, EFFRA has prepared a table, see [RD3], that is on the one hand an overview of standards and on the other hand a mapping of those standards to the concepts of the Industry 4.0 architecture RAMI 4.0. The table is still work in progress.

This is the most comprehensive overview of standards with relevance for the Change2Twin world of discourse. The T1.5 team has, therefore, attached it to the standards survey among the Change2Twin partners. Partners could either just mark listed standards as relevant or add missing standards to the list.

The survey result is documented in an excerpt of the original DMP table in Appendix A that has been adapted for this purpose. In Table 5 in the appendix, Change2Twin partners have indicated their interests in the listed standards in the third column, called “C2T partner(s)”. Standards that were not yet in the original DMP table have been added in the subsequent Table 6.

In this column 3, the acronym of interested Change2Twin partners is followed by a letter in parentheses; this letter indicates the level of partner involvement as follows:

- U: using the standard,
- M: monitoring the development of the standard, and
- D: developing the standard, that is, contributing to the work of the standardisation body in maintaining the standard.

For each Change2Twin entry in Table 5 and Table 6, the respective Change2Twin partner added a sub-chapter to Chapter 5 including details of the role of the standard in the project.

5 STANDARDS IN FOCUS OF C2T

This chapter describes standards that C2T partners have identified in Table 5 and Table 6 in Appendix A to be of special interest when implementing digital twins for SMEs. Each such standard is represented by a sub-chapter and a table of its own. Each table highlights the main characteristics of the standard. In addition, the following aspects are emphasized:

- Use in C2T,
- Tool support in C2T,
- C2T contributions, and
- SME issues.

The so highlighted standards, their roles in Change2Twin and their developments in standardisation bodies, will be followed up in the further run of Change2Twin and specifically in Task 1.5.

5.1 ISO 10303-209 (AP209)

Name	Multidisciplinary analysis and design
Version	2014
Availability	www.iso.org
Category	Data model
Use case	Data exchange, sharing, archival

In scope	• All that is in ISO 10303-242
	  • a generic framework to represent mesh and mesh-less engineering analyses;
	  • digital data on structured and unstructured analysis model grids;
	  • linear static finite element analysis;
	  • linear modes and frequencies finite element analysis;
	  • the finite element analysis model, analysis controls, and analysis results information;
	  • the plane stress and simple plane strain types of linear static and linear modes and frequencies finite element structural analyses;
	  • data describing steady or unsteady fluid dynamics flow-fields;
	  • data describing the fluid dynamics model including analysis model grid description, grid inter-connectivity, boundary conditions, and modeling parameters;
	  • data from solutions of equation sets commonly used in fluid dynamics analysis: Navier- Stokes equations, Euler equations, linear and nonlinear potential flow equations, small disturbance equations, boundary layer equations, and stream function equations;
	  • single-phase flow of a liquid or a gas;
	  • laminar flow, transitional flow, turbulent flow (direct representation of turbulence, or represented by Reynolds-averaged data);
	  • incompressible or compressible flow;
	  • unsteady flow;
	  • perfect gas, or variable chemical composition (equilibrium flow, frozen flow, or finite-rate chemical reactions);
	  • data regarding the exchange of energy by molecular transport including convection, conduction, and advectation;

	• rotating flowfields (e.g., turbomachinery); • inertial and rotating frames of reference; • Newtonian transport laws; • reference to product geometry from the fluid dynamic flow fields; • administrative information necessary to track the approval and configuration control of the analysis of a product; • transfer of partial fluid dynamics data; • the graphical presentation of: • analysis model maps; • analysis output information displays on top of the analysis model mesh; • line drawings or images which document the part aspects subjected to detail analysis. The tabular presentation of: • the analysis assumptions such as those for structural idealizations, materials, boundary conditions, and applied loadings; • critical locations in analysis models and the associated detail analysis performed.
Use in C2T	Exchange of product analysis and physical testing data files to add to and maintain the digital twin repository
Tool support in C2T	SINTEF/SISL; SINTEF/go-tools; Jotne/EDMopenSimDM
C2T contributions	SINTEF: • Update STEP integrated resources for IGA (analysis share) Jotne: • Extend AP209 for non-linear analyses and for other types of analyses than structural ones (thermal, optical, etc.)
SME issues	Dependency on vendors of analysis and simulation applications and their (limited) support of AP209

5.2 ISO 10303-242 (AP242)

Name	Managed model-based 3D engineering
Version	2020
Availability	www.iso.org
Category	Data model
Use case	Data exchange, sharing, archival
In scope	• products of automotive, aerospace and other mechanical manufacturers and of their suppliers, including parts, assemblies of parts, tools, assemblies of tools, and raw materials • engineering and product data for the purpose of long-term archiving and retrieval • product data management • process planning • mechanical design

	○ different types of 2D/3D shape models, including wireframe, surface, solid, tessellated, parametric and scanned ones ○ presentation of the shape of the product ○ representation of portions of the shape of a part or a tool by manufacturing features ○ surface conditions ○ dimensional and geometrical tolerance data ○ quality criteria and inspection results of given three-dimensional product shape data ○ product documentation as annotated 3D models and as drawings • message • interface • mating • kinematics • analysis management • composite design • electrical harness assembly design • additive manufacturing part design • requirements management
Use in C2T	Exchange of product design data files (CAD, PLM, kinematics, electric wire harness, ...) to build and maintain the digital twin repository
Tool support in C2T	SINTEF/SISL; SINTEF/go-tools; Jotne/EDMopenSimDM; Jotne/EDMtruePLM
C2T contributions	SINTEF: • Update STEP resource modules for locally refined splines • Update STEP integrated resources for IGA (design share) Jotne: • Validation of the emerging minor revision of AP242 edition 2 by processing of test data
SME issues	Dependency on CAD-vendors and their (limited) support of AP242

5.3 ISO 15948 (PNG)

Name	Information technology — Computer graphics and image processing — Portable Network Graphics (PNG): Functional specification
Version	Edition 1
Availability	https://www.iso.org/standard/29581.html
Category	Data model
Use case	Data exchange, sharing, archival
In scope	• exchange, sharing and archival of image data and other data in regular pixel form (e.g., thermal imaging data, segmentation masks)
Use in C2T	• input and output to (convolutional) neural networks and other image processing algorithms

	• storage of reconstructed models
Tool support in C2T	SINTEF segmentation software (under development)
C2T contributions	SINTEF segmentation software will use PNG as an input format.
SME issues	To be analysed

5.4 ISO 23247 DIGITAL TWIN FRAMEWORK FOR MANUFACTURING

Name	Digital twin framework for manufacturing
Version	DIS of edition 1
Availability	For Experts only from ISO/TC 184/SC 4/WG 15
Category	Framework to support the creation of digital twins of observable manufacturing elements
Use case	Design of architectures for digital twins of observable manufacturing elements
In scope	• ISO 23247-1: Overview and general principles; • ISO 23247-2: Reference architecture; • ISO 23247-3: Digital representation of manufacturing elements; • ISO 23247-4: Information exchange.
Use in C2T	Validate the applicability of the ISO 23247 reference architecture to Change2Twin manufacturing processes and pilot architectures.
Tool support in C2T	Some of the recommended data representation and exchange mechanisms are supported by several Change2Twin enabling technologies (SINTEF, Jotne, …).
C2T contributions	Feed back validation results to the standardisation working group (ISO/TC 184/SC 4/WG 15).
SME issues	To be analysed

5.5 ISO/ASTM 52915:2020 (AMF)

Name	Specification for additive manufacturing file format (AMF)
Version	Version 1.2
Availability	https://www.astm.org/Standards/ISOASTM52915.htm iso.org (TC 261)
Category	Data model
Use case	Data exchange, sharing, archival
In scope	Representing data that is suitable for 3D printing/additive manufacturing.
Use in C2T	Representing 3D model data reconstructed from image segmentation algorithms.
Tool support in C2T	SINTEF segmentation software (under development)
C2T contributions	
SME issues	To be analysed

5.6 ISO/IEC 20922:2016 (MQTT)

Name	Message Queuing Telemetry Transport (MQTT)
Version	2016-06 - v3.1.1
Availability	iso.org; ISO/IEC JTC 1 Information Technology http://mqtt.org/documentation
Category	Open standard messaging protocol for the Internet of Things
Use case	https://mqtt.org/use-cases/
In scope	It is a publish/subscribe, extremely simple and lightweight messaging protocol, designed for constrained devices and low-bandwidth, high-latency or unreliable networks. The design principles aim at minimizing network bandwidth and device resource requirements whilst also attempting to ensure reliability and some degree of assurance of delivery. These principles also turn out to make the protocol ideal of the emerging machine-to-machine (M2M) or Internet of Things world of connected devices, and for mobile applications where bandwidth and battery power are at a premium. MQTT defines three Quality of Service (QoS) levels to satisfy the different requirements of data delivery: - QoS 0 - represents a best effort message delivery and does not guarantee that the message reaches the destination. - QoS 1 - guarantees that the sent messages arrive at subscriber nodes at least once, but possible repetitions can happen. - QoS 2 - guarantees that the messages are delivered to the subscriber nodes only once.
Use in C2T	Communication protocols
Tool support in C2T	TTTech/Nerve Blue
C2T contributions	Use of the standard
SME issues	Open protocols for M2M and IoT

