INTERNATIONAL DATA SPACES ASSOCIATION

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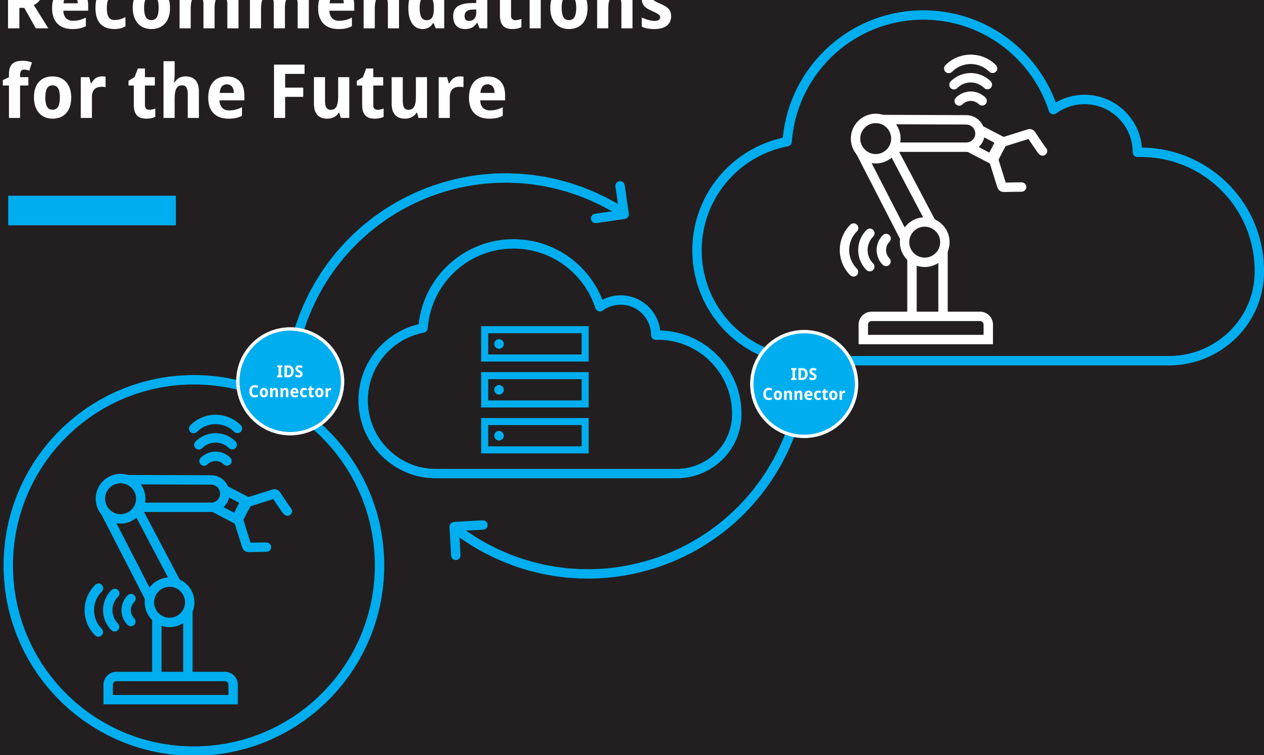
Bridging the Gap Between IDS and Industry 4.0 – Lessons Learned and Recommendations for the Future



- ● Position Paper of members of the IDS Association and of the IDS-Industrial Community
- ○ Position Paper of bodies of the IDS Association
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- ○ White Paper of the IDS Association

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1 Introduction

1.1 Motivation

The Plattform Industrie 4.0 (PI4.0) [1] and the International Data Spaces Association (IDSA) [2] are two independent, parallel initiatives with clear focuses. While PI4.0 addresses communication and interaction between networked assets in a smart factory and/or supply chain across an asset or product lifecycle, IDSA is about a secure, sovereign system of data sharing in which all stakeholders can realize the full value of their data.

Since data sharing between companies requires both interoperability and data sovereignty, the question emerges regarding the feasibility and rationality of integrating the expertise of PI4.0 and IDSA. The IDS-Industrial Community (IDS-I) is an extension of IDSA whose goal is to strengthen the cooperation between IDSA and PI4.0. Two fields of expertise could be combined: The Platform's know-how in the area of Industrie 4.0 (I4.0) and the IDSA's expertise in the areas of data sharing ecosystems and data sovereignty.

In order to realize this vision, many aspects have to be taken into account, as there are discrepancies on multiple levels. Specifically, at the reference architecture level, we have the RAMI4.0 model on the PI4.0 side and the IDS Reference Architecture Model (IDS-RAM) on the IDSA side. While the existing I4.0 and IDS specifications are incompatible e.g. in terms of models (i.e., the AAS metamodel and the IDS information model) and APIs, there is also the issue of interoperability between I4.0 and IDS solutions. These aspects are summarized in the figure below.

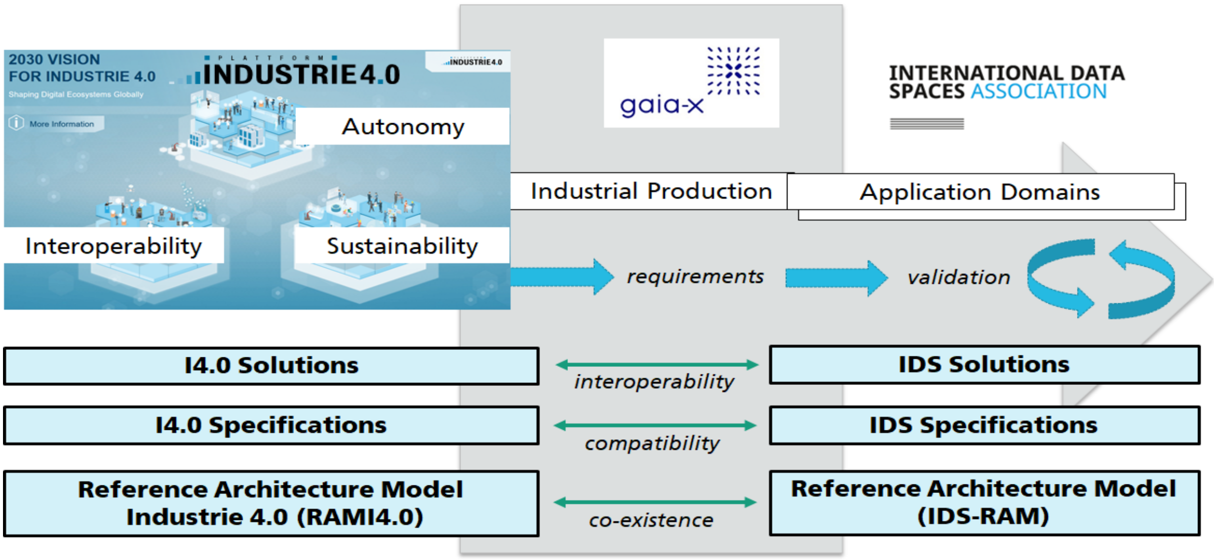

Figure 1: Vision of the IDS-I community

To achieve the vision of integrating the expertise of PI4.0 and IDSA, the IDS-I is working on adapting the IDS principles and technologies to the application domain of industrial production. We started by gathering requirements on various aspects of data sovereignty such as data sharing, data usage monitoring and control, and data provenance tracking. Since we decided to take a bottom-up approach based on use cases, the requirements were first collected using the representative use cases of the PI4.0 (e.g., collaborative condition monitoring, manufacturing as a service, etc.). They were then extended to include the use cases of the members of the IDS-I community (e.g., cross-company supply chain business networks).

1.2 Related Work

The results achieved so far have been published in the following IDS-I position papers:

- IDSA Position Paper "Data Sovereignty - Critical Success Factor for the Manufacturing Industry" (Apil 2021) [3] – This paper describes how data sovereignty, and its main concepts explicitly support the manufacturing industry to keep competitive advantages, to fulfill customers' requirements better, to increase the overall equipment effectiveness, to create and implement new and future orientated business models and services with the trusted use of more data than is available today;
- IDSA Position Paper "Data Sovereignty - Requirements Analysis of Manufacturing Use Cases" (May 2022) [4] – This paper follows a use case driven approach to reveal a structured and prioritized set of requirements on a conceptual level, abstracting from underlying technology and operational infrastructures.

1.3 Scope of the document

This document is the third position paper of IDS-I. It aims to bridge the gap between IDS and PI4.0 by not only analyzing how their existing concepts, tools, etc. have been "connected" in different contexts. Rather, this position paper makes recommendations on how different technologies could be combined in a generic way, independent of the concrete implementation of IDS and/or I4.0 relevant technology components.

This paper could be used by both the IDS and I4.0 communities to further improve their specifications, which are still under development. The lessons learned and feedback from the initial joint use of technology components from both areas could provide concrete guidance on necessary improvements that could further strengthen or extend the specifications. Furthermore, it could help to promote the IDS architecture and specifications in the industrial production and smart manufacturing community and extend typical PI4.0 use cases to include data sovereignty by incorporating IDS aspects.

1.4 On the creation of this document

This paper presents is a collection of results from various projects conducted in recent years. Maturity and foundation in the different evolutions of both, IDS and AAS should be considered as important.

1.5 Structure of this document

The paper is organized as follows: In Section 2, we provide an overview of existing tools that combine at least one IDS and one I4.0 component. In Section 3, we provide information about the research projects that use both IDS and I4.0 technologies and their technical components. Based on the overviews from Section 2 and Section 3, in Section 4 we analyze which technology components from both areas could be integrated at all and suggest how this should be done in a generic way. Finally, we summarize the results and make suggestions for the next steps.

2 Tools

The central component of the IDS is the IDS connector [5]. It is a gateway to the network and different implementations are in development to ensure data security and sovereignty. An overview of the existing implementations of the IDS connectors can be found in the IDSA Data Connector Report [6].

> The *IDSA Data Connector Report* underscores the heterogeneous nature of data connectors, which span from foundational frameworks like the Eclipse Dataspace Components to open-source solutions such as the Dataspace Connector. Additionally, proprietary offerings and off-the-shelf connectors further enrich this landscape, providing tailored solutions to meet specific needs. This nuanced understanding of data connectors reflects the diversity of requirements in industrial data sharing ecosystems.

The Asset Administration Shell (AAS) is one of the most important results of I4.0 and is used to realize the so-called industrial digital twins (DTs) [7], [8]. An evaluation and comparison of the open source AAS implementations can be found in [9].

Both concepts. the data connector on the one hand and the AAS on the other, complement each other. Several technical results are already available that exploit the synergy of both concepts by integrating them. In this section we give an overview of the tools we are aware of.

2.1 Standardized Manufacturing as a Service through Asset Administration Shell and Dataspace Connectors

2.1.1 Short description

Mondragon is working on a Manufacturing as a Service system for the execution of remote production orders built upon the implementation of emerging AAS capabilities and IDS connectors. A catalogue of the available industrial assets (presses and laser cutting machines) modelled with new AAS submodels is shared with external parties through Dataspace Connectors. Third party companies analyze assets capabilities and launch manufacturing orders remotely using the same data space. Finally, a manufacturing orchestrator is responsible for managing the production of incoming orders by executing the production tasks on the different assets using the OPC UA communication protocol.

2.1.2 Relevant parts of the architecture

The architecture of the whole system is shown in the Figure 2 [10]. The use case contains the following main components:

- AAS models for Industrial assets. An AAS is defined for each industrial asset involved in the use case. For the definition of these DTs, AAS submodel templates defined by the I4.0 initiative [11], [12] and custom submodels defined within the use case have been used. The following templates have been used:
    - Nameplate and TechnicalData submodels, for the manufacturing specifications and the technical characteristics;
    - ProductionData and OpParamSettings submodels customized by Mondragon partners, for the operational status information of the machine and the externally accessible machine operations;
    - M2MConnectivity submodel customized also by the team, to ease communication with other AAS.
- AAS Manager and Registry System. The AAS Registry is the component in charge of storing all the AASs of a given company or manufacturer. The registry backend consists of a REST API layer implemented in Python. To facilitate the management or use of the registry, an additional tool named AAS Manager is included. This Manager is a user-interface in a web application form that enables non-expert users to manage and explore the registered assets.
- Active AAS (Orchestrator). A component implemented in Node-RED that is responsible for receiving the manufacturing orders and deciding which assets will perform the requested tasks to produce the order. To achieve that, the Orchestrator queries the AAS registry for assets that satisfy each of the tasks in a manufacturing order.
- IDS Connectors. The Dataspace Connectors in this use case are responsible for the data exchange between the companies in a secure and sovereign way. The connectors manage the following two main aspects: on the one hand, sharing the AAS catalogue of the assets available in the supplier system, and on the other hand, launching the manufacturing order to the orchestrator through the connectors subscription system.

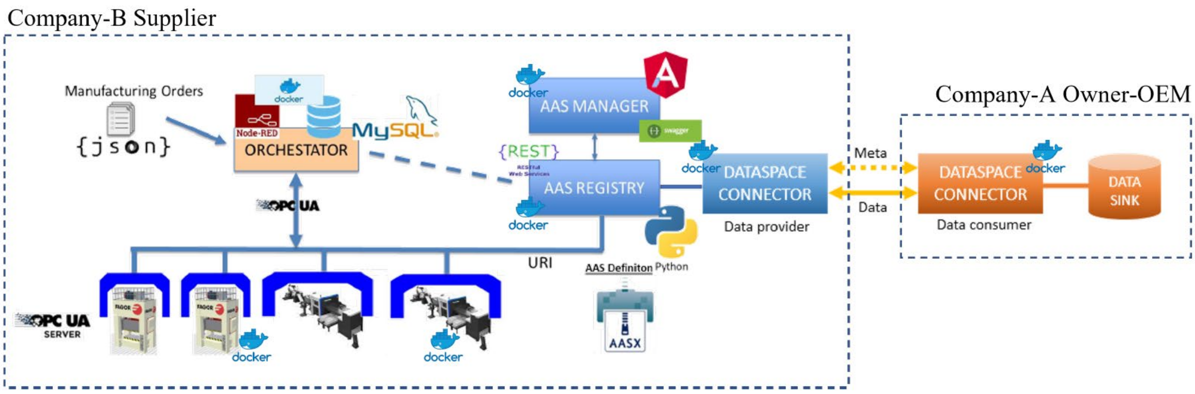

Figure 2: Architecture for Mondragon Use Case [10]

2.1.3 Usage of I4.0 & IDS concepts and components

Asset Administration Shell: 4 different AAS models have been used to define 2 industrial presses and 2 laser cutting machines. As explained in the previous section, different submodel templates have been used to define these assets.

For the storage and management of the different AASs defined two main components have been implemented. On the one hand, an AAS Registry stores all the AAS models available in the plant. This component is accessed through a REST API. On the other hand, an AAS Manager provides a graphical interface for users and allows visualization and management of the different assets available in the system.

Finally, a Node-RED orchestration system has been developed to process customer manufacturing orders and manage communication with industrial assets using the OPC UA protocol. When a new recipe arrives from the Dataspace Connector, the orchestrator first performs a query to the Registry to access both production and communication information of the required assets and then starts communicating with the industrial assets to start the production of the required pieces.

In the use case, the main usage of the data space is through the Data Connectors. They enable data exchange and service consumption between different companies or parties in a secure and sovereign way. There is a data connector located in the supplier company and another in the client company. Depending on the task that they perform, in some cases they act as a provider and in other cases as a consumer.

The data connectors have two main objectives related to data exchange, which are the following:

- Sharing the assets AAS catalogue available in the plant. The client can request the AASs registered in the supplier system via the Dataspace Connector This information is analysed and visualized with tools such as the AASX Package Explorer. To request and consume the IDS resource that contains the AAS catalogue in the supplier connector, a contract agreement is established between both connectors. The complete process of catalogue consumption is explained in Figure 3 as Sequence 1 (S1) [10].
- Launch the manufacturing order in the orchestrator. A client launches a manufacturing order through the connector via the Dataspace Connector subscription system. In turn the client handles the request and executes the recipe in the orchestrator. In this case, the client's connector acts as data publisher because it sends the manufacturing order to the other connector updating a resource where the other connector is subscribed. To implement this task, two IDS subscription types are implemented. On the one hand, the IDS-Subscription between both connectors is activated to notify and push data when the specified artefact is updated (in this case with the manufacturing order). And on the other hand, the No-IDS-Subscription that enables the addition of a backend. This backend will handle the notification and data by launching the received recipe to the orchestrator. The whole process for this task is explained in Figure 3 as Sequence 2 (S2) [10].

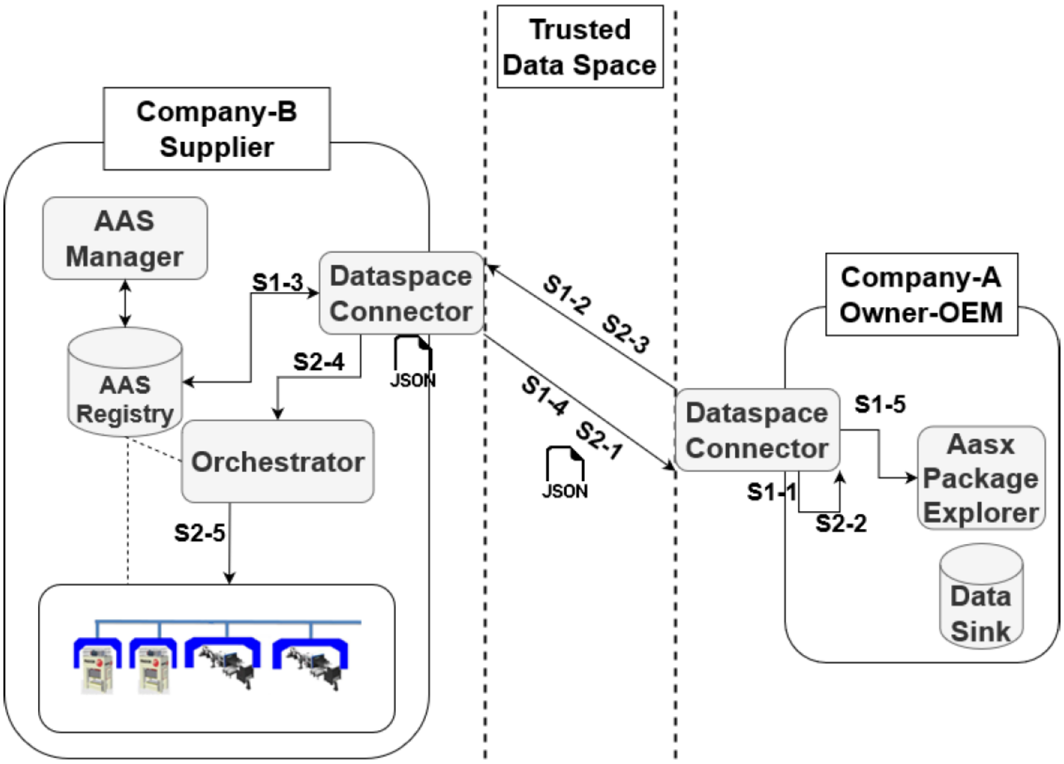

Figure 3: Data Sequences in the Use Case [10]Lessons learned from the joint use I4.0 & IDS concepts/components and recommendations for improvements

A critical insight gleaned from our study is the potential for enhancement in the integration of the IDS ecosystem with the AAS. At the time the use case was implemented, there was limited software available to integrate both technologies. In the use case, different middleware adapters were developed in Node-RED. On the one hand, this software manages the creation and interaction of the IDS Connector resources and the subscriptions system and on the other hand, it manages the storage of AAS models in the orchestrator for communication with the industrial assets. In conclusion, additional integration software is required to integrate both technologies in a more accurate and standardised way.