5.7 ISO/IEC 21778:2017 (JSON)

Name	The JSON data interchange syntax
Version	2017-11
Availability	iso.org; ISO/IEC JTC 1 Information Technology https://www.json.org/json-en.html
Category	Open standard file and data interchange format
Use case	Payload format for REST-type web-services
In scope	JSON (JavaScript Object Notation) is a lightweight data-interchange format. It is easy for humans to read and write. It is easy for machines to parse and generate. It is based on a subset of the JavaScript Programming Language Standard ECMA-262 3rd Edition - December 1999. JSON is a text format that is completely language independent but uses conventions that are familiar to programmers of the C-family of languages, including C, C++, C#, Java, JavaScript, Perl, Python, and many others. These properties make JSON an ideal data-interchange language.
Use in C2T	Communication protocols

Tool support in C2T	TTTech/Nerve Blue
C2T contributions	Use of the standard
SME issues	Open protocols for M2M and IoT

5.8 ISO/IEC 19464:2014 (MESSAGE)

Use in C2T	UNIBO: Reliable, secure, binary format, general purpose message broker allowing for point-to-point or publish-subscribe communication.
Tool support in C2T	Open source projects (i) RabitMQ (AMQP pre-v.1.0) and (ii) Apache ActiveMQ (AMQP v.1.0).
SME issues	Secure and reliable message broker allowing structured communication among interested parties.

5.9 ISO/IEC 21823-1:2019 (IOT)

Use in C2T	UNIBO: Design guidelines and standards aimed at guaranteeing peer-to-peer interoperability among IoT systems.
Tool support in C2T	N/A
SME issues	To be analysed

5.10 ISO/IEC 21823-2:2020 (IOT)

Use in C2T	UNIBO: Recommendations and principles aimed at guaranteeing transport interoperability among IoT systems.
Tool support in C2T	N/A
SME issues	To be analysed

5.11 ISO/IEC TR 30164:2020 (IOT)

Use in C2T	UNIBO: Design principles, solutions and technologies applying to edge computing for IoT systems and applications.
Tool support in C2T	N/A
SME issues	To be analysed

5.12 ISO/IEC TS 23167 (CLOUD)

Use in C2T	UNIBO: Technologies and techniques applying to and used conjunction with cloud computing.
Tool support in C2T	Highly reliable, secure, multi-Cloud middleware solutions for data at rest and data in motion scenarios developed by the Mobile Middleware Group.
SME issues	To be analysed

5.13 ISO/IEC 19510:2013 (BPMN)

Name	Business Process Model & Notation™ (BPMN™)
Version	2.0.2, January 2014
Availability	http://www.omg.org/oceb-2/ ISO 19510:2013
Category	Process modelling, workflow
Use case	Modelling Production Process
In scope	Describe the processes and provide requirements and managing of information/documentation and data during production.
Use in C2T	Describe the production process and enable a digital model of the production process at the SME manufacturer site.
Tool support in C2T	BOC ADONIS
C2T contributions	BOC: • Model production processes • Identify concepts for manufacturing that are yet not considered • Develop an add-on for “Industrial Business Process Management” • Integrate data – coming from sensors or 3rd party databases – into the digital model of the production process
SME issues	To be analysed

5.14 ISO/PAS 17506:2012 (COLLADA)

Name	COLLADA
Version	2020
Availability	https://www.khronos.org/collada/
Category	Data model
Use case	Data exchange, sharing
In scope	COLLADA (COLLAborative Design Activity) is an interchange file format for interactive 3D applications and has been adopted by ISO as a publicly available specification, ISO/PAS 17506. COLLADA defines an open standard XML schema for exchanging digital assets among various graphics software applications that might otherwise store their assets in incompatible file formats. COLLADA documents that describe digital assets are XML files, usually identified with a .dae (digital asset exchange) filename extension. COLLADA was originally intended as an intermediate format for transporting data from one digital content creation (DCC) tool to another application.
Use in C2T	Unit040: Used for the exchange of 3D models with internal and external partners.
Tool support in C2T	Prespective
C2T contributions	Unit040: Use it to import 3D models from different sources to create digital twins.
SME issues	none

5.15 IEC 61131-3 (CONTROLLERS)

Name	IEC 61131-3 , Programmable controllers: programming languages
Version	2020-01-06
Availability	iec.ch
Category	Structured Text (ST), textual
Use case	Textual modeling language
In scope	Applies to programmable controllers (PLC) and their associated peripherals such as programming and debugging tools (PADTs), human-machine interfaces (HMIs), etc., which have as their intended use the control and command of machines and industrial processes. It gives the definitions of terms used in this standard. It identifies the principal functional characteristics of programmable controller systems. IEC 61131-3**,** Structured Text **IEC 61131-3 - Wikipedia**
Use in C2T	Textual description language - to enrich the graphical modelling language (UML)
Tool support in C2T	Cordis SUITE and Author-e
C2T contributions	N/A
SME issues	None

5.16 EN9100 – 2018 (QUALITY)

Name	Documented Information Quality Management Systems – Requirements for Aviation, Space and Defence Organizations
Version	2018
Availability	https://www.beuth.de/en/standard
Category	Quality management
Use case	Quality management system requirements, definitions and nots for aviation, space and defence industry
In scope	7.5.2: When creating and updating documented information, the organization shall ensure appropriate: a) identification and description (e. g., a title, date, author, or reference number); b) format (e. g., language, software version, graphics) and media (e. g., paper, electronic); c) review and approval for suitability and adequacy. 7.5.3.2: For the control of documented information, the organization shall address thefollowing activities, as applicable: a) distribution, access, retrieval and use; b) storage and preservation, including preservation of legibility; c) control of changes (e. g., version control); d) retention and disposition; e) prevention of the unintended use of obsolete documented information by removal or by application of suitable identification or controls if kept for any purpose. Documented information of external origin determined by the organization to be necessary for the planning and operation of the quality management system shall be identified as appropriate and be controlled. Documented information retained as evidence of conformity shall be protected from unintended alterations. When documented information is managed electronically, data protection processes shall be defined (e. g., protection from loss, unauthorized changes, unintended alteration, corruption, physical damage).
Use in C2T	All documentation related to product development
Tool support in C2T	N/A
C2T contributions	
SME issues	To be analysed

5.17 ETSI MEC - MULTI-ACCESS EDGE COMPUTING

Use in C2T	UNIBO: Multi-Access Edge Computing (MEC) reference architecture and integration with the telco domain.
Tool support in C2T	Open source ETSI-compliant projects like Open Baton and Open Source MANO (OSM) with custom built extensions.
SME issues	To be analysed

5.18 ECSS-M-ST-40C_REV.1

Name	Configuration and information management
Version	3rd Issue, Revision 1, 2009
Availability	https://ecss.nl
Category	Configuration management
Use case	Documentation and configurations of space products
In scope	Describe the processes and provide the requirements for managing the information/documentation and configuration of products within a space program or project. • configuration management • change management • documentation
Use in C2T	Version control for product requirement, design files and analysis files, update the files and connect it to the correct requirements
Tool support in C2T	Jotne/EDMtruePLM
C2T contributions	Jotne: • Extend EDMtruePLM support for PDM • Monitor standard development
SME issues	To be analysed

5.19 ECSS-Q-ST-80C-REV.1

Name	Software product assurance
Version	3rd Issue, Revision 1, 2017
Availability	https://ecss.nl
Category	Product assurance
Use case	Development and maintenance of space systems
In scope	• manned and unmanned spacecraft, launchers, payloads, experiments and their associated ground equipment and facilities • software components of firmware

	• development and reuse of software that affects the quality of the space products and services • supplier selection and procurement
Use in C2T	In each step of product development, manufacturing, and testing related to the space industry.
Tool support in C2T	N/A
C2T contributions	
SME issues	To be analysed

5.20 IEEE 802.1 TIME-SENSITIVE NETWORKING (TSN)

Name	Time sensitive networking
Version	Time-Sensitive Networking (TSN) Task Group | (ieee802.org)
Availability	https://www.techstreet.com/ieee
Category	Deterministic communication
Use case	Communication of critical information Ensuring bounded latency, low packet loss and delay variation
In scope	Industrial machines and plants today use specialized fieldbuses that are incompatible with each another and set strict requirements for networks in order to help achieve the necessary communication guarantees for applications. The advent of Time Sensitive Networking (TSN) now means that industrial communication can standardize on Ethernet in the same way that enterprise IT has done. TSN provides benefits to industrial automation by providing network services that include: • bounded latency guaranties, • reliable delivery of data, • increased availability of network services for end-devices, • easy integration of innovations from open networks (more bandwidth, reliability and options), and • ability to converge applications and traffic on a single, open network. TSN adds a range of functions and capabilities to Ethernet to make it more applicable to industrial applications that require more deterministic characteristics than possible in previous Ethernet implementations.
Use in C2T	
Tool support in C2T	TTTech/Nerve Blue
C2T contributions	TTTech: Extend OPC UA over TSN
SME issues	By using open and standard technologies like OPC UA and TSN in combination, SMEs can avoid the danger that fieldbus providers simply add new layers of proprietary technology on top of TSN (vendor lock-in).

5.21 IEEE 802.1 AS - TIMING AND SYNCHRONIZATION FOR TIME-SENSITIVE APPLICATIONS

Name	Timing and Synchronization for Time-Sensitive Applications
Version	D8.3 08.11.2019
Availability	https://www.techstreet.com/ieee
Category	Deterministic communication
Use case	Real-time monitoring of machine/devices (Anomaly detection, Predictive Maintenance, Asset performance management/Operations optimisation)
In scope	IEEE 802.1AS is being developed in the 802.1 working group as part of a set of standards for audio/video bridging (AVB). This standard specifies the protocol and procedures used to ensure that the synchronization requirements are met for time-sensitive applications, such as audio, video, and time-sensitive control, across networks; for example, IEEE 802 and similar media. This includes the maintenance of synchronized time during normal operation and following addition, removal, or failure of network components and network reconfiguration. It specifies the use of IEEE 1588 standard specifications where applicable in the context of IEEE Std 802.1Q. Synchronization to an externally provided timing signal (e.g., a recognized timing standard such as UTC or TAI) is not part of this standard but is not precluded.
Use in C2T	Software stack for IEEE 802.1AS
Tool support in C2T	TTTech/Nerve Blue
C2T contributions	TTTech: Contribute to the standard development
SME issues	To be analysed

5.22 IEEE 1934-2018 - STANDARD FOR ADOPTION OF OPENFOG REFERENCE ARCHITECTURE FOR FOG COMPUTING

Use in C2T	UNIBO: Reference architecture and design guidelines for a distributed, fog-based architecture.
Tool support in C2T	Eclipse Fog05 open source project and custom extensions made to the platform.
SME issues	To be analysed

5.23 IEEE 2413:2019 ARCHITECTURAL FRAMEWORK FOR THE INTERNET OF THINGS (IOT)

Use in C2T	UNIBO: Design guidelines and principles for a distributed IoT environment.
Tool support in C2T	N/A
SME issues	To be analysed

5.24 3D MANUFACTURING FORMAT (3MF)

Name	3D Manufacturing Format
Version	Version 1.2.3
Availability	3MF Consortium (https://3mf.io/specification/)
Category	Data model
Use case	Additive manufacturing - Data exchange, sharing, archival
In scope	Representing geometry and material data that is suitable for 3D printing/additive manufacturing.
Use in C2T	Representing 3D model data reconstructed from image segmentation algorithms.
Tool support in C2T	SINTEF segmentation software (under development)
C2T contributions	
SME issues	To be analysed

5.25 ANSI/MTC1.4-2018 (MTCONNECT)

Use in C2T	UNIBO: Definition of semantic vocabulary for device/process modeling enabling data extraction and transport through XML/ReST endpoints.
Tool support in C2T	Open source implementations and components available from public repositories, maintained and extended depending on the needs.
SME issues	Provides domain specific, vendor-agnostic data modeling and extraction capabilities alleviating the vendor lock-in phenomena.

5.26 APACHE KAFKA

Use in C2T	UNIBO: Message-oriented middleware acting as data conveyor between data producers (e.g., shop floor devices) and consumers (e.g., analytic components).
Tool support in C2T	Open source project (Apache Kafka) with many integrations (connectors) built and maintained by the Mobile Middelware lab.
SME issues	Highly scalable, high throughput, policy-based integration layer alleviating the data chaos.

5.27 FMU/FMI

Name	FMU/FMI
Version	2020
Availability	https://fmi-standard.org/
Category	Data model

Use case	Data exchange, sharing
In scope	FMU/FMI is an interface to exchange dynamic models using a combination of XML files, binaries and C code zipped into a single file.
Use in C2T	Used for the exchange of models with internal and external partners using different modelling tools (e.g. Siemens, Dassault, Ansys, Altair etc.).
Tool support in C2T	Prespective (Digital Twin Software)
C2T contributions	Unit040: • Extend the support for the FMI/FMU standard within Prespective. • Enable SME's to create their own FMU models and use them in Prespective.
SME issues	The FMU/FMI standard is now still mostly used by OEM and larger tool providers.

5.28 IETF - HTTP/REST STANDARDS

Use in C2T	UNIBO: Information exchange through well-defined, stateless application-layer endpoints.
Tool support in C2T	Open architectural style, achieving interoperability among software components through well-defined endpoints.
SME issues	De-facto standard for interactive applications as opposed to using proprietary protocols.

5.29 INDUSTRIAL INTERNET CONSORTIUM - IIRA:2019

Use in C2T	UNIBO: Reference architecture for a distributed IIoT environment
Tool support in C2T	N/A
C2T Contributions	Develop edge-related functional architecture and design principles.
SME issues	To be analysed

5.30 ITU-T Y.CCCSDAOM-REQTS - CLOUD COMPUTING - REQUIREMENTS FOR CLOUD SERVICE DEVELOPMENT AND OPERATION MANAGEMENT

Use in C2T	UNIBO: Technologies and techniques applying to and used conjunction with cloud computing.
Tool support in C2T	Highly reliable, secure, multi-Cloud middleware solutions for data at rest and data in motion scenarios developed by the Mobile Middleware Group.
SME issues	Highly reliable, secure, multi-Cloud middleware solutions for data at rest and data in motion scenarios developed by the Mobile Middleware Group.

5.31 OMG DATA-DISTRIBUTION SERVICE (DDS) FOR REAL-TIME SYSTEMS STANDARD

Name	Data Distribution Service (DDS) standard
Version	v 1.4
Availability	https://www.dds-foundation.org/omg-dds-standard/
Category	Open standard messaging middleware for the Internet of Things
Use case	https://www.dds-foundation.org/who-is-using-dds-2/
In scope	DDS is an open international data-centric connectivity standard to address publish-subscribe messaging that supports needs of enterprise, real-time and embedded systems. Open interfaces and advanced integration capabilities reduce cost across system lifecycle, i.e., from development through integration and maintenance activities.
Use in C2T	Communication protocols
Tool support in C2T	Not yet; to be considered
C2T contributions	N/A
SME issues	To be analysed

5.32 OPC 10000-14 - PART 14: PUB/SUB

Name	OPC UA PubSub (UDP/IP and MQTT)
Version	2018-02-16 Release 1.04
Availability	OPC Foundation; https://reference.opcfoundation.org/v104/Core/docs/Part14/
Category	Extension of OPC UA over Internet (WAN)
Use case	Enabling secure end-to-end data exchange in highly scalable cloud-based applications
In scope	OPC UA PubSub defines an OPC UA publish-subscribe communication model which complements the client-server pattern already existing. PubSub allows distributing data and events from an OPC UA information source to interested observers. It enables the integration of OPC UA in two important ways. The first is at shop floor level where low power and low-latency communications on local networks are required. The second application is the integration of OPC UA in scalable cloud-based applications. In PubSub the participating OPC UA Applications with their roles as Publishers and Subscribers are decoupled. The number of Subscribers receiving data from a Publisher does not influence the Publisher. This makes PubSub suitable for applications where location independence and scalability are required. OPC UA Part 14 defines a Pub/Sub architecture for both LAN and WAN based communications. The difference between the two is what type of transport is used since there are different challenges to overcome in different environments: • for lateral connectivity (subnets, LANs): UDP • for vertical connectivity (cloud environments, WANs): MQTT or AMQP **OPC UA PubSub UDP** OPC UA PubSub enables use of the User Data Protocol (UDP) as transporting protocol for establishing low-latency, loss tolerating connections on LANs.

	OPC UA UDP is used to transport UADP NetworkMessages. For OPC UA UDP it is recommended to limit the MaxNetworkMessageSize plus additional headers to an MTU size. The number of frames used for a UADP NetworkMessage influences the probability that UADP NetworkMessages get lost. OPC UA PubSub with UDP is a solution that fits the needs of complex automation set-ups and can be integrated across all OT layers and embedded systems. UDP creates a low amount of overhead since error checking and processing are not performed at the level of the network interface but can be executed in the application. Thus e.g. if a package is missing there is no delay due to waiting for a correction. Hence the combination of OPC UA PubSub and UDP is well suited for use in TSN networks and devices with constrained resources like sensor nodes and low-power processors. **OPC UA PubSub MQTT** The Message Queue Telemetry Transport (MQTT) is an open standard application layer protocol for Message Oriented Middleware. MQTT is often used with a Broker that relays messages between applications that cannot communicate directly. Publishers send MQTT messages to MQTT brokers. Subscribers subscribe to MQTT brokers for messages. A Broker may persist messages so they can be delivered even if the subscriber is not online. Brokers may also allow messages to be sent to multiple Subscribers. The MQTT protocol defines a binary protocol used to send and receive messages from and to topics. The body is a binary file that can contain any data serialized using an encoding chosen by the application. The specification defines two possible encodings for the message body: the binary encoded DataSetMessage and a JSON encoded DataSetMessage. MQTT does not provide a mechanism for specifying the encoding of the MQTT message which means the Subscribers shall be configured in advance with knowledge of the expected encoding. Publishers should only publish NetworkMessages using a single encoding to a unique MQTT topic name. MQTT is typically suited for IT/OT integrations as well as cloud based applications. The messaging protocol is extremely simple and lightweight. Therefore, MQTT is a good fit for constrained devices and low-bandwidth, high-latency networks without deterministic requirements. Another advantage of MQTT is that it is supported by several industry heavyweights like Microsoft as the company's Azure IoT Hub natively supports communication over the MQTT, AMQP, and HTTP protocols.
Use in C2T	Data exchange communication protocols
Tool support in C2T	TTTech/Nerve Blue
C2T contributions	Use of the standard
SME issues	Open protocols for M2M and IIoT