Furthermore, when implementing the system to remotely launch manufacturing orders, we have noticed that the Dataspace Connectors lack of an event-driven mechanism that is capable of functioning asynchronously by publishing an event. To fill this gap, a system of IDS subscriptions has been implemented that function as an event-driven data exchange flow. But it is still not an optimised system for certain use cases.

2.1.4 Further plans related to better use or use of additional I4.0 & IDS concepts/components

To improve the system or the solution, it has been thought to add and integrate new components related to the technologies used during the use case. Firstly, in order to be able to create a trusted data space between the service provider and the different clients, the IDS Metadata Broker [14] can be implemented. The broker will act as a registry of both connectors and resources within the established data space, which will be used to discover resources and services.

Secondly, the use and deployment of the new Eclipse Dataspace Connector (EDC) [15] with the extension [16] developed by Fraunhofer to integrate the AAS has been identified. One of the hardest challenges of the use case, is the integration and the search for synergies between both technologies. With the commented extension (as outlined in its repository), the sharing of an AAS model is facilitated through the EDC.

Finally, we identify semantic technology as a facilitator for the integration between IDS and AAS. The Mondragon team believes that the capabilities brought by semantic technology need to be researched.

2.1.5 Link to the tool

- Private to Mondragon Corporation partners https://gitlab.danz.eus/qu4lity/pcyt-aas
- Private to Mondragon Corporation partners: https://gitlab.danz.eus/qu4lity/pcyt-aas

2.2 EDC Extension for Asset Administration Shell

2.2.1 Short description

As described in [17], to share data in a data space, a description of data sources in the connector catalogue is required. This is mostly a manual process where the data to be shared is selected, described, and fitted with a usage contract. In the case of the AAS as a data source, each submodel or element requires such a description. Since the EDC [15] can be extended with “EDC Extensions”, Fraunhofer IOSB created an “EDC Extension for AAS” to simplify this process for data providers [16]. In order to minimize configuration effort and prevent errors, the EDC extension [16] is able to map running AAS services like FA³ST [16] or AASX Server [19] into EDC Assets. Furthermore, this extension can also start AAS services by reading AAS models. External changes to the model of an AAS are automatically synchronized by the extension.

The extension also provides functionality for consumers interacting with AAS. Additionally, a graphical client providing API calls for simplification of processes such as contract negotiation and data transfer is available.

Figure 4 shows the integration of the EDC Extension into EDC and the AAS as a data source.

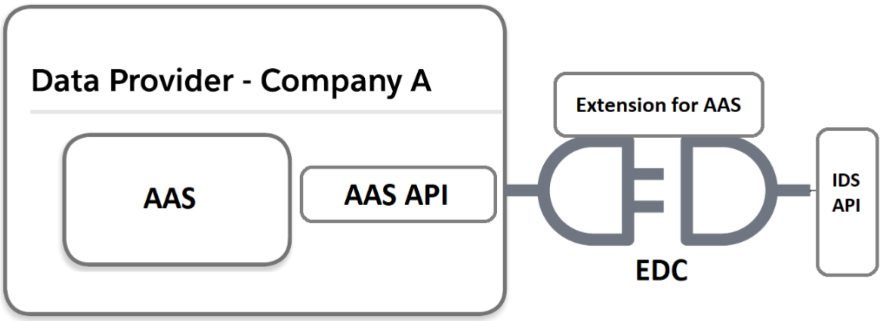

Figure 4: EDC Extension for AAS integrating AAS into DS [17]

2.2.2 Relevant parts of the architecture

The extension architecture shown in Figure 5 is the result of following considerations:

- Supporting all AAS formats
- Supporting different implementations of AAS services
- Providing graphical interfaces
- Reducing user effort

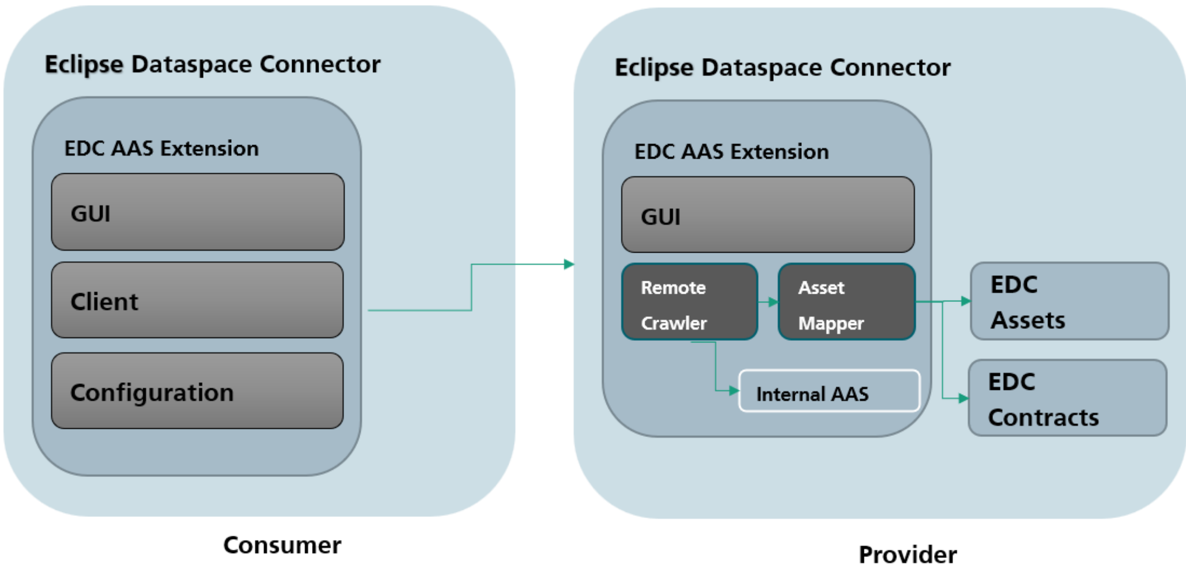

Figure 5: EDC extension for AAS for data provider and consumer side

We differentiate between already running AASs (external) and AASs that will be started from a model file (internal). In the first case, the AAS is already running as a service in the company, for example, with implementations such as NOVAAS [20] or FA³ST Service [18]. In this case, the URL of the AAS must be provided so that all re-sources can be created automatically on the basis of external AAS.

The remote crawler connects to the external AAS service and tries to retrieve all AASs found in the service. The asset mapper is responsible for mapping each AAS submodel and element into a newly created EDC Asset. For this, the asset mapper directly accesses the asset index of the EDC. Each submodel and element is then mapped into an EDC asset. In theory, the extension could be decoupled from the EDC by interacting with the EDC API to create assets and contracts, but the EDC provides convenient access to several internal components for extensions.

2.2.3 Usage of I4.0 & IDS concepts and components

The extension is part of the EDC, a connector implementing the IDS / Gaia-X specifications. It shares the I4.0 AAS with the EDC and enables integration of Industrie 4.0 and data space in a user-oriented manner. The proposed solution is extensible for different AAS implementations. The current version supports the AASs implemented by the FA³ST service [18].

2.2.4 Lessons learned from the joint use I4.0 & IDS concepts/components and recommendations for improvements

The joint use of these components focuses on the strengths of each specification, but a standardized, detailed approach to integration on specification level would benefit the user base. For example, the AAS Security specification is not yet released. In projects like Catena-X [21], use-case specific integrations are currently being standardized which should provide feedback to specifications on how to realize uniform integration.

2.2.5 Further plans related to better use or use of additional I4.0 & IDS concepts/components

Fraunhofer IOSB is actively contributing in the Industrial Digital Twin Association e.V. (IDTA) [22] to improve and test the specifications in data-sovereign Industrie 4.0 use-cases. As such, the extension will be improved with requirements emerging from project pilots and use-cases.

2.2.6 Link to the tool

- https://github.com/FraunhoferIOSB/EDC-Extension-for-AAS

2.3 Secure and Privacy-Preserving AAS

2.3.1 Short description

Eclipse BaSyx [23], IDS [2], and Gaia-X [24] are key technologies driving the next generation of digital transformation and Industrie 4.0. Eclipse BaSyx is one of the first implementation of AAS that enables the digitization of the factory by using standardized AAS. Gaia-X focuses on sovereign cloud services and infrastructure, while IDS is concerned with peer-to-peer data sharing.

Despite recent advances in sovereign data-sharing technologies, many factories are challenged by interoperability of data from different sources. They are unable to share data due concerns about privacy and data sovereignty. New technologies are necessary to bridge this gap. Privacy-Preserving Machine Learning (PPML) and Multi-Party Computation (MPC) technologies allow several parties to analyze data jointly, as if they have a shared database, without ever revealing data. The proposed novel toolchain aims at developing an interface between Eclipse BaSyx, an IDS-based connector [5] an IDS-based connector [5] as well as PPML/MPC technologies. As a result, smart factories can share/exchange privacy-sensitive data in a secure manner, while new services such as predictive maintenance can be offered in the ecosystem.

2.3.2 Relevant parts of the architecture

Figure 6 shows the overall concept of the developed toolchain, which enables factories to use machine learning models and analyze data collaboratively. On one side, Eclipse BaSyx and the AAS provides the raw data of the factory. Currently, the interface between AAS and IDS Connector is based on the MQTT protocol, but it can be easily extended to other protocols, such as HTTP over REST APIs. On the other side, an IDS-based connector encrypts the client's data and transfer it to Advaneo Trusted Data Hub (TDH). TDH is a holistic hardware-software PPML/MPC solution to radically shape the data economy by eliminating data-sharing risks and lessening the privacy-utility challenge. TDH provides several features and advantages over existing solutions (e.g., Federated Learning and Differential Privacy), making it a unique and promising solution to many privacy-sensitive applications.

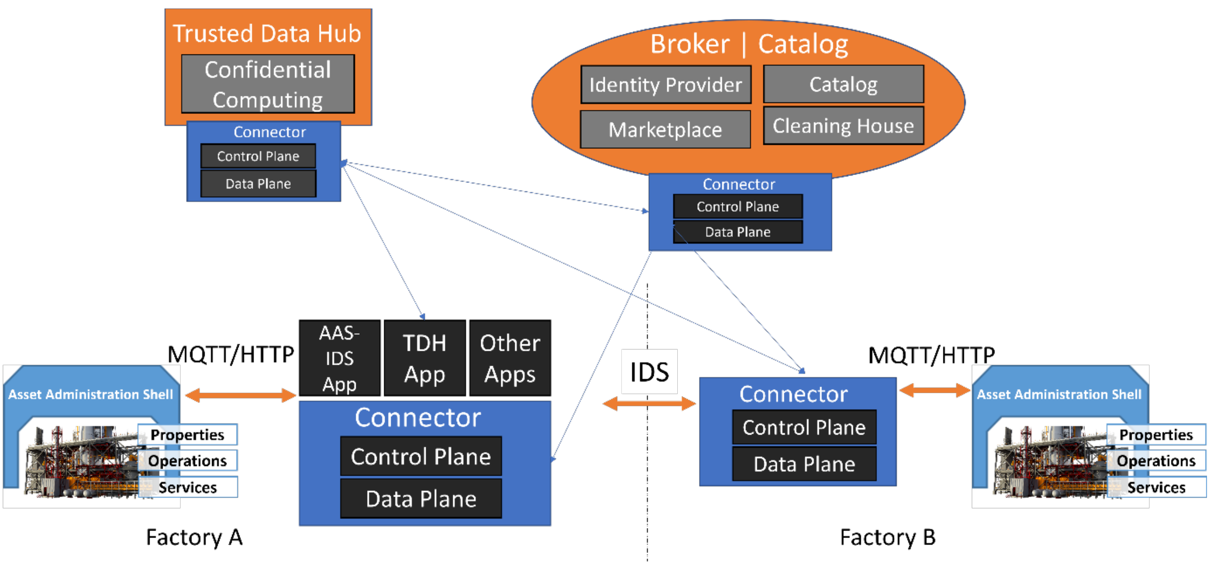

Figure 6: Toolchain Overview - Integration Eclipse BaSyx and IDS Connector

2.3.3 Usage of I4.0 & IDS concepts and components

The following IDS concepts have been implemented and integrated into the developed toolchain:

1) Data Broker and Federated Catalog: this broker/catalog has been extended to capture the nature of the dataset. Datasets can be offered to the customer in two different ways:
   - *Direct*, in which datasets can be transferred from data providers to data consumers via IDS connectors; and
   - *Indirect*, in which customers can train a model consuming the dataset using PPML technologies, but they cannot investigate the raw data due dataset sensitivity.
2) Connector: this connector provides the communication interface to data providers and data consumers in the ecosystem. Data providers can exchange their data with other peer2peer-based ecosystems while ensuring data sovereignty and data access control. Connectors are integrated to Eclipse BaSyx enabling data exchange between factories and service providers. In other words, the implemented IDS connector acts as a gateway between, Eclipse BaSyx running on the shopfloor, and PPML/MPC systems running in the cloud.

2.3.4 Lessons learned from the joint use I4.0 & IDS concepts/components and recommendations for improvements

In 2021, when this development commenced, there were roughly 10 distinct implementations of an IDS connector, including Trusted Connector, Dataspace Connector, TNO Trusted Connector, DIH Connector, and others. Many of these implementations targeted specific use cases and functionalities. However, choosing a single implementation was not straightforward. Furthermore, the Gaia-X Federated Catalog was also not completely compatible with the IDS Metadata Broker.

2.3.5 Further plans related to better use or use of additional I4.0 & IDS concepts/components

Currently the toolchain integrates the Trusted Connector [25], and the next step is to integrate the EDC connector [15]. In particular, the functionality of EDC is to be extended to support TDH as an innovative solution for PPML/MPC. Ultimately, TDH will be offered to Gaia-X as a Gaia-X node. In the upcoming releases, Eclipse BaSyx will integrate advanced data access control features, enabling factories to tailor access permissions for individual Asset Administration Shells (AAS) and Submodels. This enhancement empowers data owners to selectively share AAS data exclusively with external parties of their choosing, ensuring utmost control and privacy over their information sharing practices.

2.3.6 Link to the tool

- https://www.advaneo.de/en/trusted-data-hub-privacy-preserving-multi-party-computing/#
- https://www.eclipse.org/basyx/
- https://www.advaneo.de/en/trusted-data-hub-privacy-preserving-multi-party-computing/# https://www.eclipse.org/basyx/

2.4 FIWARE Data Space Connector

2.4.1 Short description

The FIWARE Data Space Connector [92] is crafted to adhere to DSBA Technical Convergence recommendations [93], making it a suitable option for organizations aiming to establish data spaces in alignment with these recommendations. It encompasses several seamlessly integrated modules that participants of a data space may deploy to establish connections within the data space. The current release of the FIWARE Data Space Connector integrate modules implementing:

- Interfaces with Trust Services using EBSI APIs (DID-Registry [94] for registration of trusted participants and Trusted Issuers Registry [95] for registration of trusted issuers of verifiable credentials);
- authentication based on W3C DID [96] with VC/VP standards [97] and SIOPv2 [98] / OIDC4VP protocols [99];
- authorization based on attribute-based access control (ABAC) following an XACML P*P architecture [100];
- Marketplace functions based on TMForum APIs [101], enabling providers of data and services accessible through the connector to define products and offerings around those products that can be marketed and monetized.

The FIWARE Data Space Connector can be used to govern transference of data using different RESTful APIs but has been proven already with the ETSI NGSI-LD API [102], used in combination with smart data models [103], for different use cases in multiple domains.

A new release of the FIWARE Data Space Connector is planned within the first quarter of 2024 implementing the Catalog and Transfer Process Control protocols specified under IDS Dataspace Protocol v0.8.

2.4.2 Relevant parts of the architecture

The FIWARE Data Space Connector adopts a modular architecture as proposed in the IDS RAM 4.0, description of IDS Connectors [104]. Therefore, it is targeted to implement a number of integrated modules solving how:

- authentication of users and applications can be implemented;
- policies for accessing data and data processing services, as well as for usage of data, can be enforced based on attributes of users and applications or characterizing the environment;
- acquisition of rights to use data and data services can be managed, eventually implying payment;
- transfer of data can be controlled;

- transactions can be logged and audited;
- software deployed by the organization to process data can be remotely attested;
- etc.

The table below (Table 1) lists the FIWARE Data Space Connector components including the main technology behind each component along with its role and the link to an open-source component implementation repository.