5.33 VDMA 40001-1: OPC UA FOR MACHINERY

Name	OPC UA for Machinery
Version	2020-06
Availability	https://opcua.vdma.org/
Category	Information data model
Use case	• identification and name tag of machines • finding all machines in the server
In scope	With the Companion Specifications, the OPC Foundation has created the possibility to define special information models for OPC UA. To date, the specifications for robotics, machine tools and CNC systems, among others, have been published. Further information models are in draft status. The Companion Specification OPC UA for Machinery is currently available in a draft version from the VDMA. It plays a special role within the information models. Machine components are defined in Building Blocks for Machinery in order to ultimately be able to represent entire machines. The goal of the VDMA and the OPC Foundation is not a single information model that can map all machines, but a generalised concepts that allow individual machines to be composed of building blocks and described more precisely using the Companion Specifications. In summary, the goals of OPC UA for Machinery are the harmonisation of information models in mechanical and plant engineering and the definition of information building blocks for modelling machines and plants.
Use in C2T	
Tool support in C2T	TTTech/Nerve Blue
C2T contributions	TTTech: Use of the standard
SME issues	Support communication interfaces across machines/devices

6 CONCLUSIONS

In this report, we described standards with relevance for digital twins in the smart industry context. We used internal and external sources to collect and categorize these standards. By a survey among Change2Twin partners, we identified 33 standards of particular interest, namely the usage of the standards in digital twin implementations. In some cases, project partners aim to further develop the standards. Table 4 is a summary of current C2T partner involvements with these standards.

TABLE 4: SUMMARY OF C2T PARTNER INVOLVEMENTS WITH STANDARDS

Type of involvement	Standard	C2T partners	Domain
Develop	ISO 10303 AP209, AP239, AP242	Jotne, SINTEF	Product data exchange
Develop	ISO/IEC 19510	BOC	Process modelling
Develop	IEEE 802.1AS	TTTech	Network timing
Monitor	ISO 23247	Jotne	Digital twin
Monitor	3MF	SINTEF	Additive manufacturing format
Monitor	ISO / ASTM52915 - 20	SINTEF	Additive manufacturing format
Use	IEC 61131	Author-e, Cordis	Controllers
Use	ISO/IEC 15948	SINTEF	Graphics png
Use	ECSS-M-ST-40C	SPS	Configuration management
Use	ECSS-Q-ST-80C	SPS	Software quality
Use	EN 9100	SPS	Quality
Use	ISO 10303	SPS	Product data exchange
Use	IEEE 60802	TTTech	Automation profile
Use	ISO/IEC 20922	TTTech	Messaging
Use	ISO/IEC 21778	TTTech	File format JSON
Use	OPC 10000-14	TTTech	Automation profile
Use	VDMA 40001-1	TTTech	Automation profile service architecture
Use	Apache Kafka	UNIBO	Messaging
Use	IEC 61158	UNIBO	Network protocol
Use	IEC 61784	UNIBO	Network protocol
Use	IEEE 802.11	UNIBO	Wireless protocol
Use	IEEE 802.15.4	UNIBO	Wireless protocol
Use	IEEE 802.1AS	UNIBO	Network timing
Use	IEEE P2413	UNIBO	IoT architecture
Use	ISO/IEC 19464	UNIBO	Messaging
Use	ISO/IEC 21823-1	UNIBO	IoT framework
Use	ISO/IEC 21823-2	UNIBO	IoT protocol
Use	ISO/IEC TR 30164	UNIBO	IoT Edge
Use	ISO/IEC TS 23167	UNIBO	Cloud technology
Use	ITU-T Y.cccsdaom-reqts	UNIBO	Cloud services
Use	FMI/FMU	UNIT040	Functions data exchange
Use	ISO/PAS 17506	UNIT040	3D viewing format COLLADA

Deliverable 1.5 “Second report on standards relevant for digital twins” is the next deliverable of Change2Twin Task 1.5 and is due in May 2022.

This report will support the following activities:

- Validate the identified standards for their use in existing pilots and the emerging open-call experiments;
- Monitor the developments of the identified standards in their respective standardisation bodies including the contributions by Change2Twin partners;
- Evaluate recommendations concerning competing standards, such as, MQTT and OMG DDS;
- Convince the DMP Cluster to include the Change2Twin identified standards in their standards overview;
- Prepare a user-friendly best practice guide to the most important standards that accelerate digital twin implementations for SMEs (coordinate with WP6);
- Perform the SME compatibility test for the identified standards. Change2Twin focusses on SMEs, also with respect to their access to relevant standards. Small Business Standards (SBS) is a European non-profit association co-financed by the European Commission and EFTA Member States to represent and defend small and medium-sized enterprises’ interests in the standardisation process at European and international levels. SBS has developed a test that evaluates the SME friendliness of standards:
    - For the test, see https://www.sbs-sme.eu/sme-compatibility-test-standards .
- Ensure that standards compliance is a selection criterion for enabling technologies in the marketplace listings; coordinate with WP2 and with the D1.3 editing team.

7 REFERENCES

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[RD6] DMP Cluster, https://www.efpf.org/event/DMP-Cluster-Meeting

[RD7] Framework for a digital twin in manufacturing: Scope and requirements, Guodong Shao and Moneer Helu, Journal: Manufacturing Letters 24, 2020, pages 105-107

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Appendix A EFFRA Manufacturing Standards overview and C2T involvements

EFFRA is preparing a table, see [RD3] that is on the one hand an overview of standards and on the other hand a mapping of those to the concepts of the Industry 4.0 architecture RAMI 4.0. This table is work in progress. The list of standards may not be complete, and the mappings to the RAMI 4.0 framework are not finalized. An excerpt of version 0.2 of this table is listed in Table 5, below.
Change2Twin partners have in Table 5 indicated their interests in the listed digital twin related standards in the third column, called "C2T partner(s)". Standards that were not yet in the original table have been added in Table 6.
The acronym of interested partners in Table 5 and Table 6 is followed by a letter in parentheses; this letter indicates the level of partner involvement as follows:

- U: using the standard,
- M: monitoring the development of the standard, and
- D: developing the standard, that is, contributing to the work of the standardisation body in maintaining the standard.

TABLE 5: C2T STANDARDS INVOLVEMENTS BASED ON EFFRA STANDARDS OVERVIEW AND MAPPING MATRIX

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
DIN German Institute for Standardisation	DIN SPEC 27070:2020		Requirements and reference architecture of a security gateway for the exchange of industry data and services	Link	2020	DIN						
TC 65/SC 65C - Industrial networks	IEC 61158 series	UNIBO (U)	Industrial communication networks - Fieldbus specifications	Link	-	IEC						
ISO/TC 184/SC 4 Industrial data	ISO 23952:2020		Quality information framework (QIF) — An integrated model for manufacturing quality information	Link	2020	ISO						

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
MTConnect	ANSI/MTC1.4-2018		MTConnect	Link	2018	MTConnet						
Apache Software Foundation	Apache Kafka	UNIBO (U)	Apache Kafka	Link		Apache Software Foundation		x	x			
ANSI	B11.0 - 2020		Safety of Machinery	Link	2020	ANSI						
ANSI	B11.Tr10—202x		Functional Safety of Artificial Intelligence for Machinery Applications	Link	-	ANSI						
MESA	B2MML		Business To Manufacturing Markup Language	Link	_	MESA						
AIA - Global Association for Vision Information	Camera Link		Camera Link	Link		AIA	x		x			
CEN Workshop of MONSOON H2020 Project (MOdel based coNtrol framework for Site-wide OptimizatiON	CWA 17492:2020		Predictive control and maintenance of data intensive industrial processes (MONSOON)	Link	2020	CCMC						

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
of data-intensive processes)												
W3C	DCAT		Data Catalog Vocabulary (DCAT) - Version 2	Link	2020	W3C				x		
DIN German Institute for Standardisation	DIN SPEC 16592:2016		Combining OPC Unified Architecture and Automation Markup Language.	Link	2016	DIN						
DIN German Institute for Standardisation	DIN SPEC 13266:2020-04		Guideline for the development of deep learning image recognition systems	Link	2020	DIN						
DIN German Institute for Standardisation	DIN SPEC 2343:2020-09		Transmission of language-based data between artificial intelligences - Specification of parameters and formats	Link	2020	DIN						
DIN German Institute for Standardisation	DIN SPEC 91406:2019-12		Automatic identification of physical objects and information on physical objects in IT systems, particularly IoT systems	Link	2019	DIN						
DIN German Institute for Standardisation	DIN SPEC 92001-1:2019-04		Artificial Intelligence – Life Cycle Processes and Quality Requirements – Part 1: Quality Metamodel	Link	2019	DIN						
DIN German Institute for Standardisation	DIN SPEC 92001-2		Artificial Intelligence - Life Cycle Processes and Quality Requirements - Part 2: Robustness	Link	2020	DIN						
e@Class e.V.	eCl@ss		eCl@ss	Link	2002-2019	eCl@ss e. V.						

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
CEN/TC 459/SC 3 Structural steels other than reinforcements	EN 10219-1:2006		Cold Formed Welded structural Hollow Sections of non-alloy and fine grain steels – Part 1: Technical delivery conditions	Link	2006	CEN						
CEN/TC 459/SC 10 Steel tubes and iron and steel fittings	EN 10305-3:2016		Steel Tubes for precision applications – Technical delivery conditions – Part 3: Welded cold sized tubes	Link	2016	CEN						
CEN/TC 459/SC 10 Steel tubes and iron and steel fittings	EN 10305-5:2016		Steel tubes for precision applications – Technical delivery conditions – Part 5: Welded cold sized square and rectangular tubes	Link	2016	CEN						
CEN/TC 319 Maintenance	EN 13306:2018		Maintenance – Maintenance terminology	Link	2018	CEN						
CEN/TC 319 Maintenance	EN 16646:2014		Maintenance – Maintenance within physical asset management	Link	2014	CEN						
CEN/TC 319 Maintenance	EN 17007:2017		Maintenance process and associated indicators	Link	2017	CEN						
DIN German Institute for Standardisation	EN 61069 series		Industrial-process measurement, control and automation - Evaluation of system properties for the purpose of system assessment	Link	-	_						

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
DIN German Institute for Standardisation	EN 61310 sreies		Safety of machinery - Indication, marking and actuation	Link	-	DIN						
DIN German Institute for Standardisation	EN 62745:2017		Safety of machinery - Requirements for cableless control systems of machinery (IEC 62745:2017)	Link	2017	DIN						
CEN	EN 9100	SPS (U)	General quality management requirements for aviation	Link	2018	CEN						
ITU	FG Cloud TR Version 1.0 (02/2012)		FG Cloud Technical Report Part 2: Functional requirements and reference architecture	Link	2012	ITU						
AIA - Global Association for Vision Information	GigE Vision		GigE Vision	Link		AIA			x			
IETF	HTTP/REST standards		(standards collection)	Link	-	IETF			x			
International Data Spaces Association	IDS-RAM:2019		IDSA Reference Architecture Model 3.0	Link	2019	IDSA						
IEC/TC 65 Industrial-process	IEC /TR 62837:2013		Energy efficiency through automation systems	Link	2013	IEC						

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
measurement and control												
IEC/TC 2 Rotating machinery	IEC 60034 series		Rotating electrical machines	Link	_	IEC						
TC 44 - Safety of machinery - Electrotechnical aspects	IEC 60204:2020 SER		Safety of machinery - Electrical equipment of machines - ALL PARTS	Link	2020	IEC						
IEC/ TC 3 - Documentation, graphical symbols and representations of technical information	IEC 60445:2017 RLV		Basic and safety principles for man-machine interface, marking and identification - Identification of equipment terminals, conductor terminations and conductors	Link	2017	IEC						
IEC/TC 65/SC 65B Measurement and control devices	IEC 61131 series	Cordis (U), Author-e (U)	Programmable controllers - ALL PARTS	Link	-	IEC						
IEC TC3/SC 3D Product properties and	IEC 61360-1:2017		Standard data element types with associated classification scheme - Part 1: Definitions - Principles and methods	Link	2017	IEC						

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
classes and their identification												
IEC/TC 65/SC 65B Elements of systems	IEC 61499 series		Function blocks	Link	-	IEC	x					
IEC TC 65/SC 65A System aspects	IEC 61511-1:2016+AMD1: 2017 CSV Consolidated version		Functional safety - Safety instrumented systems for the process industry sector - Part 1: Framework, definitions, system, hardware and application programming requirements	Link	2017	IEC						
TC 65/SC 65C - Industrial networks	IEC 61784 series	UNIBO (U)	Industrial communication networks - Profiles	Link	-	IEC						
IEC/TC 22/SC 22G Adjustable speed electric drive systems incorporating semiconductor power converters	IEC 61800 series		Adjustable speed electrical power drive systems	Link	_	IEC						
IEC/TC 65/SC 65E Devices and integration	IEC 61804 series		Function blocks (FB) for process control and electronic device description language (EDDL)	Link	-	IEC						

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
in enterprise systems												
IEC/TC 65/SC 65E Devices and integration in enterprise systems	IEC 61987 series		Industrial-process measurement and control - Data structures and elements in process equipment catalogs	Link	2016	IEC						
TC 44 - Safety of machinery - Electrotechnical aspects	IEC 62061:2015 CSV		Safety of machinery - Functional safety of safety-related electrical, electronic and programmable electronic control systems	Link	2015	IEC						
IEC/TC 65/SC 65E Devices and integration in enterprise systems	IEC 62264 series		Enterprise-control system integration - Part 2: Object and attributes for enterprise-control system integration	Link	_	IEC						
ISO/TC 184 Automation systems and integration	IEC 62264-1:2013		IEC 62264-1:2013 Enterprise-control system integration — Part 1: Models and terminology	Link	2013	IEC						
IEC/TC 56 - Dependability	IEC 62402:2019		Obsolescence management	Link	2019	IEC						
IEC/TC 65 Industrial-process	IEC 62424		Representation of process control engineering - Requests in P&I diagrams and data exchange between P&ID tools and PCE-CAE tools	Link	2016	IEC						

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
measurement and control												
IEC/TC 65 Industrial-process measurement and control	IEC 62443 series		Security for industrial automation and control systems	Link	-	ANSI, IEC, ISA						
IEC/TC 65/SC 65E Devices and integration in enterprise systems	IEC 62453 series		Field device tool (FDT) interface specification	Link	2016	IEC						
IEC/TC 65/SC 65E Devices and integration in enterprise systems	IEC 62541 series		OPC unified architecture – Part 1: Overview and concepts	Link	-	IEC						
IEC TC 8 System aspects of electrical energy supply	IEC 62559-2:2015		Use case methodology - Part 2: Definition of the templates for use cases, actor list and requirements list	Link	2015	IEC						
IEC/TC 65/SC 65E Devices and integration	IEC 62714 series		Engineering data exchange format for use in industrial automation systems engineering - Automation Markup Language	Link	-	IEC						

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
in enterprise systems												
IEC/TC 65 Industrial-process measurement and control	IEC 62890:2020		Industrial-process measurement, control and automation - Life-cycle-management for systems and components	Link	2020	IEC						
IEC TC 65 WG24 Asset Administration Shell for Industrial Applications	IEC 63278-1 ED1		Asset administration shell for industrial applications – Part 1: Administration shell structure	Link		IEC						
IEC/TC 65 Industrial-process measurement and control	IEC PAS 63088:2017		Smart manufacturing – Reference architecture model industry 4.0 (RAMI4.0)	Link	2017	IEC						
IEC/TC 65 Industrial-process measurement and control	IEC TS 62832-1:2016		Industrial-process measurement, control and automation - Digital factory framework - Part 1: General principles	Link	2016	IEC						
IEEE Institute of Electrical and	IEEE 1589-2020		IEEE Standard for Augmented Reality Learning Experience Model	Link	2020	IEEE				x		

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
Electronics Engineers												
IEEE Institute of Electrical and Electronics Engineers	IEEE 802.11 Standards	UNIBO (U)	IEEE 802.11 Standards	Link		IEEE			x			
IEEE Institute of Electrical and Electronics Engineers	IEEE 802.15.4-2020	UNIBO (U)	IEEE Standard for Low-Rate Wireless Networks	Link		IEEE			x			
IEEE Institute of Electrical and Electronics Engineers	IEEE 802.1AS-2020	UNIBO (U), TTTech (U)	IEEE Standard for Local and Metropolitan Area Networks--Timing and Synchronization for Time-Sensitive Applications	Link	2020	IEEE			x			
IEEE Institute of Electrical and Electronics Engineers	IEEE P2413:2019	UNIBO (U)	Architectural Framework for the Internet of Things (IoT)	Link	2020	IEEE						
Industrial Internet Consortium	IIRA:2019		The Industrial Internet of Things Volume G1: Reference Architecture Version 1.9	Link	2019	IIC						
ISO/TC 176/SC 2 Quality systems	ISO 10005:2018		Quality management — Guidelines for quality plans	Link	2018	ISO						