Table 1: FIWARE Data Space Connector components

Component	Role	Link
VCVerifier	Verifier	https://github.com/FIWARE/VCVerifier
VCWaltid	Backend for managing credentials and DIDs, supports the verifier and issuer	https://github.com/FIWARE/VCWaltid
credentials-config-service	Credentials Config provider for the verifier	https://github.com/FIWARE/credentials-config-service
Keycloak + keycloak-vc-issuer plugin	Issuer of VCs	https://www.keycloak.org / https://github.com/FIWARE/keycloak-vc-issuer
Orion-LD	Context Broker	https://github.com/FIWARE/context.Orion-LD
trusted-issuers-list	Acts as Trusted Issuers List by providing an EBSI Trusted Issuers Registry API	https://github.com/FIWARE/trusted-issuers-list
Kong + kong-plugins-fiware	Kong API-Gateway with the kong-pep-plugin serving as API-Gateway and PEP	https://konghq.com / https://github.com/FIWARE/kong-plugins-fiware
dsba-pdp	DSBA-compliant PDP	https://github.com/FIWARE/dsba-pdp
Keyrock	Authorization Registry (storing role / ABAC-policy mappings)	https://github.com/ging/fiware-idm
tmforum-api	TMForum APIs for contract management	https://github.com/FIWARE/tmforum-api

contract-management	Notification listener for contract management events out of TMForum	https://github.com/FIWARE/contract-management
MongoDB	Database	https://www.mongodb.com
MySQL	Database	https://www.mysql.com
PostgreSQL	Database	https://www.postgresql.org

In the following diagram (Figure 7), a logical overview of the different components of the FIWARE Data Space Connector is attached.

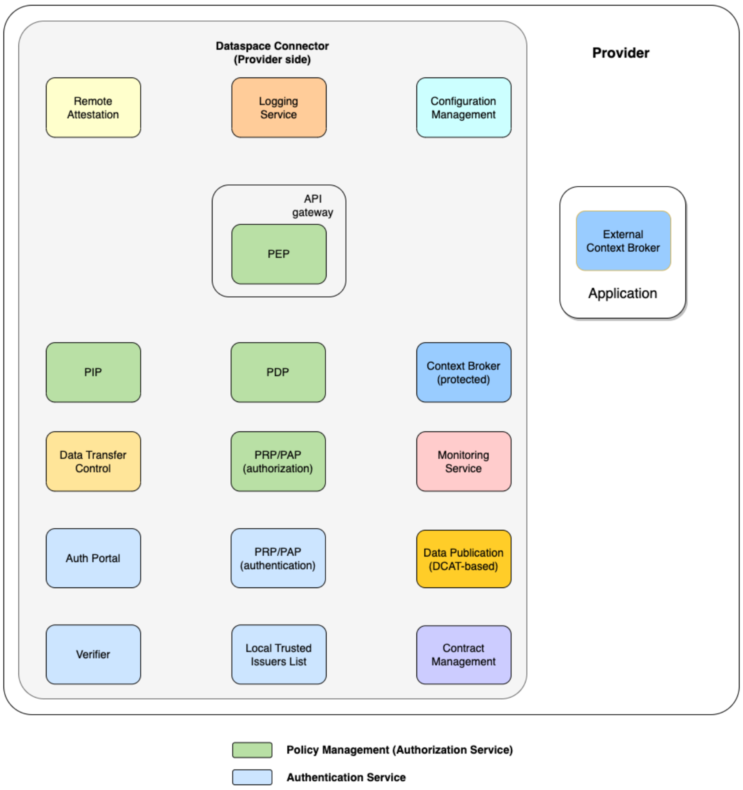

Figure 7: Overview of the different components of the FIWARE Data Space Connector

2.4.3 Usage of I4.0 & IDS concepts and components

The FIWARE Data Space Connector operates using NGSI-LD as an API for accessing attributes of digital twins. In this context, there is an active workstream that employs NGSI-LD as an API for accessing information related to AAS. The initiative originates from developments carried out within the Corosect project and has resulted in significant outcomes for I4.0 contexts. Firstly, it has led to an agile standardization process within the Smart Data Models program [105], the details associated to this are available in the following repository [106]. Secondly, the work carried out has resulted in additional features being developed for the NGSI-LD standard. These enhancements are slated for publication in the upcoming version (v1.8.1) which is available as a stable draft document in the European Telecommunications Standards Institute (ETSI) portal [107]. These promising results show a solid commitment to advancing NGSI-LD related standards and component functionalities in their intersection with DT and AAS information management.

In the first release of the FIWARE Data Space Connector, implementation of functions dealing with authentication, authorization (policy enforcement) and how acquisition of rights to use data and services can be managed (marketplace/trading functions) have been prioritized, following DSBA Technical Convergence recommendations. Specification of functions for authentication, authorization and marketplace functions will be contributed as new protocols under IDS Dataspace Protocol specifications although the specific process to follow is still under discussion. The new release of the FIWARE Data Space Connector will incorporate an implementation of Catalog and Transfer Process Control protocols already specified as part of IDS Dataspace Protocol v0.8.

2.4.4 Lessons learned from the joint use I4.0 & IDS concepts/components and recommendations for improvements

The FIWARE Data Space Connector has been thoroughly tested and found to comply with DSBA recommendations in various scenarios. This first series of aimed at assessing and showcasing the applicability of NGSI-LD in them. In a new series of actions, NGSI-LD is being tested as a valid API for managing Digital Twin and AAS information in near real-time and will look for enabling the necessary technical convergence with the DSBA's data space connector recommendations. The successful demonstration of NGSI-LD in I4.0 contexts is a key step to enhance the interoperability of I4.0 systems with systems from other application domains where NGSI-LD is endorsed as a preferred standard.

2.4.5 Further plans related to better use or use of additional I4.0 & IDS concepts/components

There is a specific FIWARE Technical Roadmap Working Group which continuously drives the evolution of the NGSI-LD standard and Smart Data Models to accelerate the performance and functionalities of the FIWARE Data Space Connector in this context. In particular, the applicability of data space connectors in the emerging scenarios of online marketplaces for cloud and edge services is a major topic in the roadmap of this working group. The evolution of the context broker technology to enhance its real-time performance and identifying/solving potential problems related to the technical convergence with the DSBA requirements for IDS connectors is another topic identified as a top priority.

2.4.6 Link to the tool

- https://github.com/FIWARE/data-space-connector

3 Projects

In the previous section, we provided an overview of the tools that enable the joint use of IDS and I4.0 technology components. In this section, we present several research projects that either apply these tools or use the technology components from both areas in a combined manner.

Each project description follows a consistent format. It begins with a brief project overview, followed by an exploration of scenarios requiring the integrated use of I4.0 and IDS concepts/components. Subsequently, relevant architectural aspects are presented, accompanied by explanations of the application of I4.0 and IDS concepts/components. Insights gleaned from the combined utilization of I4.0 and IDS are then discussed, along with recommendations for improvement, and identification of project outcomes pertinent to the IDS-I community. Lastly, we summarize how the project can contribute to and benefit from the IDS-I position paper, before providing links to relevant project results.

3.1 Catena-X

3.1.1 Short project description

Catena-X is an open an interoperable data ecosystem for the automotive industry. It relies on Gaia-X [26] and IDS principles to build a trusted environment enabling sovereign data sharing. The ecosystem is open to different groups of participants, independent of their companies' size. To allow participation, Catena-X provides a standard library, certified services and certified applications [27]. As stated in the operating model [28], Catena-X follows a decentralized approach to prevent lock-in effects and allows different service providers, such as business application, on-boarding service and consulting service providers, to compete in the ecosystem.

3.1.2 Project-relevant scenario(s)

Two Catena-X use cases will be examined in the following to get an overview of two different architectures relying on different components of the relevant initiatives.

The Quality use case [29] allows to exchange quality notification between partners. These quality notifications may be either quality investigations or quality alerts. Quality investigations are triggered manually by a customer based on an event, such as identifying problems with a car. Quality alerts are triggered manually by a supplier based on an event, such as identifying problems with a component. These notifications may be classified using a criticality such as "life-threatening" which can be set to indicate that the airbag is malfunctioning. The Trace-X is a free open-source software (FOSS) application software that allows SMEs to send and receive quality notifications following the Catena-X standards. This application provides an API as specified in the respective standards [30], [31], that specifies how to exchange quality investigation and quality alert notifications for given parts. The API is only available through an EDC.

The described scenario pertains to the quality use case [29], involving a car manufacturer (referred to as the customer) detecting quality issues within a vehicle. Upon owners bringing their cars in for maintenance, a defective engine is identified as the source of the problem. To delve deeper into the quality concern, a quality investigator can access pertinent information via the Digital Twin (DT) associated with the car. Initially, the investigator identifies the affected vehicles, then rectifies the faulty components using the bill of materials, and subsequently initiates quality investigations for those parts.

Upon receiving notification, the manufacturer commences an investigation into the issue, leveraging manufacturing data and the bill of materials. The manufacturer may either detect the quality issue independently or trace it back to specific components within the engine. In the latter case, the manufacturer requests quality investigations for the implicated components. If additional faulty items are identified, this information can be relayed to affected customers, potentially extending to other affected customers as well. The relevant recipients for such notifications can be determined through the reverse direction of the bill of materials.

The Demand and Capacity Management (DCM) use case facilitates interoperable definitions for joint demand and capacity planning. It offers semantic definitions for exchanged demand and capacity data [32], outlines business processes for data handling [33], and furnishes an API for implementing data exchange [34]. This use case enables customers and manufacturers to align long-term material demands with capacity groups on a weekly basis, spanning multiple months to years. Capacity groups are established to identify potential bottlenecks; for instance, materials like doors and windows may be grouped together if they share the same machinery, personnel, or critical supply dependencies. The standard delineates the process for matching these information objects. Actual demand and capacity planning activities are contingent upon the participants of the use case. Upon any updates to the data, partners promptly share these updates with each other.

The DCM use case [33] encompasses the following scenario: A car manufacturer generates primary demand forecasts and subsequently derives secondary demands for required components. One such component of secondary demand is the central control unit. Observing that the demand for the next year's week 23 series of cars exceeds current capacity, the DCM user categorizes and transmits this demand data to their central control unit supplier using demand categories (e.g., series and after-sales demands) via DCM APIs through the EDC.

Upon receiving the latest demands, which replace previous demand information, the supplier assesses their ability to fulfill the demands and identifies any bottlenecks. If capable, the supplier updates capacity planning and demand planning, accordingly, subsequently transmitting the new capacities to customers and the new demands to suppliers. If unable to meet the demand, the supplier may initiate communication with relevant partners to strategize on mitigating the bottleneck.

Further use cases [35] provide solutions for product carbon footprints, circular economy including digital product passes, manufacturing as a service, modular production and material flow simulations.

3.1.3 Architecture

In the following the architectures of the two use cases above are described in more detail. The components usage per use case is summarized in Table 2.

Quality

A sketch of the architecture used for the quality use case, can be seen in Figure 8. It considers the Connector [36], the Data Chain [37] and the Digital Twin KIT [38].

The provider side of Figure 8 may be implemented per use case as needed within the systems (e.g. enterprise resource planning, product life cycle and quality systems). For the quality use case SME may use the “Simple Data Exchanger” [39] application, which can provide predefined kinds of submodels in the data space from an Excel file upload performing the steps 1.a to 1.e. This contains the creation of submodels, registering the submodels as data assets in the EDC and registering the submodels in the Digital Twin Registry (DTR). Use cases handling frequently changing data may want to integrate their systems directly.

The consumer side of Figure 8, starts the quality investigation via the FOSS application “Trace-X” [40]. To get information regarding the child items of the concrete assets to investigate, it triggers the FOSS application “Item Relationship Service (IRS)” (step 2) [41]. The IRS implements the steps 3.a to 3.c in an automated fashion.

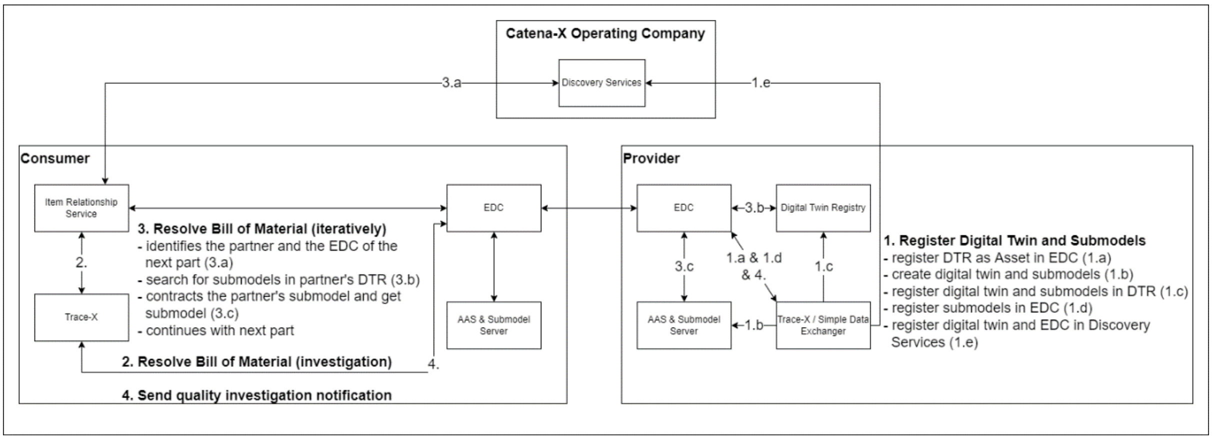

Figure 8: Simplified architecture of the Quality use case[1]

As previously stated, the IRS provides the capability to resolve bills of material of a given material. The DTs are linked via the global asset IDs (Catena-X ID) in bill of material

[1] The Simple Data Exchanger is used to provide and register DT data as a CSV upload. The Trace-X applications allows to exchange quality investigations and alerts via an API that is exposed via the EDC. The Trace-X application uses the IRS to resolve the bill of material for a given serial part. Except for Trace-X and the Simple Data Exchanger, these components can be found in the Connector, Data Chain and Digital Twin KIT in Catena-X. Discovery Services may be decomposed into Discovery Finder, BPN Discovery and EDC Discovery. Identification and authentication mechanisms and the Semantic Hub have been omitted.

submodels. The IRS identifies the owner and the Eclipse EDC via the Discovery Services provided by the Catena-X Operating Company. Then the IRS determines the hosting EDC of the submodel in question via the provider partner's DTR. Knowing this EDC, the IRS may contract and receive the submodels in question. The IRS continues to contract submodels of the partners along the supply chain until the end is reached or no access is given by the contract definitions in the participant's EDC. Beside resolving the bill of material, additional information may be collected from the DT providing the bill of material aspect.

DCM

The DCM use case [32], [33], [34] uses the EDC to exchange demand and capacity messages proxied via the EDC to the partners endpoints. The flow relies on a push mechanism sending semantically defined submodels. The information exchange uses, same as the quality use case, a value-only JSON serialization. The DCM use case does not need the interfaces defined by the Asset Administration Shell specification [42]. The information exchange therefore can be performed with submodels as type 1 AAS [43].

Optionally (and not stated in Figure 9), the Discovery Services may be used to identify the partners' EDC based on a Catena-X specific identifier.

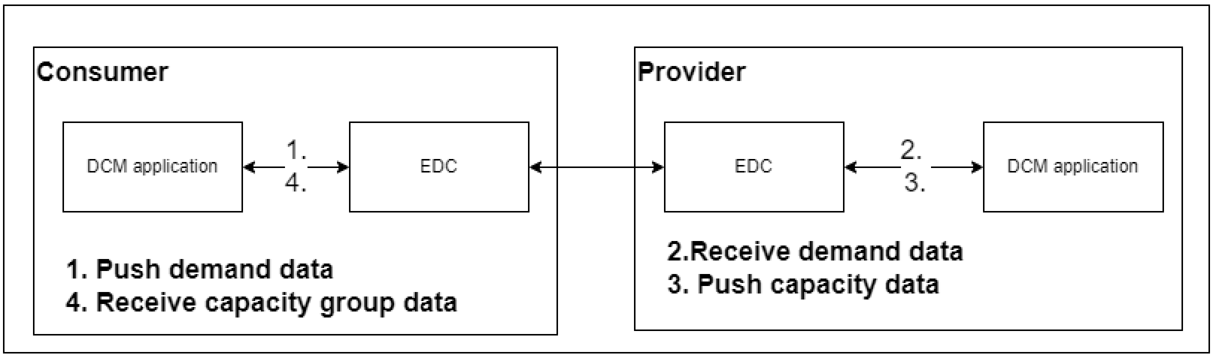

Figure 9: Simplified architecture of the DCM use case. The dcm applications implement the demand and capacity exchange endpoints and exchange information via the EDC

3.1.4 Usage of I4.0 & IDS concepts/components

Table 2 summarizes the usage concepts and components implemented by the previously described Use Cases.

Catena-X follows IDS and Gaia-X principles [28]. The "Tractus-X Connector" (also called EDC) is an adoption of the EDC. The Tractus-X Connector provides further implementations to e.g., enforce access policies according to the identifier of a business partner. Within release 3.1, the connector relies on a Dynamic Attribute Provisioning Service (DAPS) implementation according to the IDS Reference Architecture Model (IDS RAM) for identification. For upcoming releases this component is likely to be replaced by the Self-Sovereign Identity, that is developed as part of the European Self Sovereign Identity Framework (ESSIF) in Gaia-X, to achieve a more decentralized identity management. Catena-X also provides a control plane adapter wrapping the contract definition [44], [45].

Catena-X provides a Governance Framework [46] defining the basic principles of the data ecosystem with the "10 Golden Rules" [47]. More detailed "Use Case Policies" clarify the key aspects per use case while the "Use Case Framework Document" provides usage policies that may be enriched with access policies and automated contract negotiation. Explicitly the use case policies and the use case framework document provide the organizational guideline of data sovereignty.

Catena-X provides a DTR implementing the version 3.0 specification of the AAS Metamodel and Interfaces for AAS Discovery and Registration [43], [42]. Catena-X provides additional Discovery Services to identify the owner and the responsible IDS Connector for a DT [38].

Catena-X uses the Semantic Aspect Meta Model (SAMM) to model the data exchanged. The tooling is able to generate submodel templates and JSON schemata from the created model artifacts [48]. The Semantic Hub [49] hosts these versioned model artifacts in a human and machine-readable way. The Semantic Hub may be seen as an IDS Vocabulary Hub.

For use cases relying on the AAS interfaces, such as quality, data is exchanged via submodel interfaces of the AAS proxied through the EDC [50]. Quality hosts the bill of materials and manufacturing data in AAS and uses the IRS to collect the data via the EDC from their upstream and downstream partners [29]. Within Catena-X, there are DTs and submodel templates available for different life cycle phases of the assets. The semantic definitions are available via the "Semantic Hub" [49], which provides further information about submodels available an IDS Vocabulary Provider. For the Quality use case the "as built" life cycle is relevant because it allows to follow the chain of specifically identifiable parts (via e.g. "vehicle identification number") and products that have been built into the car.

According to data sovereignty principles, each partner only keeps the data he owns, meaning that the customer manufacturer only has the item-related data of his car and the bill of material pointing to the global asset ids of the AAS representing the items that are built into this car. The supplier decides which data in the form of submodels he wants to share with which partner by defining asset policies in the EDC based on Catena-X specific identifiers of the partners. Catena-X additionally provides a governance framework with explicit agreements on data usage. The provisioning of this data is use case specific. The Simple Data Exchanger provides a CSV upload and registration of the data, which may be used for static (non-frequently changing) data provisioning.

Data Chains in Catena-X may be resolved via the IRS. The IRS determines the partners' EDC via the discovery interfaces and identifying information such as specific and global asset IDs. The IRS searches in the decentralized Digital Twin Registry of a specific partner for the needed submodels. The models are registered with an EDC endpoint which the IRS uses to contract the submodel usage and receive the submodel data via the AAS interfaces proxied through the IDS connector's data plane. The IRS works fully automated in a job-based fashion for a specific set of relational submodels. It can resolve relational submodels, if the respective submodel data references further DTs and the party using the IRS is allowed to contract the data at the owning participants IDS connector. As the IRS relies on specific submodels [37], it must be enhanced for further application on e.g. resolving bill of processes.

Table 2: Summary of components and concepts used per use case

Initiative	Component / Concept	Implementation	Description	Used by Quality	Used by DCM
IDS	EDC	Tractus-X EDC	This connector is compliant to the Data Space Protocol. It provides additional extensions for Catena-X.	x	x
IDS	Data Sovereignty	Governance Framework	The Governance Framework defines the core values and breaks them down to use cases and application providers.	x	x
IDS	Vocabulary Provider	Semantic Hub	The Semantic Hub provides a human- and machine-readable representation of the semantics of submodels via the Semantic Aspect Meta Model.	Optional	Optional
IDS	Dynamic Attribute Provisioning Service	Omejdn Server	The identity provider may add further information that can be evaluated by an IDS connector to increase data sovereignty.	x	x
I4.0	AAS (Information Model)	Semantic Aspect Meta Model (SAMM)	SAMM is a meta language to define messages and submodels semantically. It is defined within the eclipse semantic modelling framework. Based on the models, one can generate submodel templates and json-only serializations.	x	x
I4.0	AAS (AAS and Submodel Interfaces)	None	The AAS interfaces and repository functionality may be implemented by a repository or by binding the interface to internal applications.	x	
I4.0	AAS (Registry and Discovery Interfaces)	Digital Twin Registry	The Digital Twin Registry implements the discovery and registration interfaces of the AAS specification.	x	
Gaia-X	Federated network	Decentralized DTR	The DTR is decentralized to ensure compliance and full control about the meta data search for specific partners.	x	
Gaia-X	Federated network	Discovery Services (discovery finder, bpn discovery, edc discovery)	The discovery services allow to find the respective data provider and his EDC for global and specific asset IDs.	x	Optional

Gaia-X	Self-Sovereign Identity Framework	Managed Identity Wallet	Provides a more decentralized approach of identity management. Usage is upcoming.	x	x

3.1.5 Lessons learned from the joint use I4.0 & IDS concepts/components and recommendations for improvements

Catena-X uses the I4.0 API and the concepts of the AAS as the default way to provide and exchange information. Additionally, all information exchanged between companies passes an EDC connector. The combination of these concepts leads to extra effort, when only implementing one use case. Often a use case specific API might be more appropriate and would allow more freedom than using a submodel which follows a semantic description. The assumption is that it will pay off in the long-term as soon as partners start participating in different use cases and may reuse the way of data provisioning. The adoption of Catena-X and further enhancement of the use cases will show whether this assumption is true.

Data Sovereignty in Catena-X has not yet been designed in the terms of technical enforceability of policies but is an ongoing process. Within Catena-X's Governance Framework, use cases do have framework agreements that are contractual definitions on how to process data in the context of the use case. Those are one organizational way to ensure that legacy systems can be used so that adoption is easier for companies.

Catena-X has not yet deeply gone into the vertical direction providing e.g., operation capabilities of the I4.0 concepts. It may be beneficial in future to make use of these concepts to provide information faster from systems closer to the shop floor.

3.1.6 Project results related to the IDS-I position paper

The standard library provides the standards created by the Catena-X Automotive Network e.V to ensure interoperability. The developer portal and the KITS provided via eclipse Tractus-X as well as all applications publicly available via the eclipse-Tractus-X repository on GitHub may be reused. The applications Item Relationship Service, Digital Twin Registry, Simple Data Exchanger and Trace-X are applications that could be (enhanced and) reused. Also, the semantic definition framework with SAMM may be reused.

3.1.7 Project contribution to IDS-I

Catena-X connected several different initiatives. It is currently in an evaluation phase with one operating company called Cofinity-X. It's the first large scale data space integrating AASs that actively starts considering scaling issues.

The architecture may be reused for further initiatives. The Governance Framework is one approach to tackle legal constraints and cooperation down to the application providers and operators. Components mentioned above like the DTR, the IRS, the identification mechanisms and the Tractus-X EDC can be reused, if modified or expanded.

3.1.8 Project benefit from IDS-I

There could be insights on scaling and ensuring antitrust laws compliancy from other projects and tools mentioned in the position paper. There might be beneficial ideas on how to continue the post consortia work on Catena-X.

3.1.9 Link to the project and relevant results

- Catena-X Website
- Catena-X standard library
- Eclipse Tractus X Website (Devloper Hub, and KITs)
- eclipse/tractus-x GitHub repositoryCatena-X Website,
- Catena-X standard library,
- Eclipse Tractus X Website (Devloper Hub, and KITs),
- eclipse/tractus-x GitHub repository.

3.2 CircularTwAIn - AI Platform for Integrated Sustainable and Circular Manufacturing

3.2.1 Short project description

The Circular TwAIn project [51] will create a novel AI Platform for Integrated Sustainable and Circular Manufacturing, resulting in the development of interoperable circular DTs and integration into data spaces. Circular TwAIn aims at developing a fully digitalized value chain through a holistic approach to circular manufacturing process chains. Circular TwAIn aims to transition manufacturing and process industry towards sustainable, eco-friendly and circular production. The key factor is a full integration among systems, reached through the usage of AI DTs for each level (product / process / human) leading to „Circularity by-design".

3.2.2 Project-relevant scenario(s)

The Circular TwAIN project has three use-cases, where joint use of components is required. These are the Battery Remanufacturing pilot, the Waste of Electrical and Electronic Equipment (WEEE) pilot and the petrochemical optimization pilot. The Battery Remanufacturing pilot is concerned with the optimal recycling decision of batteries based on a Digital Battery Passport involving several actors like recycling centers and battery / component manufacturers. The WEEE pilot is concerned with the disassembly and sorting of electrical waste like PC and smartphone, which is still a manual worker process. In the petrochemical pilot, the CO^2 emissions of a chemical process are optimized based on several parameters obtained from data spaces.

3.2.3 Architecture

The Circular TwAIn Reference Architecture (see Figure 10), which is based on the edge-cloud paradigm, has been designed to facilitate the development of circular applications, such as recycling, re-manufacturing, de-manufacturing, and more. It has been designed as a logical view, in order to emphasize the necessary components for supporting the three main pillars that should sustain the "project building": Circular Economy, Data Spaces and Artificial Intelligence.

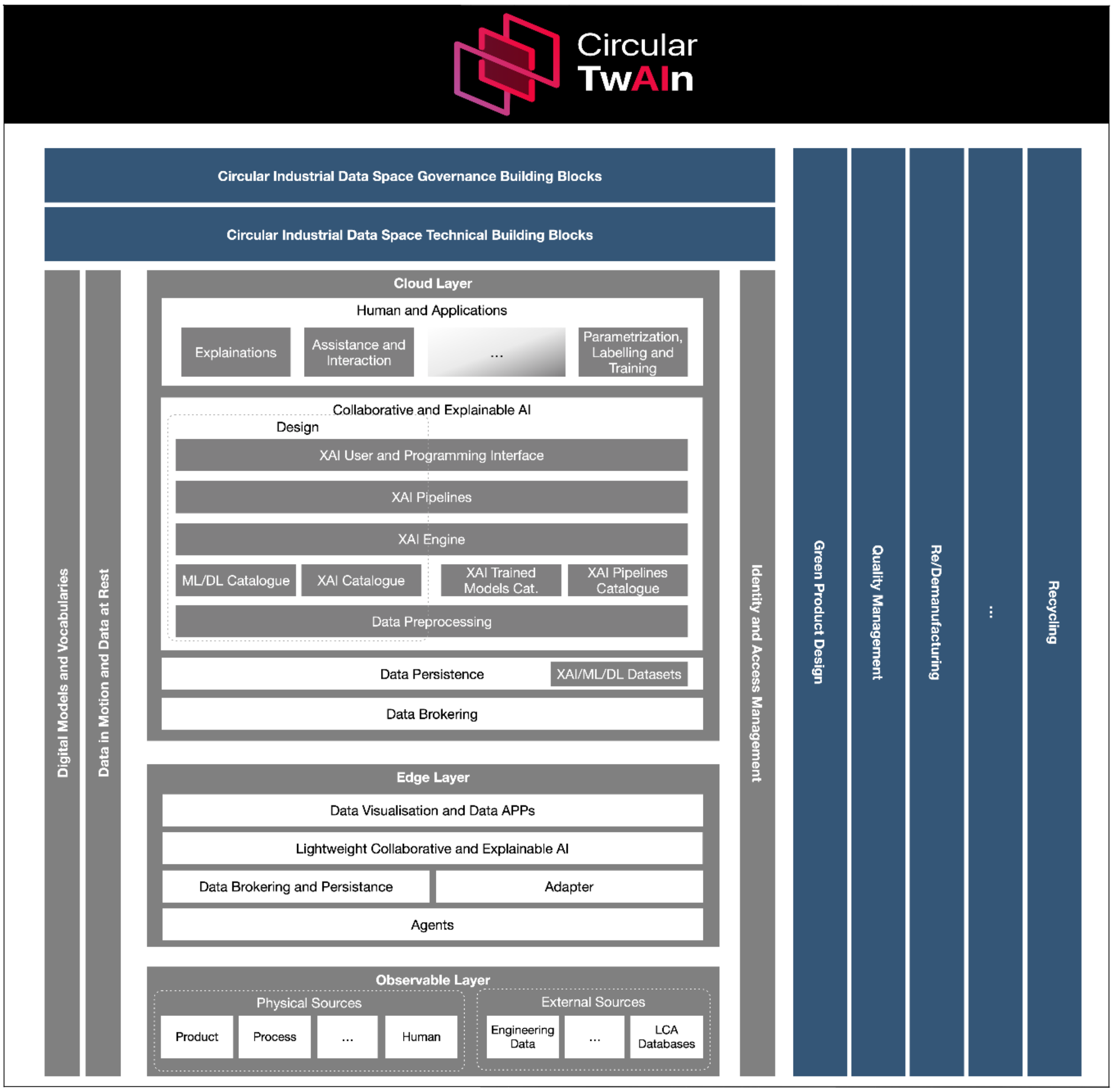

Figure 10: The Circular TwAIn Reference Architecture

This architecture provides support for such applications through various means, including:

- Seamless data sharing between circular actors, which enables the efficient transfer of data among the stakeholders involved in the circular process;

- Collaborative and Explainable AI, which allows multiple stakeholders to work together on AI projects and provides them with the necessary tools to understand how the AI models are making decisions;
- DTs (Product, Process, Human), which create a virtual representation of a product, process, or human, and allow stakeholders to experiment with different scenarios and optimize the circular process.

The Circular Economy is based on the principles of reducing waste and promoting the reuse and recycling of resources. To achieve this, Industry must have access to relevant data and be able to share it securely with other stakeholders. Common digital models and vocabularies development and adoption are fundamental for promoting cross-border data exchange and digital services integration across diverse sectors. Additionally, other components support the creation of data value, like the XAI Catalog, while some ensure data sovereignty and trust, like the Identity and Access Management component. Finally, Circular Economy Applications (Green Design, Quality management, Re/De-manufacturing, Recycling) are the primary focus for the entire architecture, where the convergence of business objectives and technological capabilities is realized. The implementations cover a wide range of processes, starting from the initial phases of product lifecycle, aided by AI generative design to minimize environmental impact, to optimizing processes and products, managing quality, and enabling human-robot interaction for de-manufacturing and re-manufacturing.

In the context of CircularTwAIn, the reference architecture provides a framework for user interaction with DTs, which are considered as one of the key technologies. The nature of the interactions is bidirectional: users can not only receive predictions, explanations and insights from XAI pipelines, but also communicate with the DTs through input commands. This allows for a more comprehensive understanding of the processes and data being analyzed and enables users to make informed decisions based on the insights gained from the DTs.

3.2.4 Usage of I4.0 & IDS concepts/components

DTs for processes, products and humans are the foundation of the Circular TwAIn architecture. These are implemented with the I4.0 AAS. The data is then processed by the Circular TwAIn platform and data space applications to enable data-sovereign sharing of relevant data. Concerning the software components for the data space, two connectors are in use: the connector of EDC [15] and the TRUE connector [55]. These connectors are both aiming to be compliant with the IDS specification, but additional work must be done to make them compatible with each other.

For the AAS implementations, currently FA³ST Service [18] and NOVAAS [20] are in consideration. As with the connectors, additional work must be done regarding the APIs to align them in an interoperable manner.

3.2.5 Lessons learned from the joint use I4.0 & IDS concepts/components and recommendations for improvements

The joint use of data space and DT components enables the Circular TwAIn architecture and pilots. However the project pilots should provide feedback to the IDS and AAS specifications to improve the integration between AAS and IDS. User-friendly solutions must be provided to enable customers to share data with both specifications.

3.2.6 Project results related to the IDS-I position paper

The relevant project results include the following papers: [52], [53]. In [52], the authors provided a survey and an evaluation of four open-source AAS implementations that are currently to be considered. The main conclusion of the work reported is that there is no AAS implementation that fully implements the AAS specification. There are some aspects of the AAS specification that are not covered by any implementation, and many that are not fully implemented. However, all considered AAS implementations support the minimum required functions. In addition, the survey provides useful feedback to further refine the AAS specification to help software developers understand the semantics of the AAS meta-model and API. In [53] the design of data spaces in combination with DTs is discussed. A generic approach for a data space with DTs is proposed that does not require changes in DT or DS specifications.

3.2.7 Project contribution to IDS-I

The Circular TwAIn project offers three pilots to further advance the technical components and test the integration of AAS with the IDS. So far, components like FA³ST Service, FA³ST Registry, NOVAAS, EDC Extension for AAS and TRUE Connector were improved to support the pilots. In the future, the interoperability between these components will be improved. Since the EDC Extension for AAS only supports EDC, a similar component will be provided for the TRUE Connector.

3.2.8 Project benefit from IDS-I

The project could benefit from a clear integration proposal which is accepted by both IDTA and IDSA. The IDS-I is a link between those organizations and could provide such a proposal.

3.2.9 Link to the project and relevant results

- https://www.circular-twain-project.eu/
- https://github.com/Circular-TwAIn/

3.3 EUR3KA – EUropean Vital Medical Supplies and Equipment Resilient and Reliable Repurposing Manufacturing as a Service NetworK for Fast PAndemic Reaction

3.3.1 Short project description

The EUR3KA project [54] aims to build and validate a plug and response network that will enable manufacturers to respond to the challenges arising from the COVID19 healthcare crises and related future events that could disrupt production operations. It addressed the most important challenges faced by manufacturers: the need to operate their plants despite COVID19 measures and restrictions, the need to address disruptions in the supply chain, the need to design new, as well as the need to certify the products in-line with applicable regulatory requirements. To make this happen, the Consortium partners performed (i) the development of a pool of services for manufacturing response for the optimization of cross-sectorial supply network; (ii) the development of services for assessment of supply chain resilience, for smart matching and mediation services (that is a kind of smart search engine to match medical product manufacturing specifications and EUR3KA manufacturing network resources); (iii) the provision of production continuity solutions in terms of advanced AI-powered data driven decision support services for risk and the social distancing virtual assessment for virtual repurposing and commissioning, to extend the manufacturing equipment for remote and connected operation.

3.3.2 Project-relevant scenario(s)

In the following picture is depicted a 3D printing scenario based on the adoption of a dedicate 3DP Data Space (3DP DS) (see Figure 11). It offers the possibility to create 3D printable models that can be put in the catalogue from which the consumer can look for a component to print. The catalogue is accessible from the 3D printing network using an IDS connector. Then the provider IDS connector will share the model that will be sent to the 3D printer.

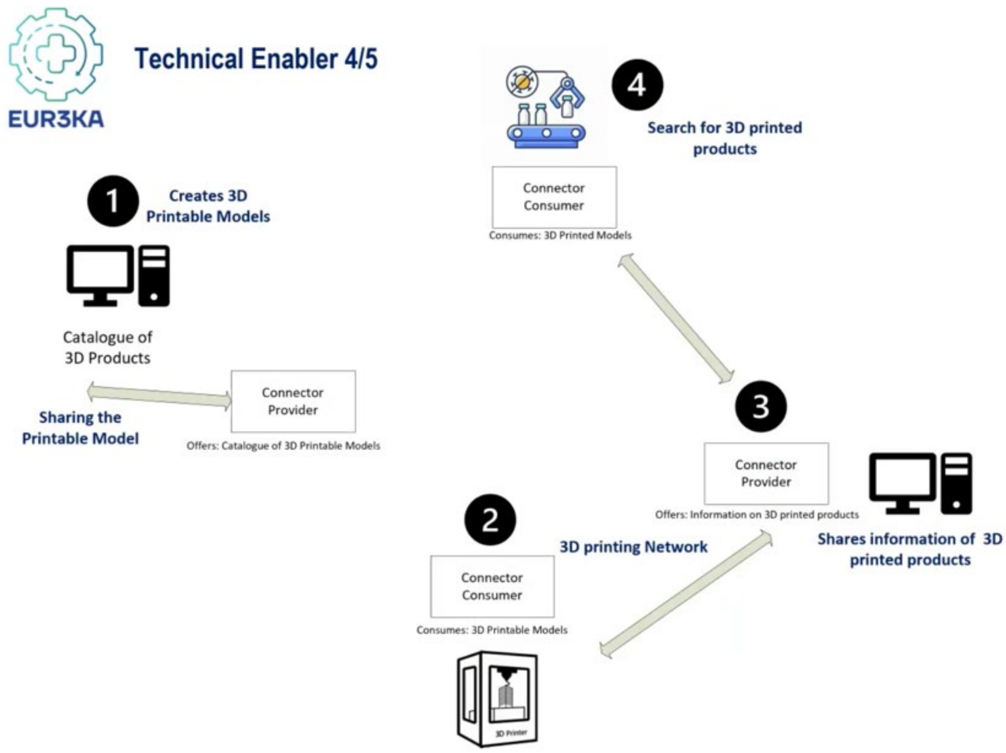

Figure 11: EUR3KA "3D Printing Data Space" scenario

The data exchange has been implemented through the interaction between two different IDS Connectors: the TRUE Connector [55] (acting as a consumer) and the Dataspace Connector [56] (as a provider). The infrastructural components (Broker, CH, etc.) have been offered as-a-service in order to guarantee the minimum services for supporting the data sovereignty.