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
ISO/TC 176/SC 2 Quality systems	ISO 10007:2017		Quality management — Guidelines for configuration management	Link	2017	ISO						
ISO/TC 299 Robotics	ISO 10218-1:2011		Robots and robotic devices — Safety requirements for industrial robots — Part 1: Robots	Link	2011	ISO						
ISO/TC 299 Robotics	ISO 10218-2:2011		Robots and robotic devices — Safety requirements for industrial robots — Part 2: Robot systems and integration	Link	2011	ISO						
ISO/TC 184/SC 4 Industrial data	ISO 10303 series	SINTEF (D), SPS (U), Jotne (D)	Industrial automation systems and integration — Product data representation and exchange	Link	_	ISO				x		
ISO/TC 184 Automation systems and integration	ISO 10303-236:2006		Industrial automation systems and integration – Product data representation and exchange – Part 236: Application protocol: Furniture catalogue and interior design – and Application modules	Link	2006	IEC						
ISO/TC 184/SC 4 Industrial data	ISO 10303-239	SPS (U), Jotne (D)	Industrial automation systems and integration — Product data representation and exchange — Part 239: Application protocol: Product life cycle support	Link	2005	ISO						
ISO/TC 199 Safety of machinery	ISO 11161:2007		Safety of machinery — Integrated manufacturing systems — Basic requirements	Link	2007	ISO						
ISO/TC 184/SC 5 Interoperability,	ISO 11354-1:2011		Advanced automation technologies and their applications — Requirements for establishing	Link	2011	ISO						

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
integration, and architectures for enterprise systems and automation applications			manufacturing enterprise process interoperability — Part 1: Framework for enterprise interoperability									
ISO/TC 184/SC 5 Interoperability, integration, and architectures for enterprise systems and automation applications	ISO 11354-2:2015		Advanced automation technologies and their applications — Requirements for establishing manufacturing enterprise process interoperability — Part 2: Maturity model for assessing enterprise interoperability	Link	2015	ISO						
ISO/TC 199 Safety of machinery	ISO 12100:2010		Safety of machinery – General principles for design – Risk assessment and risk reduction	Link	2010	ISO						
ISO/TC 108/SC 5 Condition monitoring and diagnostics of machine systems	ISO 13372:2012		Condition monitoring and diagnostics of machines — Vocabulary	Link	2012	CEN						

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
ISO/TC 108/SC 5 Condition monitoring and diagnostics of machine	ISO 13374-1:2003		Condition monitoring and diagnostics of machines — Data processing, communication and presentation — Part 1: General guidelines	Link	2003	ISO						
ISO/TC 108/SC 5 Condition monitoring and diagnostics of machine	ISO 13381-1:2015		Condition monitoring and diagnostics of machines — Prognostics — Part 1: General guidelines	Link	2015	ISO						
ISO/TC 184/SC 4 Industrial data	ISO 13584 series		Industrial automation systems and integration - Parts library	Link	-	ISO						
ISO/TC 199 Safety of machinery	ISO 13849-1:2015		Safety of machinery — Safety-related parts of control systems — Part 1: General principles for design	Link	2015	DIN						
ISO/TC 199 Safety of machinery	ISO 13849-2: 2012		Safety of machinery - Safety-related parts of control systems - Part 2: Validation	Link	2012	ISO						
ISO/TC 299 Robotics	ISO 14539:2000		Manipulating Industrial Robots--Object handling with grasp-type grippers --Vocabulary and presentation of characteristics	Link	2000	ISO						
ISO/TC 159/SC 3 Anthropometry	ISO 14738:2002		Safety of machinery — Anthropometric requirements for the design of workstations at machinery	Link	2002	ISO						

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
and biomechanics												
ISO/TC 184/SC 5 Interoperability, integration, and architectures for enterprise systems and automation applications	ISO 15746 series		Automation systems and integration — Integration of advanced process control and optimization capabilities for manufacturing systems- SER	Link	_	ISO						
ISO/TC 184/SC 4 Industrial data	ISO 15926 series		Integration of life-cycle data for process plants	Link	-	ISO						
ISO/TC 184/SC 4 Industrial data	ISO 18828-3:2017		Industrial automation systems and integration — Standardized procedures for production systems engineering — Part 3: Information flows in production planning processes	Link	2017	ISO						
ISO/TC 184/SC 5 Interoperability, integration, and architectures for enterprise systems and	ISO 19439:2006		Enterprise integration — Framework for enterprise modelling	Link	2006	ISO						

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
automation applications												
ISO/TC 184/SC 5 Interoperability, integration, and architectures for enterprise systems and automation applications	ISO 20140-5:2017		Automation systems and integration — Evaluating energy efficiency and other factors of manufacturing systems that influence the environment — Part 5: Environmental performance evaluation data	Link	2017	ISO						
ISO/TC 184 Automation systems and integration	ISO 20534:2018		Industrial automation systems and integration – Formal semantic models for the configuration of global production networks	Link	2018	ISO						
ISO/TC 130 Graphic technology	ISO 21632:2018		Graphic technology — Determination of the energy consumption of digital printing devices including transitional and related modes	Link	2018	ISO						
ISO/TC 184/SC 5 Interoperability, integration, and architectures for enterprise systems and	ISO 22400-2:2014		Automation systems and integration — Key performance indicators (KPIs) for manufacturing operations management — Part 2: Definitions and descriptions	Link	2014	ISO						

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
automation applications												
ISO/TC 184 Automation systems and integration	ISO 22549-1:2019		Automation systems and integration – Assessment on convergence of informatization and industrialization for industrial enterprises – Part 1: Framework and reference model	Link	_	ISO						
ISO/TC 184 Automation systems and integration	ISO 22549-2:2019		Automation systems and integration –Assessment on convergence of informatization and industrialization for industrial enterprises — Part 2: Maturity model and evaluation methodology	Link	_	ISO						
ISO/TC 307 - Blockchain and distributed ledger technologies	ISO 22739		Blockchain and distributed ledger technologies – Terminology	Link	2020	ISO				x		
ISO/TC 184/SC 4 Industrial data	ISO 23247 series	Jotne (M)	Automation systems and integration — Digital Twin framework for manufacturing	Link	_	ISO						
ISO/TC 307 - Blockchain and distributed ledger technologies	ISO 23257		Blockchain and distributed ledger technologies — Reference architecture	Link		ISO						
ISO/TC 184 Automation	ISO 23570-1:2005		Industrial automation systems and integration — Distributed installation in industrial applications — Part 1: Sensors and actuators	Link	2005	ISO						

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
systems and integration												
ISO/TC 184/SC 4 Industrial data	ISO 23952:2020		Automation systems and integration — Quality information framework (QIF) — An integrated model for manufacturing quality information	Link	2020	ISO		x		x		
ISO/TC 262 - Risk Management	ISO 31000:2018		Risk management — Guidelines	Link	2018	ISO						
ISO/TC 299 Robotics	ISO 8373:2012		Robots and robotic devices — Vocabulary	Link	2012	ISO						
ISO/TC 176/SC 2 Quality systems	ISO 9000 GLOSSARY		Glossary – Guidance on selected words used in the ISO 9000 family of standards	Link	2019	ISO						
ISO/TC 176/SC 2 Quality systems	ISO 9000:2015 FAMILY		Quality management systems	Link	2015	CEN						
ISO/TC 176/SC 2 Quality systems	ISO 9001:2015		Quality management systems — Requirements	Link	2015	ISO						
ISO/TC 299 Robotics	ISO 9283:1998		Manipulating industrial robots — Performance criteria and related test methods	Link	1998	ISO						
ISO/TC 154 Processes, data elements and	ISO 9735 series		Electronic data interchange for administration, commerce, and transport (EDIFACT)	Link	-	ISO						

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
documents in commerce, industry, and administration												
ISO/TC 299 Robotics	ISO 9787:2013		Robots and robotic devices — Coordinate systems and motion nomenclatures	Link	2013	ISO						
ISO/TC 199 Safety of machinery	ISO TR 21260		Safety of machinery — Mechanical safety data for physical contacts between moving machinery or moving parts of machinery and persons	Link	_	ISO						
ISO/IEC JTC 1/SC 38 Cloud Computing and Distributed Platforms	ISO(IEC CD 22123-2		Information technology — Cloud computing — Part 2: Concepts	Link	-	ISO/IEC						
ISO/IEC JTC 1/SC 27 Information security, cybersecurity and privacy	ISO/IEC 15408 series		Information technology – Security techniques – Evaluation criteria for IT security	Link	-	ISO/IEC						
ISO/IEC JTC 1/SC 38 Cloud Computing and Distributed Platforms	ISO/IEC 17788:2014		Information technology – Cloud computing – Overview and vocabulary	Link	2014	ISO/IEC						

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
ISO/IEC JTC 1/SC 27 Information security, cybersecurity and privacy	ISO/IEC 18045:2008		Information technology — Security techniques — Methodology for IT security evaluation	Link	2008	ISO/IEC						
ISO/IEC JTC 1 Information Technology	ISO/IEC 19464:2014	UNIBO (U)	Information technology – Advanced Message Queuing Protocol (AMQP)	Link	2014	ISO/IEC						
ISO/IEC JTC 1 Information Technology	ISO/IEC 19510:2013	BOC (D)	Information technology – Object Management Group Business Process Model and Notation	Link	2013	ISO/IEC						
ISO/IEC JTC 1 Information Technology	ISO/IEC 19845:2015		Information technology – Universal Business Language Version 2.1 (UBL v2.1)	Link	2015	ISO/IEC						
ISO/IEC JTC 1/SC 42 Artificial Intelligence	ISO/IEC 20546:2019		Information technology - Big data - Overview and vocabulary	Link	2019	ISO/IEC						
ISO/IEC JTC 1/SC 42 Artificial Intelligence	ISO/IEC 20547-3:2020		Information technology - Big data reference architecture - Part 3: Reference architecture	Link	2020	ISO/IEC						

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
ISO/IEC JTC 1 Information Technology	ISO/IEC 20922:2016	TTTech (U)	Information technology – Message Queuing Telemetry Transport (MQTT) v3.1.1	Link	2016	ISO/IEC				X		
ISO/IEC JTC 1 Information Technology	ISO/IEC 20924:2018		Information technology — Internet of Things (IoT) — Vocabulary	Link	2018	ISO/IEC						
ISO/IEC JTC 1 Information Technology	ISO/IEC 21778:2017	TTTech (U)	Information technology – The JSON data interchange syntax	Link	2017	ISO/IEC						
ISO/IEC JTC 1/SC 41 Internet of Things and related technologies	ISO/IEC 21823-1:2019	UNIBO (U)	Internet of things (IoT) — Interoperability for IoT systems — Part 1: Framework	Link	2019	ISO/IEC						
ISO/IEC JTC 1/SC 41 Internet of Things and related technologies	ISO/IEC 21823-2:2019	UNIBO (U)	Internet of things (IoT) — Interoperability for IoT systems — Part 2: Transport interoperability	Link	2020	ISO/IEC						
ISO/IEC JTC 1/SC 41 Internet of Things and related technologies	ISO/IEC 21823-3		Internet of things (IoT) — Interoperability for IoT systems — Part 3: Semantic interoperability	Link	-	ISO/IEC						

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
ISO/IEC JTC 1/SC 38 Cloud Computing and Distributed Platforms	ISO/IEC 22123-1		Information technology — Cloud computing — Part 1: Terminology	Link	-	ISO/IEC						
ISO/IEC JTC 1/SC 42 Artificial Intelligence	ISO/IEC 22989		Artificial Intelligence Concepts and Terminology	Link	_	ISO/IEC						
ISO/IEC JTC 1/SC 42 Artificial Intelligence	ISO/IEC 23053		Framework for Artificial Intelligence (AI) Systems Using Machine Learning (ML)	Link	_	ISO/IEC						
ISO/IEC JTC 1 Information Technology	ISO/IEC 2382:2015		Information technology — Vocabulary	Link	2015	ISO/IEC						
ISO/IEC JTC 1/SC 42 Artificial Intelligence	ISO/IEC 23894		Information Technology — Artificial Intelligence — Risk Managemen	Link	_	ISO						
ISO/IEC JTC 1/SC 42 Artificial Intelligence	ISO/IEC 24668		Information technology — Artificial intelligence — Process management framework for Big data analytics	Link	_	ISO						

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
ISO/IEC JTC 1/SC 27 Information security, cybersecurity and privacy	ISO/IEC 27000:2018		Information technology – Security techniques – Information security management systems – Overview and vocabulary	Link	2018	IEC						
ISO/IEC JTC 1/SC 27 Information security, cybersecurity and privacy	ISO/IEC 27001:2013		Information technology – Security techniques – Information security management systems – Requirements	Link	2013	ISO/IEC						
ISO/IEC JTC 1/SC 27 Information security, cybersecurity and privacy	ISO/IEC 27002:2013		Information technology – Security techniques – Code of practice for information security controls	Link	2013	ISO/IEC						
ISO/IEC JTC 1/SC 27 Information security, cybersecurity and privacy	ISO/IEC 27005:2018		Information technology -Security techniques – Information security risk management	Link	2018	ISO/IEC						

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
ISO/IEC JTC 1/SC 27 Information security, cybersecurity and privacy	ISO/IEC 27009:2020		Information technology – Security techniques – Sector-specific application of ISO/IEC 27001 – Requirements	Link	2020	ISO/IEC						
ISO/IEC JTC 1/SC 27 Information security, cybersecurity and privacy	ISO/IEC 27017:2015		Information technology — Security techniques — Code of practice for information security controls based on ISO/IEC 27002 for cloud services	Link	2015	ISO/IEC						
ISO/IEC JTC 1/SC 27 Information security, cybersecurity and privacy	ISO/IEC 27019:2017		Information technology — Security techniques — Information security controls for the energy utility industry	Link	2017	ISO/IEC						
ISO/IEC JTC 1/SC 31 Automatic identification and data capture	ISO/IEC 29161:2016		Information technology — Data structure — Unique identification for the Internet of Things	Link	2016	ISO/IEC						

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
ISO/IEC JTC 1 Information Technology	ISO/IEC 30118 series		Information technology – Open Connectivity Foundation (OCF) Specification – Part 1: Core specification	Link	-	ISO/IEC						
ISO/IEC JTC 1/SC 41 Internet of Things and related technologies	ISO/IEC 30144		Information technology – Sensor network system architecture for power substations	Link	-	ISO/IEC						
ISO/IEC JTC 1/SC 41 Internet of Things and related technologies	ISO/IEC 30147		Information technology – Internet of things – Methodology for trustworthiness of IoT system/service	Link	-	ISO/IEC						
ISO/IEC JTC 1/SC 41 Internet of Things and related technologies	ISO/IEC 30149		Internet of things (IoT) – Trustworthiness framework	Link	-	ISO/IEC						
ISO/IEC JTC 1/SC 41 Internet of Things and related technologies	ISO/IEC 30161		Internet of Things (IoT) – Requirements of IoT data exchange platform for various IoT services	Link	-	ISO/IEC						
ISO/IEC JTC 1/SC 41 Internet	ISO/IEC 30162		Internet of Things (IoT) – Compatibility requirements and model for devices within industrial IoT systems	Link	-	ISO/IEC						

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
of Things and related technologies												
ISO/IEC JTC 1/SC 41 Internet of Things and related technologies	ISO/IEC 30163		Internet of Things (IoT) – System requirements of IoT/SN technology-based integrated platform for chattel asset monitoring supporting financial services	Link	-	ISO/IEC						
ISO/IEC JTC 1/SC 41 Internet of Things and related technologies	ISO/IEC 30165		Internet of Things (IoT) – Real-time IoT framework	Link	_	ISO/IEC						
ISO/IEC JTC 1/SC 41 Internet of Things and related technologies	ISO/IEC 30166:2020		Internet of things (IoT) — Industrial IoT	Link	2020	ISO/IEC						
ISO/IEC/JTC 1/SC 40 - IT Service Management and IT	ISO/IEC 38500		Information technology -- Governance of IT for the organization	Link	2015	IEC						

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
ISO/IEC/JTC 1/SC 40 - IT Service Management and IT	ISO/IEC 38505-1:2017		Information technology -- Governance of IT -- Governance of data -- Part 1: Application of ISO/IEC 38500 to the governance of data	Link	2017	IEC						
ISO/IEC/JTC 1/SC 40 - IT Service Management and IT	ISO/IEC 38506:2020		Information technology -- Governance of IT -- Application of ISO/IEC 38500 to the governance of IT enabled investments	Link	2020	IEC						
ISO/IEC JTC 1/SC 42 Artificial Intelligence	ISO/IEC 38507		Information technology --Governance of IT -- Governance implications of the use of artificial intelligence by organizations	Link	_	ISO/IEC						
ISO/IEC JTC 1/SC 32 Data management and interchange	ISO/IEC 6523-1:1998		Information technology – Structure for the identification of organisations and organisation parts – Part 1: Identification of organisation identification schemes	Link	1998	ISO/IEC						
ISO/IEC JTC 1/SC 38 Cloud Computing and Distributed Platforms	ISO/IEC DIS 19944-1		Cloud computing – Cloud services and devices: data flow, data categories and data use — Part 1: Fundamentals	Link	-	ISO/IEC						
ISO/IEC JTC 1/SC 27	ISO/IEC NP 24392		Information technology -- Security techniques --Security reference model for Industrial Internet Platform (IIP)	Link		IEC						

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
Information security, cybersecurity and privacy												
ISO/IEC JTC 1/SC 42 Artificial Intelligence	ISO/IEC TR 20547-1:2020		Information technology — Big data reference architecture — Part 1: Framework and application process	Link	2020	ISO/IEC						
ISO/IEC JTC 1/SC 42 Artificial Intelligence	ISO/IEC TR 20547-2:2018		Information technology - Big data reference architecture - Part 2: Use cases and derived requirements	Link	2018	ISO/IEC						
ISO/IEC JTC 1/SC 42 Artificial Intelligence	ISO/IEC TR 20547-5:2018		Information technology - Big data reference architecture - Part 5: Standards roadmap	Link	2018	ISO/IEC						
ISO/IEC JTC 1/SC 41 Internet of Things and related technologies	ISO/IEC TR 22417:2017		Information technology — Internet of things (IoT) use cases	Link	2017	ISO/IEC						
ISO/IEC JTC 1/SC 42 Artificial Intelligence	ISO/IEC TR 24027		Information technology — Artificial Intelligence (AI) — Bias in AI systems and AI aided decision making	Link	_	ISO/IEC						