The other scenario is related to Manufacturing as a Service and its realization using the Smart Factory Web (SFW) [57]. While factory capabilities are public information and are used for registration in the SFW, capacity and workload are sensitive data and are therefore not stored in the SFW. To take this sensitive information into account and thus to ensure trustworthiness in dynamic marketplace scenarios, there is a need to attach the SFW to a trusted data space that ensures data sovereignty. Therefore, we have extended the SFW with the EDS connector [15], since IDS is a viable option to technically enforce these usage restrictions.

Additionally, this scenario validated an enriched version of the IDS connector, where the Smart Matching and Mediation App (SMMA) can fetch sensitive data (e.g. prices) via EDS connectors from AAS services of different suppliers. The supplier connectors must provide a contract that matches the expected contract of the consumer connector. Otherwise, the supplier cannot be considered. Given a SFW request in the form of supply chains and constraints, the SMMA filters and sorts the supply chains based on the data retrieved from the supplier connectors (e.g. price). However, the SMMA does not send the sensitive data back to the SFW, only the filtered and sorted supply chains. The EDS connectors ensure that no sensitive data leaves the secure IDS environment.

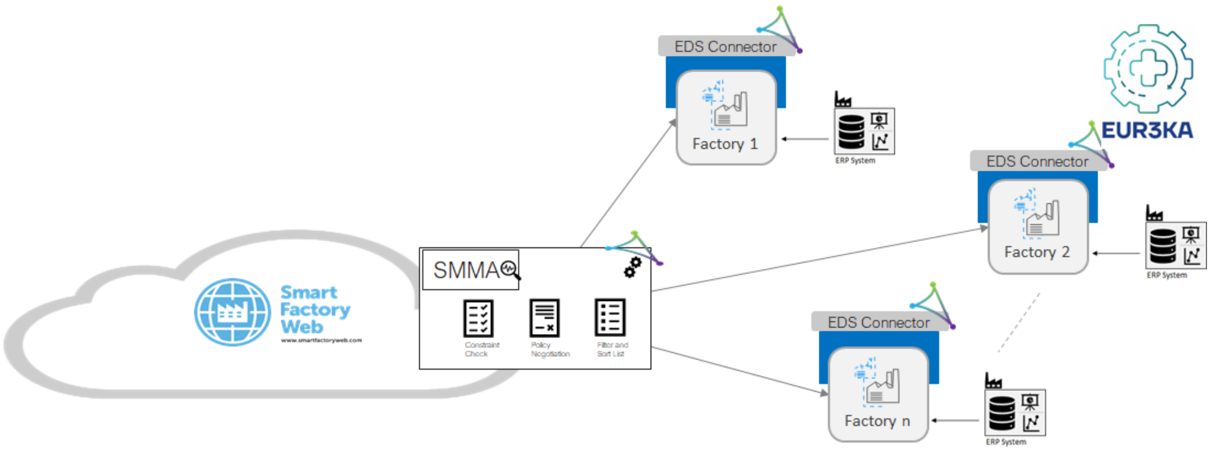

Figure 12: EUR3KA "Repurposing Plug & Response (MaaS) platform" scenario

3.3.3 Architecture

The EUR3KA architecture related to the 1st use case mentioned above is shown in Figure 13.

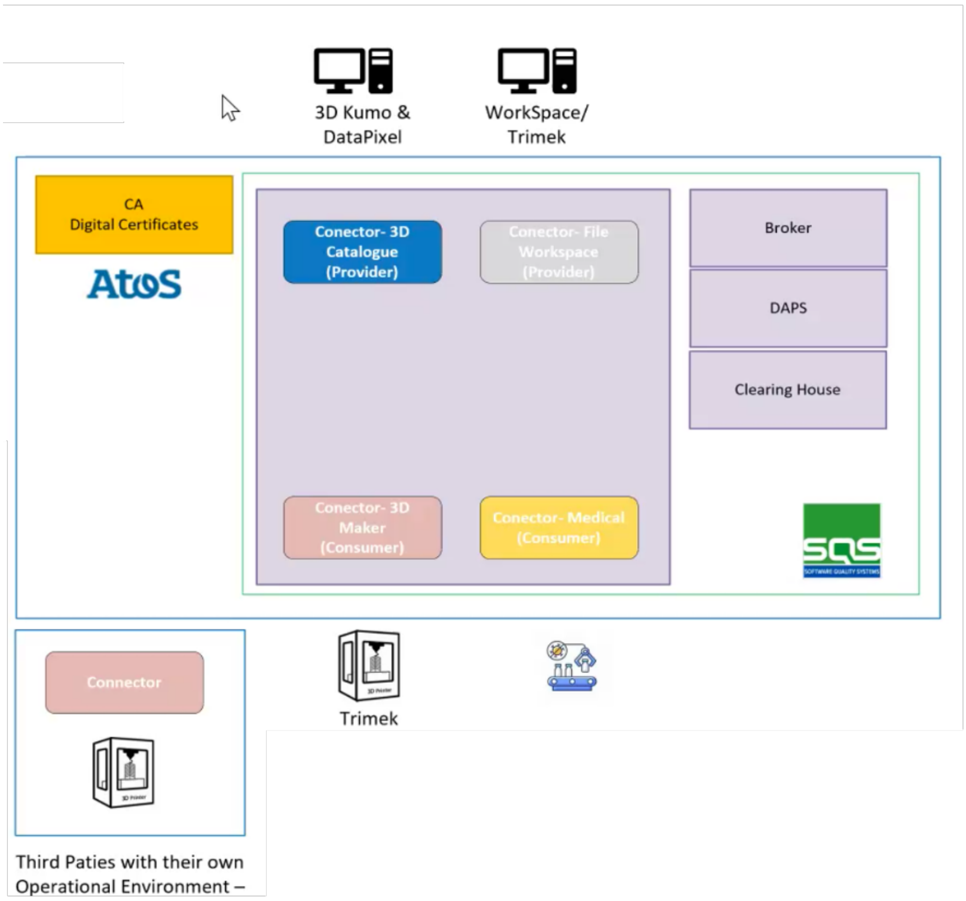

Figure 13: EUR3KA architecture supporting the "3DP DS" scenario

3.3.4 Usage of I4.0 & IDS concepts/components

Below the components and services enabling the data space:

- Certification Authority and DAPS by ATOS
- IDS Connectors: TRUE Connector, DSC, EDC
- Broker: Metadata Broker
- Clearing House: FhG

The 2nd use case uses the EDC AAS extension introduced in section EDC Extension for Asset Administration Shell. The AASs are used to model factory constraints. Additionally, an AAS submodel template was proposed as shown in Figure 14.

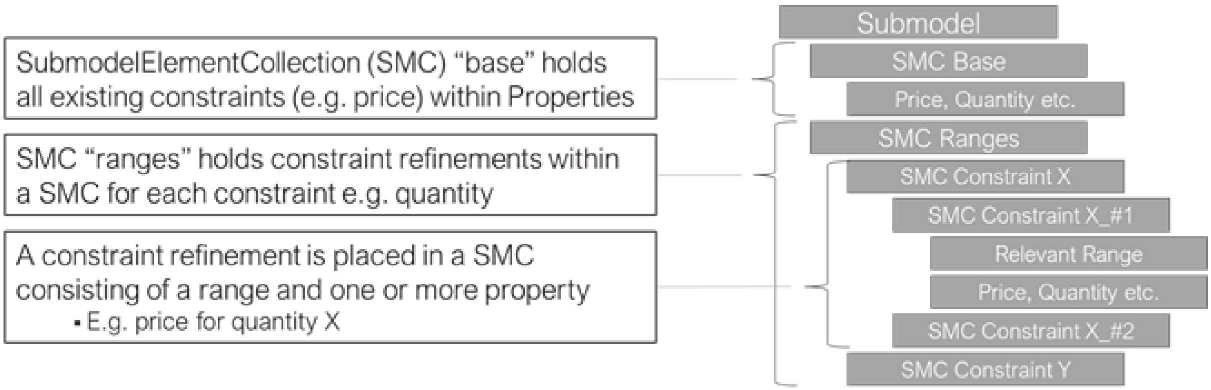

Figure 14: EUR3KA AAS Submodel template for constraints

3.3.5 Lessons learned from the joint use I4.0 & IDS concepts/components and recommendations for improvements

The interoperability between existing IDS components is crucial on both sides, infrastructural components and connectors. In this way, the scenarios can easily scale.

3.3.6 Project results related to the IDS-I position paper

1) TRUE Connector: an open source implementation of an IDS Connector, compliant with the latest IDS specifications (i.e., IDS Info Model 4) and can be easily customized to fit a widespread number of scenarios thanks to the internal separation of the Execution Core Container and the Data App. The TRUE Connector is currently finalizing the IDS certification process.
2) SQS Technical Enablers: a set of components, integrated in a web platform based on Mango Apps, designed to support the provision of certification services as well as the marketing of certified products and services to the data space community.

3.3.7 Project contribution to IDS-I

The numerous results of the project, particularly with regard to the architecture, the software components (e.g. SMMA) and the use cases from which knowledge has been gained, have already been taken into account in this IDS-I position paper.

3.3.8 Project benefit from IDS-I

Sharing architectural approaches and (OSS) tools with other stakeholders interested in I4.0 & IDS convergence can realize/boot the project impact after the project end.

3.3.9 Link to the project and relevant results

- https://www.eur3ka.eu/
- https://digitalfactoryalliance.eu/
- https://github.com/Engineering-Research-and-Development/true-connector
- https://www.sqs.es/sqs-first-accredited-laboratory-for-the-validation-of-ids-components/?lang=en

3.4 DaCapo - Digital assets and tools for Circular value chains and manufacturing products

3.4.1 Short project description

DaCapo is a Research and Innovation Action [58] with the goal of creating human-centric digital tools and services to improve the adoption of Circular Economy (CE) strategies along both manufacturing value chains and products lifecycle. The DaCapo tools and services will focus on the introduction of new digital assets, AI-based systems and the application of process and product DTs and will substantially improve the sustainability and efficiency of imported and critical raw materials in manufacturing.

The project will develop a Circular Economy Decision Support System (CE-DSS) based on Digital Product Passport, Digital Thread, Data Spaces and DT concepts and will deploy a number of open RTO-hosted Didactic Factories providing showrooms, validation and training facilities for the EU manufacturing sector and society.
DaCapo has received funding from the European Union under the HORIZON program (Call id HORIZON-CL4-2022-TWIN-TRANSITION-01 and grant agreement number 101091780) and is supported by a consortium of 15 partners from 10 European countries, coordinated by the AIMEN Technology Centre in Spain.

3.4.2 Project-relevant scenario(s)

DaCapo use cases span across three critical value chains in Aeronautics, ICT & consumer electronics (smartphones), and warehousing (logistics, including construction) sectors. The first use case led by GKN Aerospace aims to extend sustainable manufacturing and repairability approaches for aeronautic value chains. The second use case focuses on Eco-design, diagnosis and maintenance of modular mobile phones by FAIRPHONE. In the third use case, PESMEL explores R-cycles in material flows for warehouse design, construction, and operations.

The use cases will focus on the creation and boosting of circular economy with the help of Data spaces and Digital product passports. The FAIRPHONE use case, for instance, targets Design & Engineering, Product Use, and End-of-Life stages and employs three new strategies to increase the product sustainability: i) creation of a product DT ii) adopting the DPP to be assigned to each mobile phone tracing key materials and components data and; iii) deployment of new digital diagnosis tools.

3.4.3 Architecture

The Reference Architecture defined for the DaCapo project is a complex data-driven and layered architecture based on the advanced guidelines of RAMI 4.0 developed by the German industry network PI 4.0. The figure below (see Figure 15) shows the three main layers.

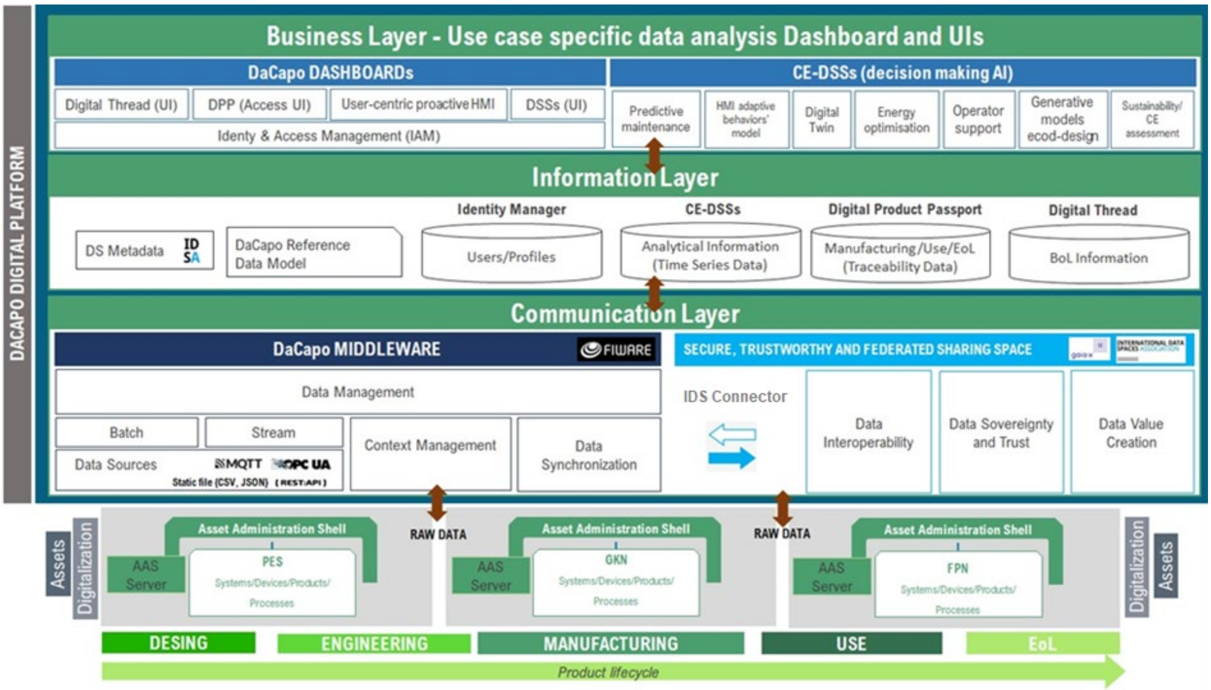

Figure 15: DaCapo Blueprint

The Asset and Integration/Digitalisation layers lay the foundation, is concerned with the main "data producers" and how the data is extracted and/or collected from the different sources. Asset Administration Shell is an essential part of this layer.

The Communication and Information Layers are the central pieces of the DaCapo reference architecture, receiving and managing data from heterogeneous sources. DaCapo Data Space within this layer is based on IDS & Gaia-X elements and provides means for secure and sovereign data exchange between trusted parties in the context of DaCapo use cases. The Digital Product passport enables circular economy based on data exchange. The Digital Thread backend collects, stores and provides access of different types of data generated along the product lifecycle that needs to trace for decision making at different stages of the lifecycle, and is based on the DT concepts.

The Functional & Business Layers are added on top, providing the DaCapo dashboards and the CE-DSS (Circular Economy Decision Support System) component to support the operators and other end users during the decision-making process.

3.4.4 Usage of I4.0 & IDS concepts/components

The DaCapo reference architecture is based on the principles of RAMI 4.0 from I4.0. The project also envisions setting up a DaCapo Dataspace based on IDS/Gaia-X elements. The Digital Product Passport implementation will rely on data exchange within this Dataspace.

DaCapo project will implement a Digital Thread to be adopted within the company but provided of interfaces for external collaboration with suppliers and customers. Data Spaces and IDS connectors are a technology and service that can be used for this purpose, together with the data shared using the DPP solution.

3.4.5 Lessons learned from the joint use I4.0 & IDS concepts/components and recommendations for improvements

The DaCapo project is still in its early stages (project started in January 2023) but has already benefited from collaborating with other projects (CIRPASS, Circular TwAIn (see section CircularTwAIn - AI Platform for Integrated Sustainable and Circular Manufacturing) and READY) working on Data Spaces and Digital Product Passports in a workshop jointly organized by IDSA and the Manufacturing CSA DS 4.0 [59]. Here are some learnings from that workshop:

1) Data spaces are originated by B2B relationships. On the other hand, the Digital product passports add a B2C dimension, offering consumers data about products. How to extend the usually B2B based data networks to individual end-users remains an open question. How can these individuals in the value chain be represented, which tools can they be offered? The concept of intermediaries can be an option but needs further development. Technical and governance requirements for personal participation in data spaces need to be defined. There may also be legal dimensions to consider such as anonymization requirements whenever a consumer is involved.
2) Access rights and data usage control mechanisms of a Data Space need to be extended to the consumers, who are usually external to the B2B network. This represents additional challenges when implementing Digital Product passports based on data spaces, requiring yet another shift from the B2B mindset to B2C.

Regarding the lessons learned within the context of the project itself, it is worth mentioning that:

1) DaCapo has concluded that developing vocabularies for circular economy is critical for achieving semantic interoperability within value chains across manufacturing ecosystems. This has been added as a de-facto goal of the project.
2) The state-of-the-art design of the DaCapo reference architecture proves the value of following a layered architecture approach guided by the RAMI 4.0 principles from I4.0. The blueprint comprising of functional and technological building blocks facilitate modular development and maintenance of digital solutions. By designing each block to be modular and independent, it becomes possible to reuse existing building blocks and easily add, remove, or modify components, resulting in enhanced scalability and flexibility.

3.4.6 Project results related to the IDS-I position paper

The project started in Jan 2023, and has already successfully delivered a **blueprint** for a robust digital architecture for optimizing operational efficiency and data sovereignty.

A Whitepaper with title "**Circular business models for EU manufacturing value chains**", and a conference paper titled "**Digital Product Passport trials to support the concept's introduction in industry**" is released by the project team.

DaCapo has participated in two **workshops** organized by IDSA, DS 4.0, Digital Factory Alliance, joining other collaborative projects exploring **opportunities and challenges for implementing Digital Product Passports (DPPs) with Data Spaces to enable Circular economy**. The project will be contributing to an IDSA/IDS-I joint paper on DPPs and Data spaces, as a subsequent result of the workshop.

DaCapo project will also continue with the following developments on its Digital Platform, and tests and demonstrations in the Didactic Factories and in GKN Aerospace and FAIRPHONE Use Cases:

1) Implementation of DPP (Digital Product Passport), as a future tool to standardized Life-Cycle information along the complete value chain and for battery use cases, to be used by both the battery-related results linked to use phase, as well as the end-of-life solutions.
2) IDS Connector – a test, demonstration, evaluation, and adoption of data spaces that can be used as a method to access/share/exchange data in the Value Chain (additional information to that included in the DPP) – the results will be experienced and knowledge from a functional and cyber security perspectives.
3) A system design and architecture with well-defined interfaces, for data acquisition from necessary sources and sensors, in machines, processes, facilities etc., to get access to all data input to build internal knowledge, build and validate models of DTs, simulations, analytics, etc. As part of this, the test and demonstration of AAS concept is expected.

3.4.7 Project contribution to IDS-I

The project holds the potential to make a significant contribution to the IDS-I community. This contribution would entail a detailed exploration of various use cases where DPP and data spaces are seamlessly integrated, effectively showcasing how data spaces bolster DPP's standardized Life-Cycle information across the entirety of the value chain for circular economy, with a particular emphasis on battery use cases. Additionally, the project aims to provide a practical demonstration of implementing DT and AAS models through the utilization of IDS connectors.

Furthermore, the project's impact will extend beyond this contribution. It will encompass the formulation of essential vocabularies for circular economy, thereby facilitating the attainment of semantic interoperability. This endeavor aligns harmoniously with the overarching objective of designing a comprehensive reference architecture. The proposed architecture will serve as a tangible demonstrator of embracing a layered architectural approach, following the ideas of RAMI 4.0 from PI 4.0 and IDS RAM4.0 can be really helpful and practical. This whole effort will prove how well-structured design can make things work better.

In summation, the project's multifaceted contributions are poised to greatly enrich the IDS-I community efforts while concurrently fostering advancements in both semantic interoperability and architectural best practices.

3.4.8 Project benefit from IDS-I

The project stands to gain substantial advantages from IDS-I. This document not only serves as a conduit for enhancing visibility regarding the DaCapo project's objectives and results, but it also offers a unique vantage point to identify potential synergies with IDS-I community members. Moreover, leveraging this position paper could significantly expedite the establishment of meaningful connections within the global IDS-I community, further amplifying our project's impact on an international scale.

3.4.9 Link to the project and relevant results

- DaCapo blueprint for a robust digital architecture for optimizing operational efficiency and data sovereignty. See press release in July 2023 [60] referring to the M6 deliverable Digital architecture and requirements.
- A Whitepaper, “Circular business models for EU manufacturing value chains”: https://www.dacapo-project.eu/s/D12.pdf
- A paper presented at the XXXIV ISPIM Innovation Conference, 'Digital Product Passport trials to support the concept's introduction in industry': https://www.dacapo-project.eu/s/Digital-Product-Passport-trials-to-support-the-concepts-introduction-in-industry.pdf
- Materials from the two workshops exploring opportunities and challenges for implementing Digital Product Passports (DPPs) with Data Spaces to enable Circular economy: https://internationaldataspaces.org/archive/#IDSA-in-projects-2023
- Project communication kit is available at [61]
- For further details, please see the project website [58] or contact the coordinator Lucía Alonso Ferreira (lucia.alonso@aimen.es) at the AIMEN Technology Centre.

3.5 BD4NRG: Big Data for Next Generation Energy

3.5.1 Short project description

The Eu-funded BD4NRG project [62] focuses on addressing emerging challenges in big data management for energy sector with an innovative open holistic solution for smart grid-tailored, near real time, energy-specific and AI-based open Big Data Analytics modular framework. The vision is to deliver holistic services for techno-economic optimal management of Electric Power and Energy Systems (EPES) value chain. Services range from optimal risk assessment for energy efficiency investments planning, to optimized management of grid and non-grid owned assets, improved efficiency, and reliability of electricity networks operation, while at the same time contributing to achieve fair energy prices to the consumers and laying the foundations for an EU-level energy-tailored data sharing economy. To do this the project relies on a reference architecture specifically designed for smarty energy that aligns together various architectures (such as BRIDGE-RA, COSMAG, SGAM, IDS-RAM, Gaia-X, RAMI4.0 and FIWARE), to deliver an AI-driven big data framework for enabling cross-stakeholders data-driven services and full interoperability of leading-edge big data technologies with smart grids standards and operational frameworks.

3.5.2 Project-relevant scenario(s)

The BD4NRG project encompasses many stakeholders in the electricity sector as well as cross-sectorial areas such as mobility and buildings. The Big Data services implemented during the project are demonstrated in twelve large scale pilots (LSPs) that accommodated a set of data analytics use cases organized into three clusters, namely: a) BD-4-NET: focuses on increasing the reliability of electricity network; b) BD-4-DER: focuses on optimizing the management of assets (Distributed Energy Resources – DER) connected to the grid; and c) BD-4-ENEF: focuses on de-risking investments in energy efficiency and increasing the efficiency and comfort of buildings. Within the three clusters, there are a set of use cases where the applications of I4.0/IDS/Gaia-X specific concepts are required. Specifically, several use cases need large-scale data sharing between the involved stakeholders to improve analytics services and control. However, sharing sensitive information requires mechanisms to avoid disallowed data sharing and data misuse. Here the design principles specified by IDSA and Gaia-X play a fundamental role in providing a set of rules or agreement to be followed by all the stakeholders to smoothly interact on organizational, business, and operational level. Alongside, some other use cases are mainly focused on mission critical processing performed in locally deployed infrastructures where analytics services are deployed and executed. In this case, the successful implementation of data-driven applications and end-to-end data pipeline requires an interoperability layer where real-time data can smoothly flow between data analytics services. To make it happen, data need to be structured in information and data models that are technology and sector agnostic so they can be exchanged and processed smoothly. Here, the I4.0 AAS concept provides a sound approach to interoperability. Thanks to the standardized information model and REST API, the AAS allows to model and to query static and dynamic data related to physical assets.

3.5.3 Architecture

The BD4NRG developed a reference architecture (BD4NRG-RA) with the aim of offering a standardized way of managing, sharing, and using data and related analytics services [63]. The BD4NRG RA has the ambition of really pushing the exploitation of energy Big Data pipelines while facilitating the implementation of such solutions. The RA (see **Error! Not a valid bookmark self-reference.**) follows a layered architectural model where horizontal layers identify and group together components and functionalities that are required to build end-to-end Big Data pipelines, i.e. from data ingestion, transformation, integration, aggregation, storage to analytics services, typically internally to energy stakeholders infrastructure.

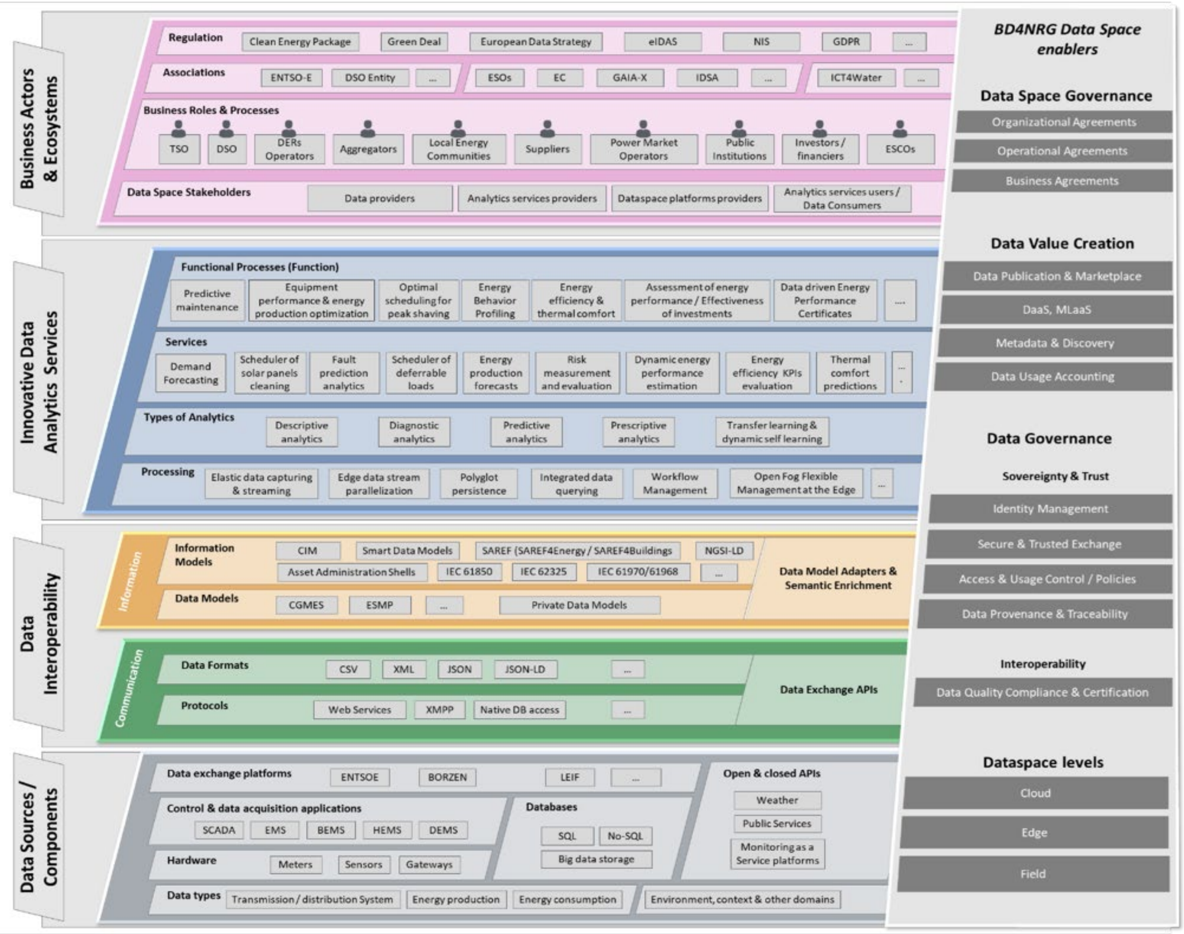

Figure 16: BD4NRG Reference Architecture [63]

On the other hand, the horizontal layers identify and group together components and functionalities that are required to create distributed BD4NRG data space. In this landscape, the AAS plays a fundamental role in the Data Interoperability Layer for harmonizing both communication and information models, while IDS and Gaia-X specifications and related components guarantee the data space implementation and operation to assure data sovereignty & trust and data usage and to track data provenance and usage.

3.5.4 Usage of I4.0 & IDS concepts/components

The BD4NRG RA defines a “matrix” that gives birth to concrete architectures. The definition of such a “matrix” enables system architects to identify and select functionalities, components, architectural options as well as communication protocols needed to build their own Big Data solutions. This is what has been done in the context of each LSP where a concrete architecture has been designed to support the use cases. One of this concrete design is the BD4NRG Data Lakehouse Platform (inspired to the Lakehouse architectural model) that essentially considers the following horizontal and vertical layers of the BD4NRG RA (see The BD4NRG developed a reference architecture (BD4NRG-RA) with the aim of offering a standardized way of managing, sharing, and using data and related analytics services [63]. The BD4NRG RA has the ambition of really pushing the exploitation of energy Big Data pipelines while facilitating the implementation of such solutions. The RA (see **Error! Not a valid bookmark self-reference.**) follows a layered architectural model where horizontal layers identify and group together components and functionalities that are required to build end-to-end Big Data pipelines, i.e. from data ingestion, transformation, integration, aggregation, storage to analytics services, typically internally to energy stakeholders infrastructure.

Figure 16): a) Data Sources / Components layer; b) Data Interoperability layer; c) Processing sublayer within the Innovative Data Analytics Services; and d) Security and Trust layer.

In Figure 17, I4.0 components (i.e. AAS) are located on the left side (Edge Integration), while IDS and Gaia-X are located on the right side to manage the data provisioning and data consuming activities in all the cases where inter-companies data sharing is needed. Going into detail, real-time streaming of asset data (measurements and observations) is one of the key requirements for developing advanced services for data-informed decisions. In this direction, the design of edge data spaces and supporting infrastructure for implementing SmartLocalGrids (SLGs) is an integral part of the BD4NRG project [64].

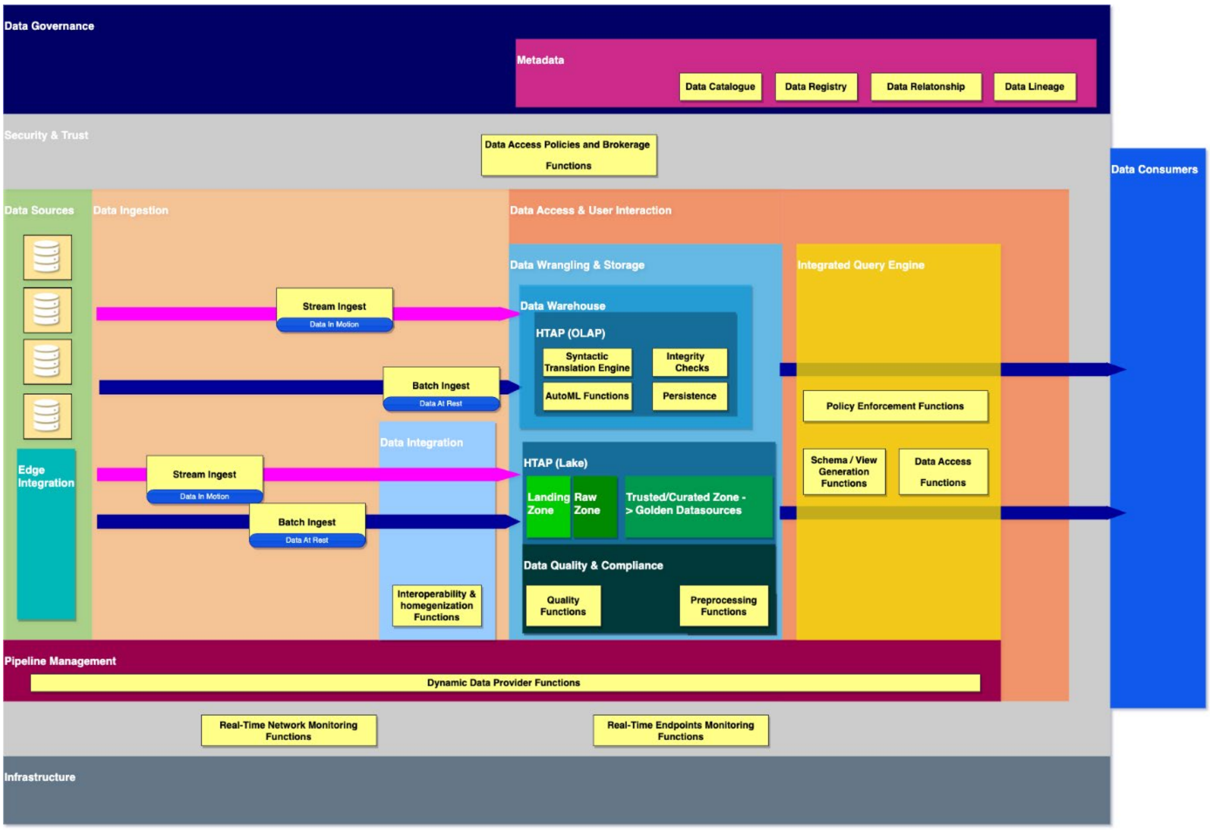

Figure 17: BD4NRG Data lakehouse platform overview

The edge infrastructure hosts a fully compliant I4.0 data service-based platform designed using a broker topology model where assets events are broadcasted to a lightweight message broker. The core component of such I4.0 data platform is the AAS that is responsible for collecting the data from the physical asset while ensuring interoperability and communication harmonization. The AAS will be responsible to hold standards digital models for of the underlying physical asset (see The BD4NRG developed a reference architecture (BD4NRG-RA) with the aim of offering a standardized way of managing, sharing, and using data and related analytics services [63]. The BD4NRG RA has the ambition of really pushing the exploitation of energy Big Data pipelines while facilitating the implementation of such solutions. The RA (see **Error! Not a valid bookmark self-reference.**) follows a layered architectural model where horizontal layers identify and group together components and functionalities that are required to build end-to-end Big Data pipelines, i.e. from data ingestion, transformation, integration, aggregation, storage to analytics services, typically internally to energy stakeholders infrastructure.

Figure 16). The physical asset is an inverter which available data is mapped to the AAS meta-model. The prototype provides an implementation of the AAS component based on NOVA Asset Administration Shell (NOVAAS) [65]. AAS events are streamed to the BD4NRG data platform and stored within the data warehouse for further processing and feeding Business Intelligence applications. The BD4NRG Data Lakehouse platform has been designed to enable the creation of global data ecosystem where different organizations and in general stakeholders can share data in a trusted and controlled environment. Therefore, the platform has been designed following the IDS-RAM where connectors are designed, configured and used to create trust between participants in the data space, to allow secure collaboration over private data, to establish rules and policies on how to use data, etc.