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
ISO/IEC JTC 1/SC 42 Artificial Intelligence	ISO/IEC TR 24028:2020		Information technology - Artificial intelligence - Overview of trustworthiness in artificial intelligence	Link	2020	ISO/IEC						
ISO/IEC JTC 1/SC 42 Artificial Intelligence	ISO/IEC TR 24029		Information technology -- Artificial Intelligence (AI) -- Assessment of the robustness of neural networks	Link	_	ISO/IEC						
ISO/IEC JTC 1/SC 42 Artificial Intelligence	ISO/IEC TR 24030		Artificial Intelligence (AI) — Use cases	Link	_	ISO/IEC						
ISO/IEC JTC 1/SC 41 Internet of Things and related technologies	ISO/IEC TR 30164:2020	UNIBO (U)	Internet of things (IoT) – Edge Computing	Link	2020	ISO/IEC						
ISO/IEC/JTC 1/SC 40 - IT Service Management and IT	ISO/IEC TR 38505-2:2018		Information technology — Governance of IT — Governance of data — Part 2: Implications of ISO/IEC 38505-1 for data management	Link	2018	IEC						
ISO/IEC JTC 1/SC 38 Cloud Computing and	ISO/IEC TS 23167:2020	UNIBO (U)	Information technology — Cloud computing — Common technologies and techniques	Link	2020	ISO/IEC						

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
Distributed Platforms												
ISO/IEC JTC 1/SC 27 Information security, cybersecurity and privacy	ISO/IEC TS 27100		Information technology -- Cybersecurity -- Overview and concepts	Link	2020	ISO/IEC						
ISO/IEC JTC 1/SC 7 Software and systems engineering	ISO/IEC TS 33052:2016		Information technology – Process reference model (PRM) for information security management	Link	2016	ISO/IEC						
ISO/IEC JTC 1/SC 7 Software and systems engineering	ISO/IEC/IEEE 42010:2011		Systems and software engineering — Architecture description	Link	2011	ISO/IEC /IEEE						
ISO/IEC JTC 1/SC 7 Software and systems engineering	ISO/IEC/IEEE 90003:2018		Software engineering — Guidelines for the application of ISO 9001:2015 to computer software	Link	2018	ISO						
ISO/IEC JTC 1/SC 41 Internet of Things and related technologies	ISO/IEC30141: 2018		Internet of Things (loT) — Reference Architecture	Link	2018	ISO/IEC						

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
ISO/TC 184/SC 4 Industrial data	ISO/PAS 17506:2012	UNIT040 (U)	Industrial automation systems and integration — COLLADA digital asset schema specification for 3D visualization of industrial data	Link	2012	ISO						
ISO/TC 299 Robotics	ISO/TR 13309:1995		Manipulating industrial robots — Informative guide on test equipment and metrology methods of operation for robot performance evaluation in accordance with ISO 9283	Link	1995	ISO						
ISO/TC 299 Robotics	ISO/TR 20218-1:2018		Robotics — Safety design for industrial robot systems — Part 1: End-effectors	Link	2018	ISO						
ISO/TC 199 Safety of machinery	ISO/TR 22100-4:2018		Safety of machinery — Relationship with ISO 12100 — Part 4: Guidance to machinery manufacturers for consideration of related IT-security (cyber security) aspects	Link	2018	ISO						
ISO/TC 307 - Blockchain and distributed ledger technologies	ISO/TR 23244		Blockchain and distributed ledger technologies — Privacy and personally identifiable information protection considerations	Link	2020	ISO						
ISO/TC 307 - Blockchain and distributed ledger technologies	ISO/TR 23245:2020		Blockchain and distributed ledger technologies — Security risks, threats and vulnerabilities	Link	2020	ISO						

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
ISO/TC 262 - Risk Management	ISO/TR 31004:2013		Risk management — Guidance for the implementation of ISO 31000	Link	2013	ISO						
ISO/TC 299 Robotics	ISO/TS 15066:2016		Robots and robotic devices — Collaborative robots	Link	2016	ISO						
ISO/TC 176/SC 2 Quality systems	ISO/TS 9002:2016		Quality management systems — Guidelines for the application of ISO 9001:2015	Link	2016	ISO						
ITU	ITU-T Y.cccsdaom-reqts	UNIBO (U)	Cloud computing - Requirements for cloud service development and operation management	Link	_	ITU						
ITU	ITU-T Y.MLaaS-reqts		Cloud computing- functional requirements for machine learning as a service	Link	_	ITU						
mimosa.org	MIMOSA		MIMOSA is a 501 (c) 6 not-for-profit industry trade association dedicated to developing and encouraging the adoption of open, supplier-neutral IT and IM standards enabling digital physical asset lifecycle management spanning plants, platforms and facilities. MIMOSA standards support key functional and interoperability requirements for Critical Infrastructure Management on a cross-sector basis, addressing the highly heterogeneous and interdependent nature of critical infrastructure. MIMOSA standards and collaboratively developed specifications enable Digital Twins to be defined and maintained on a supplier-neutral basis, while also using	Link	2020	mimosa.org	x					

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
			those Digital Twins to provide Context for Big Data (IIOT and other sensor-related data) and Analytics. In cooperation with other associations, these workstreams provide a pragmatic basis for Industrial Digital Transformation based on the Open Industrial Interoperability Ecosystem (OIIE).									
W3C	ODRL		ODRL Information Model 2.2	Link	2018	W3C				x		
OPC Foundation	OPC 40501-1		UA CS for Machine Tools Part 1 - Monitoring and Job (ZIP/PDF)	Link	2020	OPC Foundation		x	x			
W3C	OWL		Web Ontology Language (OWL)	Link	2009	W3C						
IEEE Institute of Electrical and Electronics Engineers	P1686-2013		P1686 - Standard for Intelligent Electronic Devices Cyber Security Capabilities	Link	2014	IEEE						
Eclipse Foundation	Production Performance Management Protocol (PPMP)		Production Performance Management Protocol Specification	Link		Eclipse Foundation		x	x			
W3C	RFD		Resource Description Framework (RFD)	Link	2014	W3C						

							RAMI 4.0 Category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
W3C	RIF		Rule Interchange Format (RIF)	Link	2010	W3C						
Open Source Robotics Foundation	ROS		Robot Operating System (ROS)	Link		Open Source Robotics Foundation		x	x	x	x	
IPC-CFX (IPC 2-17 – Connected Factory Initiative Subcommittee)	Software tools for Connected Factory Exchange SDK Version 1.0.5		Software tools for Connected Factory Exchange SDK Version 1.0.5	Link		IPC International						
W3C	SPARQL		SPARQL Query Language for RDF	Link	2013	W3C						
ITU	Suppl on Y. Sup.aisr		Artificial Intelligence Standard Roadmap	Link	_	ITU						
VDMA	VDMA 24582:2014		Fieldbus neutral reference architecture for Condition Monitoring in production automation	Link	2014	VDMA						
ITU	Y.ccrm		Cloud computing - Framework of risk management	Link	_	ITU						
ITU	Y.csb-arch		Cloud Computing -Functional architecture for cloud service brokerage	Link	-	ITU						

TABLE 6: C2T ADDITIONS TO THE EFFRA STANDARDS OVERVIEW

							RAMI4.0 category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
ISO/IEC JTC 1/SC 24 Computer graphics, image processing and environmental data representation	ISO/IEC 15948:2004	SINTEF (U)	Information technology — Computer graphics and image processing — Portable Network Graphics (PNG): Functional specification	Link	2004	ISO						
ISO/TC 261 Additive manufacturing	ISO / ASTM52915 - 20	SINTEF (M)	Specification for additive manufacturing file format (AMF) Version 1.2	Link	2020	ISO						
3MF Consortium	3MF	SINTEF (M)	3D Manufacturing Format	Link	2018	3MF						
ESA ECSS	ECSS-M-ST-40C_Rev.1	SPS (U)	Configuration and information management		2009	ESA				X		
ESA ECSS	ECSS-Q-ST-80C-Rev.1	SPS (U)	Software product assurance		2017	ESA					X	

							RAMI4.0 category					
Committee	**ID**	**C2T partner(s)**	**Title**	**Link**	**Date of Publication**	**Publisher**	**Asset**	**Integration**	**Communication**	**Information**	**Functional**	**Business**
IEC/IEEE	IEEE 60802	TTTech (U)	TSN Profile for Industrial Automation	Link	2018	IEC/IEEE			X			
VDMA	VDMA 40001-1	TTTech (U)	OPC UA FOR MACHINERY Part 1: Basic Building Blocks	Link	2020	VDMA			X			
OPC Foundation	OPC 10000-14	TTTech (U)	OPC UA PubSub	Link	2020	OPC Foundation			X			
Modelica Association	FMI/FMU	UNIT040 (U)	Functional Mock-up Unit / Functional Mockup Interface, version 2.0.2	Link	2020-12-15	https://fmi-standard.org/		X				