The Figure 19 shows the link between the IDS components and the BD4NRG Data Lakehouse Platform. The platform has been designed to be smoothly deployed within LSP's infrastructure. To enable and ensure the sharing of both data-at-rest and data streaming in motion for creation cross-sectorial services, the IDS reference architecture components have been included to establish the pillars for secure data sharing. Eventually, the BD4NRG project aspires to push digital technologies for big data in a very data-intensive business domain like energy. Here the IDS components – App Store, Metadata Broker, Clearing House, and Identity Management (DAPS and CA) – plays a fundamental role in creating a collaborative hub for extracting value from the available data by providing the foundation for the development of the BD4NRG marketplace platform.

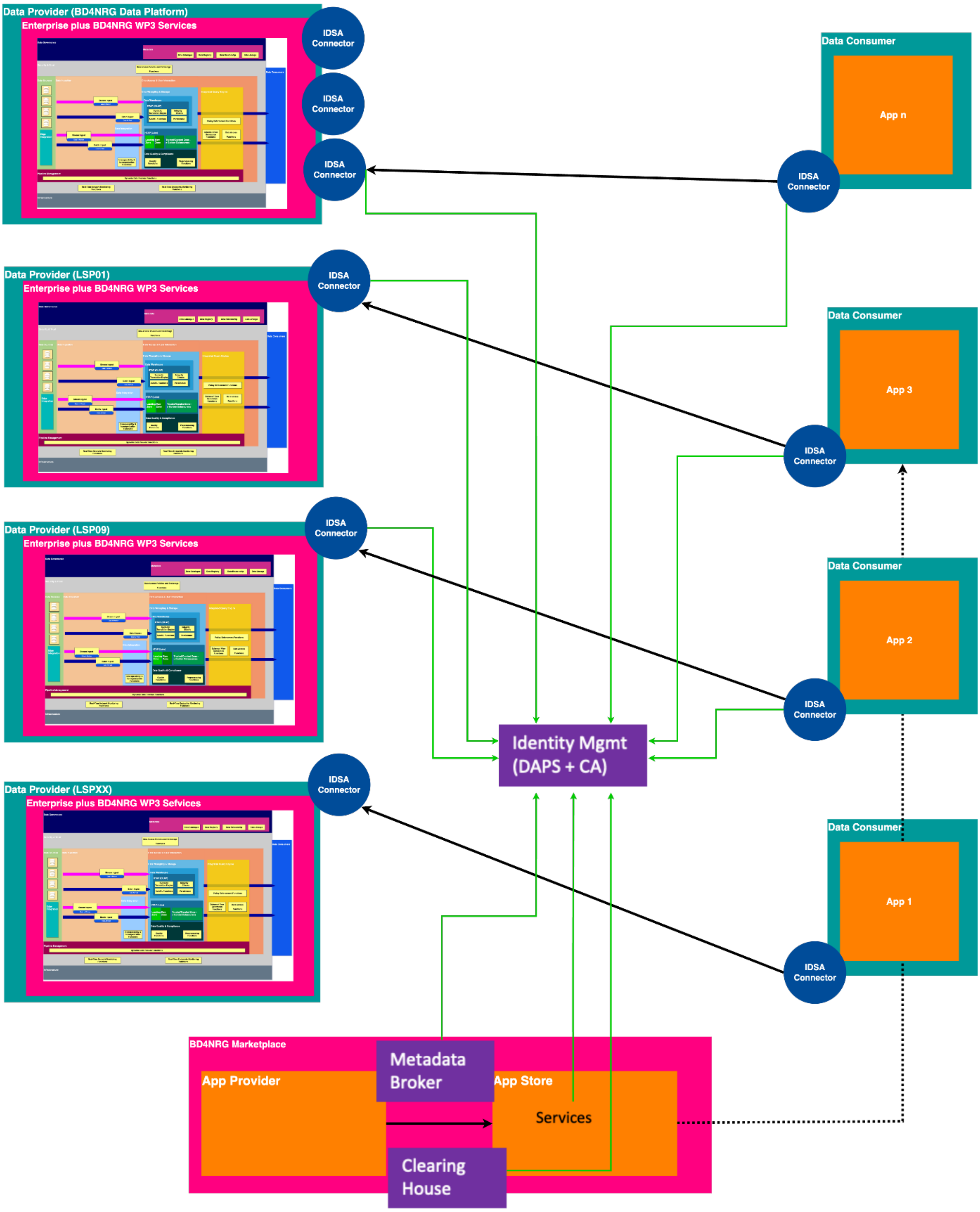

Figure 18: Linking IDs with the BD4NRG Data Lakehouse Platform

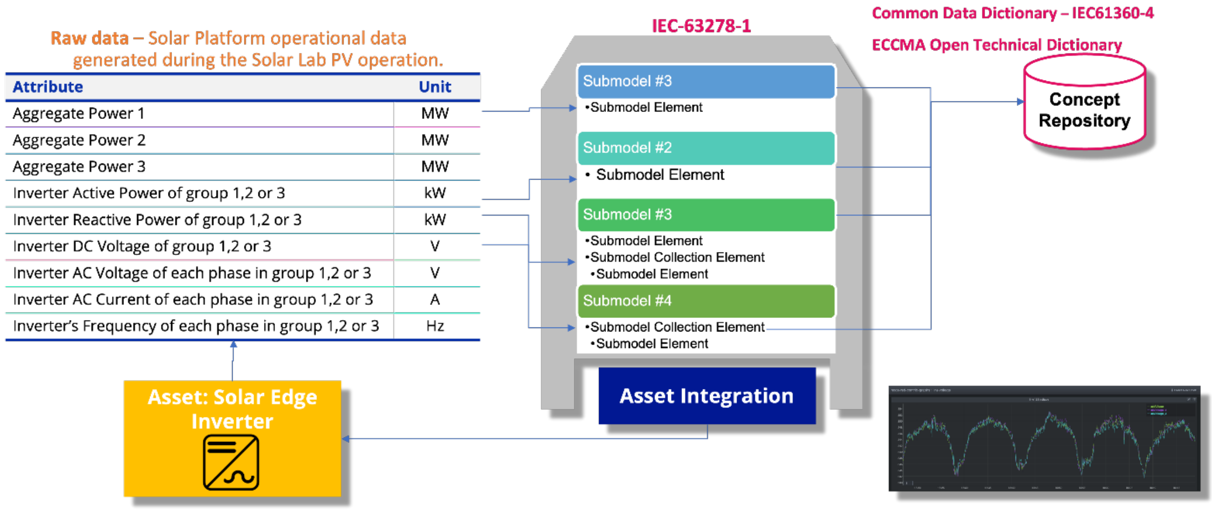

Figure 19: Connection between the AAS and the physical asset (Solar Edge inverter) [64]

3.5.5 Lessons learned from the joint use I4.0 & IDS concepts/components and recommendations for improvements

The simultaneous presence of different but interrelated concepts poses significant challenges and doubts about the role and the boundaries between them as well as how they can be complementary used to empower an industrial data space. As a matter of fact, despite the active involvement of all the stakeholders in the design of the BD4NRG data platform several challenges emerged related to the integration, deployment and usage of IDS and Gaia-X concepts. If – from one side – the adoption of the AAS is straightforward, the connection between the AAS and IDS by using the so-called IDS connectors is something still not well explored.

Thus, one of the main findings and recommendation for improvements, is the need to establish a pragmatic approach to data spaces based on a ready-to-use framework (i.e. guidelines, regulatory compliance, architectural patterns, technological choices and development views) that can lower or remove the barriers and the reluctance to the use of I4.0, IDS and Gaia-X concepts. In this landscape, the implementation of experimentation infrastructures that can be easily integrated within testbeds could support the experimentation and testing while highlighting the value added of the deployment of such technologies.

3.5.6 Project results related to the IDS-I position paper

The main project results related to the IDS-I position paper are:

- BD4NRG Reference Architecture
- BD4NRG Data lakehouse platform
- Smart Local Grids implemented using a compliant I4.0 data service-based platform at the edge

3.5.7 Project contribution to IDS-I

The project makes several contributions towards cross-domain Big Data Platforms in the energy sector. It started by analyzing state-of-the-art reference models and extended and upgraded them with data spaces aspects to cover cross-sectorial, multi stakeholder, multi-domain data sharing in secured, controlled, and trusted environment. Moreover, it adds more details and concrete elements to the other layers derived directly from the analyzed reference models directly derived from the BD4NRG Use Cases that cover a broad range of topics and applications in the energy domain. In this scenario, the way SLGs are designed and developed was subject of study since the very beginning to present a specific strategy and approach for developing interoperable edge clouds for the energy domain based on edge computing principles while addressing data sources heterogeneity and standardized communications.

3.5.8 Project benefit from IDS-I

The IDS-I position paper will contribute to enhance the comprehension of the I4.0, IDS and Gaia-X reference models and components while clarifying the various dimensions, the relationships between them and how they can be connected to create an infrastructure to support and regulate data sharing and reuse for multilateral collaboration. The paper will provide a coherent set of conceptual and technical foundations, specifications, as well as a joint approach to facilitate and – thus – accelerate the implementation and operationalization of cross-company collaboration and data sharing. All these aspects together will contribute to build a solid awareness about the importance of having a fully working/operational data space for unleashing the potential of data in data-driven innovation combined with AI.

3.5.9 Link to the project and relevant results

- https://www.bd4nrg.eu
- https://www.bd4nrg.eu/resources/publications
  https://www.bd4nrg.eu/resources/publications
- http://www.bd4nrg-dashboard.vm.fedcloud.eu:8080/http://bd4nrg-dashboard.vm.fedcloud.eu:8080/ (a centralized BD4NRG data lakehouse platform used as playground for testing and development)

3.6 Flex4Res: - Data Spaces for Flexible Production Lines and Supply Chains for Resilient Manufacturing

3.6.1 Short project description

Our global supply of goods, from consumer electronics to aerospace components, is fundamentally supported by the manufacturing industries. Increasing manufacturing flexibility to be able to change process parameters as new products evolve will help the global supply chain be more resilient in the face of both big and small challenges. The Flex4Res project [66] aims to use manufacturing data spaces and IDS or Gaia-X technologies to share data among all parties in the horizontal supply chain. The AAS concept is used in order to model the data that will be shared through the manufacturing data spaces. The Flex4Res solution will be applied on four industrial pilot cases coming from the consortium members, addressing steel production, steel processing, precision machining, and progressive forming.

3.6.2 Project-relevant scenario(s)

Based on IDS or Gaia-X and AAS technologies, Flex4Res implements a data space for data sharing. The project has four use cases, namely Hans Berg, Sidenor, Voestalpine, and Goimek, where different challenges aim to be addressed on different hierarchical layers of the production system, i.e., macro, meso, and micro level. Below are presented the challenges and visions for each of the four use cases separately.

Hans Berg

Challenge: A tool or material needs to be adjusted if it has changed. At the moment, it is done manually, and the employee doing it will determine how long it takes and whether it is successful. A substantial amount of material is wasted due to manual operation and numerous adjustment trials. Due to the lack of necessary data from within the tool, the adjustment measures are determined according to the defect pattern. The knowledge created by a reconfiguration and tool adjustment expert is specific to one product and can only be partially transferred to other products.

Vision: Reducing the time needed to retool, the quantity of defective parts produced, and the requirement for the necessary experience to carry out the adjustment tasks. Sharing data through the manufacturing data space connectors enable communication between Hans Bers Enterprise resource planning (ERP) and service providers. Data from the tools and adjustment data are modeled as AASs.

Industry partner: Hans Berg GmbH & Co. KG

Sidenor

Challenge: Disruptions from both internal and external sources necessitate moving the production to a different production site than was initially intended. Reconfiguration is currently done manually and is based on spreadsheet calculations and expert knowledge. Additionally, decisions made at the network level are unrelated to the factory-level reconfiguration required.

Vision: Assisting users during the reconfiguration planning process will help cut down on the time needed for reconfiguring the production plans for the production network. IDS/Gaia-S connectors will be used to transfer data from Sidenor's ERP model as AAS models through manufacturing data spaces to the supply chain level.

Industry partner: Sidenor Group

Voestalpine

Challenge: The products come in a variety of sizes and shapes, and only equipment with the necessary capabilities, which also depend on other factors like tools, can machine them.

Vision: Highly flexible production planning and scheduling that takes into account the state of the machines and manufacturing utilities as well as the ability to change the manufacturing processes while production is still going on. The data exchange between the service provider and Voestalpine will be accomplished through the use of manufacturing data spaces. Data from tools, can machines, sizes and shapes of the products are modeled as AASs.

Industry partner: voestalpine High Performance Metals Digital Solutions GmbH

Goimek

Challenge**:** The plant's production is divided up into various working areas. The process steps are adaptable, and planification is carried out once a week. A master production plan is created using information from the purchase orders, and it is then transformed into a final production plan. Numerous events, including machine maintenance, a shortage of supplies, problems with the quality of the product, etc., could change this planification. These unanticipated events may have a significant effect.

Vision: By creating a cross-site production planner that can be adjusted on the fly, production will become more efficient, competitive, and predictable. Data from Goimek's ERP are modeled as AASs and transferred through manufacturing data spaces.

Industry partner: GOIMEK S. Coop

3.6.3 Architecture

In Figure 20, the high-level Flex4Res architecture is presented. The primary components of the architecture include the Resilience Assessment toolbox, Reconfiguration strategies toolbox, AAS, data space, data space connector app, and data space connectors. The AAS is used to provide a standardized way of accessing the data from the assets of the industrial partners. The data space components (data space connector and data space connector app, identity provider, cleaning house, and IDS broker) will enable peer-to-peer data exchange between the Flex4Res services and the AAS, the adoption of data space technologies in the data space components ensures sovereign data exchanges with respect to the data access policies of the industrial partners.

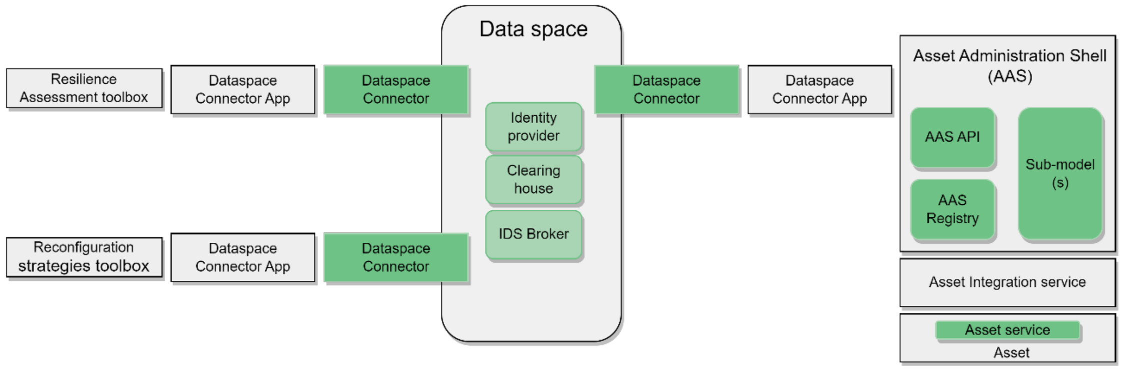

Figure 20: Flex4Res Architecture

Figure 21 illustrates the Flex4Res services from the Resilience Assessment and Reconfiguration toolboxes. In detail, data from the plant's ERP are parsed into AAS models (i.e., IDTA models could be used). AAS models can be accessed from the Resilience Assessment toolbox and Reconfiguration strategies toolbox through the data space. The Resilience Assessment toolbox includes tools for the supply chain, factory, shop floor, and resource levels. These tools aim to assess resilience in these hierarchical levels of a manufacturing system. Additionally, the Reconfiguration strategies toolbox include tools for the same levels as mentioned for the Resilience Assessment toolbox, see Figure 21below. The reconfiguration strategies toolbox provides tools that calculate new strategies to improve the resilience of each of the hierarchical levels. The four use cases of the project have challenges in the different hierarchical levels. AAS data are shared through the data space via the use of data space connectors.

Figure 21 shows the use of the Flex4Res architecture in a generic example, to explain the services. The broad concept is that an industry can use some or all of the tools to assess the resilience at various levels of hierarchy. A tool from the Reconfiguration strategies toolbox will be used to compute a new resilient strategy if the assessment reveals that a strategy is not resilient.

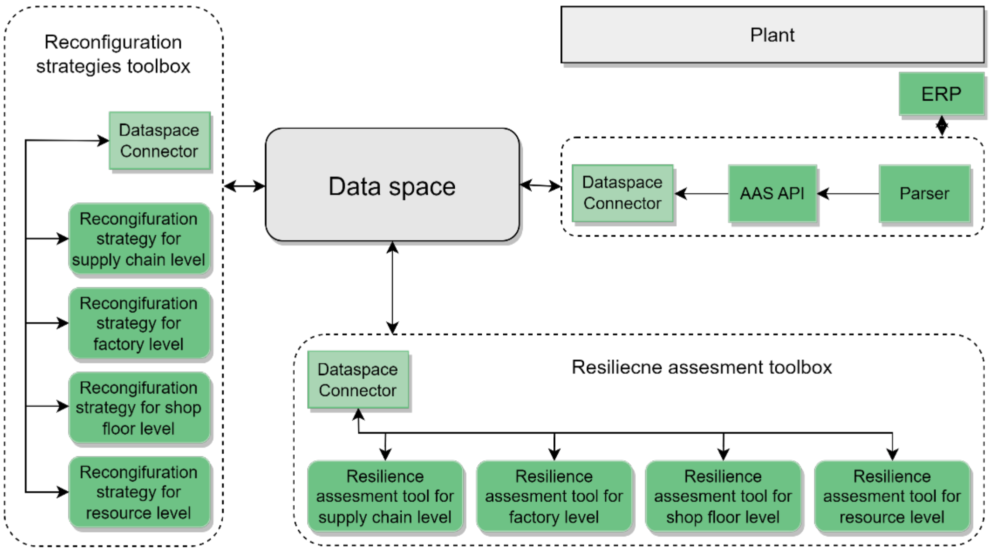

Figure 21: Example of Flex4Res services

3.6.4 Usage of I4.0 & IDS concepts/components

The AAS concept is used to model and capture all information from the physical assets and share DTs between companies and service providers. In addition, AAS models describe the input and output for the services developed in the project. Additionally, the data space connectors and accompanying data space components facilitate data exchange between companies. The IDS/Gaia-X technologies aim to enable resilience assessment and reconfiguration strategy deployment over the manufacturing data spaces. Manufacturing data spaces aims to increase productivity, efficiency, and decision-making while also taking data security and compliance requirements into account.

3.6.5 Lessons learned from the joint use I4.0 & IDS concepts/components and recommendations for improvements

Despite the project is at its early phase some interesting developments have contributed to elaborating knowledge and understanding regarding data spaces applications in industrial practice. More specifically, the integration of AAS into data spaces ecosystems envisions benefiting manufactures to use a standardized way of representing and managing physical and processes information in a digital form. Moreover, the use case developments will investigate the feasibility of combining IDS and Gaia-X components in order to develop the Flex4Res data space for sharing data in different hierarchical layers. Additionally, a key lesson learned underscores the critical importance of interoperability and standardization. The pivotal role of standardized interfaces and protocols in facilitating seamless data exchange within the manufacturing ecosystem has been duly acknowledged. Therefore, emphasizing the importance of interoperability and standardization aligns with the project's aim to develop resilient manufacturing solutions that can adapt to dynamic operational environments and leverage the full potential of data-driven technologies.

3.6.6 Project results related to the IDS-I position paper

The expected results of the project are the following:

- Flex4Res Federated data spaces framework
- Resilience Assessment Toolbox
- Reconfiguration Strategies Toolbox
- Inefficiency monitoring and auto diagnostic cycles for maintenance flexibility
- Resilient production planner based on real-time data monitoring of machine status and production execution
- Optimized reconfiguration of value chains

3.6.7 Project contribution to IDS-I

The project could contribute to the IDS-I position paper with the following ways:

- Deployment of IDS or Gaia-X for resilient manufacturing value chains
- Systematic integration of AAS with IDS or Gaia-X
- Hybrid Gaia-X or IDS data spaces (if we have both IDS and Gaia-X) in the project

3.6.8 Project benefit from IDS-I

The project will benefit from the IDS-I position paper by gaining access to the IDS-I community so we may identify experts that may help us with the investigation of using IDS connectors for data sharing through data spaces. Also, for the communication and dissemination of the activities of the project.

3.6.9 Link to the project and relevant results

Considering that Flex4Res started the 1st January 2023, the only relevant result of the project is the following publication [67].

3.7 KI-Reallabor: AI Living Lab – Living Lab for the Application of Artificial Intelligence in Industrie 4.0

3.7.1 Short project description

AI Living Lab is a research project funded by the German Federal Ministry for Economic Affairs and Climate Action, Running from 2020 – 2023. The project structure of the AI Living Lab in Lemgo is depicted in Figure 22. The use of artificial intelligence promises high benefits in industrial applications and in the development of new business models but is often subject to many limitations. On one hand, current AI technologies are often not directly related to the practical problems of industry, and on the other hand, there is a lack of access to usable industrial infrastructures and real production facilities for testing.

The AI Living Lab in Lemgo responds to this challenge with an open and at the same time protected collaboration space for humans and technology, allowing innovation processes with as few regulations as possible to explore the potential and impact of AI in close cooperation between science and industry in a real production environment. This is addressed by the AI Living Lab, in particular in the form of a real production operated in the SmartFactoryOWL [68].

Since October 2021, cups made of sustainable bio-based plastic are being produced in the SmartFactoryOWL. These cups are developed by the start-up CUNA Products GmbH and distributed in a reusable system that returns used cups to production. Under the leadership of Fraunhofer IOSB-INA, ten partners from the fields of mechanical engineering, factory equipment and plastics production have joined forces in the CUNA production to jointly test an Industrie 4.0-compliant data infrastructure and collect realistic data sets.

Production based on an injection molding process with connected peripherals, robotics and laser marking provides a practical environment and complexity for this. Likewise, data is used in Hackathons organized by the AI Living Lab in the SmartFactoryOWL. In these Hackathons teams solve challenges defined by the industry partners. The best solutions are implemented and evaluated at the CUNA production.

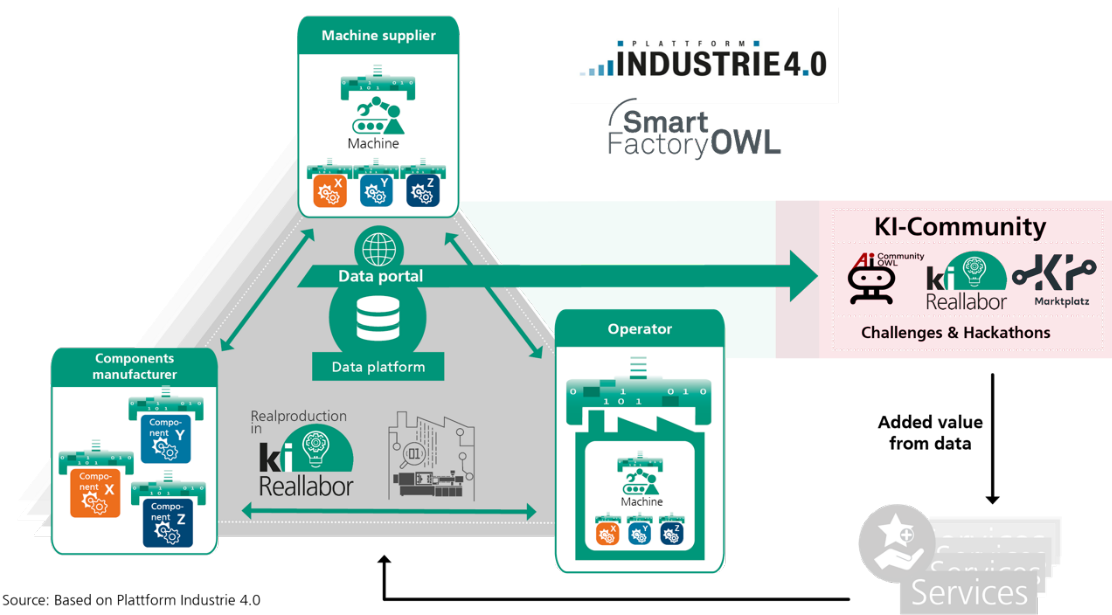

Figure 22: Project structure

3.7.2 Project-relevant scenario(s)

With regard to a Manufacturing Data Space, one main use case that is prototypically implemented in the project and in the SmartFactoryOWL is "Collaborative Condition Monitoring" (CCM) specified by the PI4.0 [69]. The use case CCM deals with the collection and use of operating data to optimize the reliability and service life of machines and their components during operation (see Figure 23). CCM supplements the classic version with the aspect of multilateral cooperation by enabling cross-company and cross-competition sharing of data. In the real world, installed machines come from different machine suppliers that are equipped with different products from different component suppliers. Today, it's a challenge for component suppliers to access the data of their delivered products. Even if the interoperability of information models is increasing by the usage of standardized Submodels and Application Programming Interfaces (APIs) of the AAS, challenges with regard to Discovery, Trust, and Sovereign Data Access remain. This is where the Gaia-X Federation Services come into play.

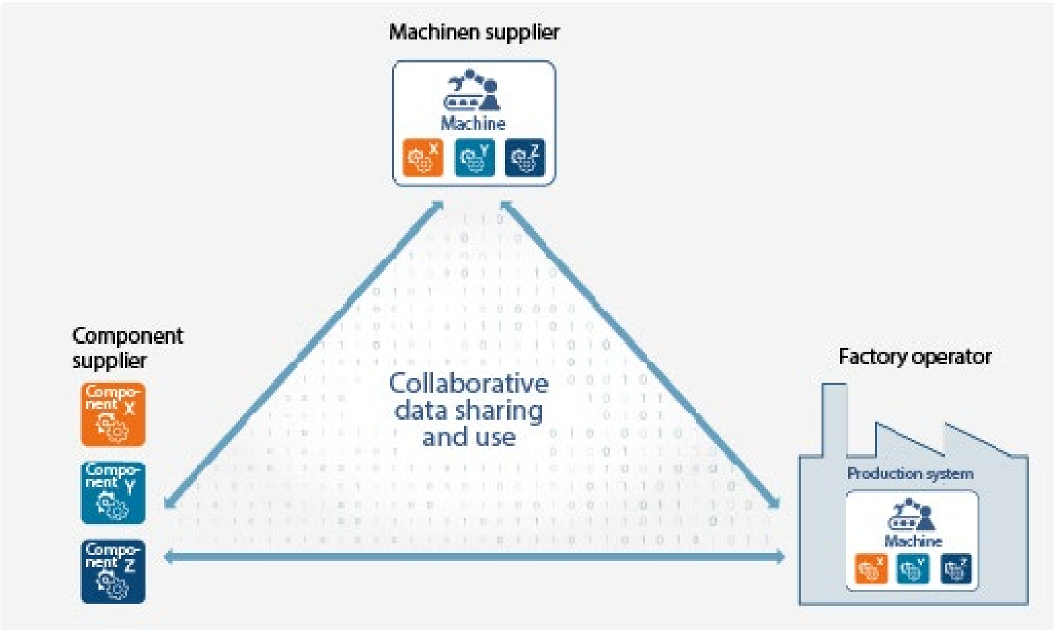

Figure 23: Collaborative Condition Monitoring

3.7.3 Architecture

The base architecture of the implementation for a pilot run is depicted in Figure 24. For evaluation purposes the so-called Customizable Production System (CPS) from SmartFactoryOWL has been used. The CPS and its location in the Data Ecosystem of Gaia-X are depicted in Figure 25.

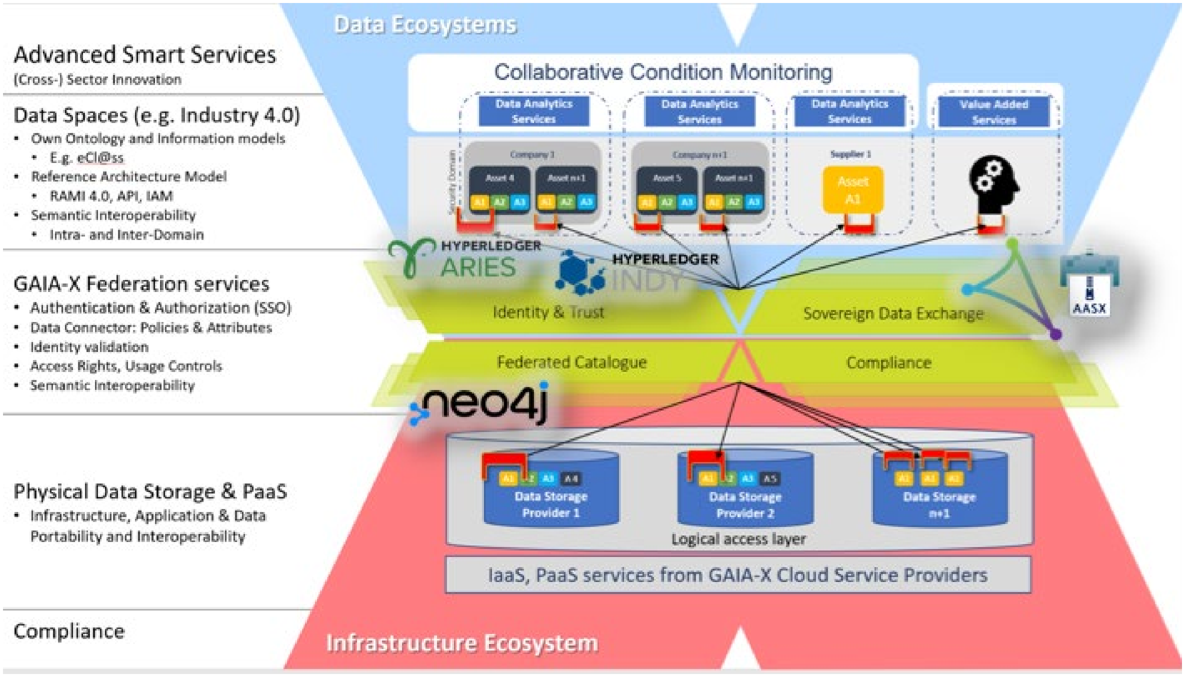

Figure 24: Piloting CCM in the AI Living Lab based on the Gaia-X Architecture [70]

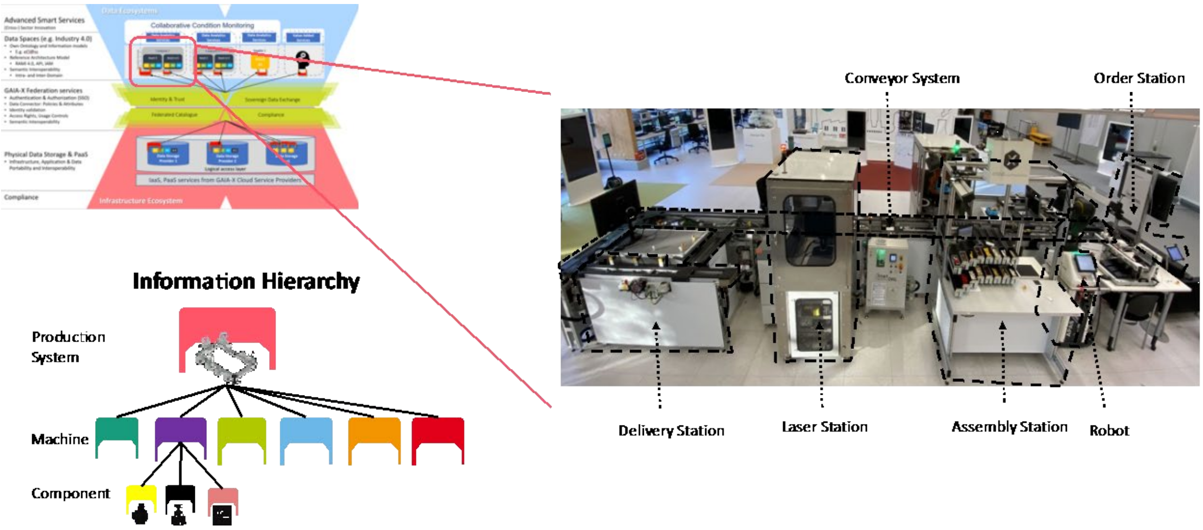

Figure 25: The location of the Customizable Production System (CPS) from SmartFactoryOWL in the architecture

3.7.4 Usage of I4.0 & IDS concepts/components

Together with a team consisting of partners from PI4.0 and ZVEI, suitable technologies for the implementation of CCM were discussed and selected for a pilot run. The technology stack is depicted in Figure 26.

In general, the AAS has been used as a standardized information model and API. AAS were modeled for the different components of the CPS and instantiated using the Open Source

AASXServer [19]. Furthermore, live data from a drive of the CPS has been integrated in the drive's AAS, that should be shared with the drive's manufacturer (Component Supplier in Figure 26). Metadata about the available process data has been registered in a neo4j graph database as a Gaia-X compliant Federated Catalogue. For evaluation purposes the core ontology of Gaia-X and relevant parts of the AAS were modelled in neo4j. To establish an Identity & Trust infrastructure, the Open Source and Distributed Ledger Technologies Hyperledger Aries and Hyperledger Indy were selected. For sovereign data exchange, the EDC has been applied.

The demonstration sequence is as follows: (1) the operator SmartFactoryOWL registers metadata from the AAS of the CPS drive in the neo4j database, acting as the Federated Catalogue. (2) The component supplier queries the neo4j database for the AAS of its drive, containing the desired process data and finds the endpoint of the drive's AAS. (3) The component supplier initiates a connection to the SmartFactoryOWL and is authenticated using its decentralized identity. (4) SmartFactoryOWL accepts the connection and shares the drive's AAS with the component supplier via the EDC, giving them access to the process data.

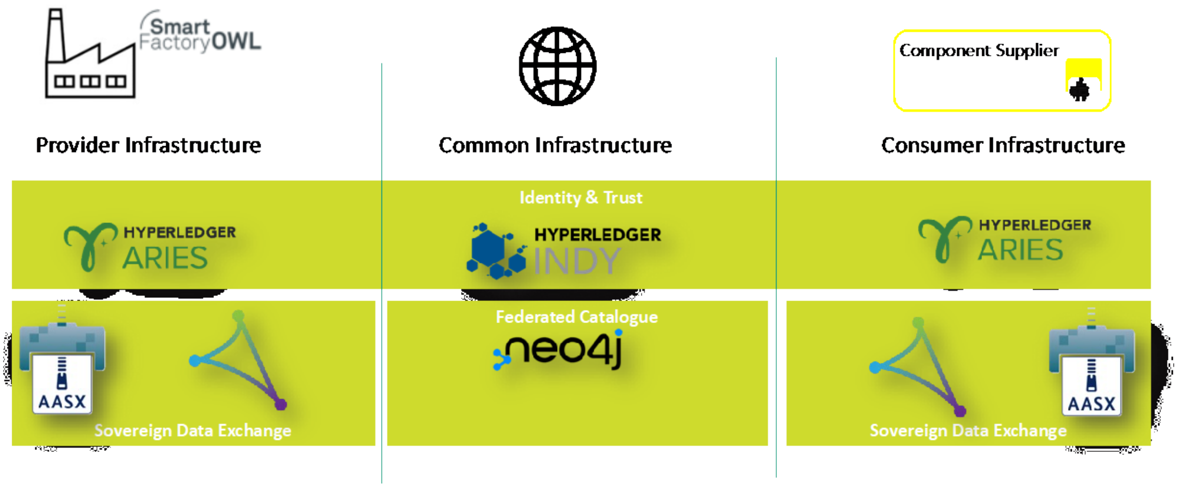

Figure 26: The technology stack used for evaluation purposes

3.7.5 Lessons learned from the joint use I4.0 & IDS concepts/components and recommendations for improvements

Mastering the heterogeneous technology stack depicted in Figure 26 is challenging. Although, one vision for Industrie 4.0 is interoperability, key technologies like the ones used here all comprise different APIs. After achieving interoperability on the shop floor, different technologies need to be integrated in Edge Clouds by mapping different APIs. What makes this task even more cumbersome is that the documentation of the technologies is often poor. What is still missing is an overall concept and architecture for the integration, e.g. how to use Self Sovereign Identities in AAS and EDC. Also exchanging live data is not supported out of the box by the EDC.

3.7.6 Project results related to the IDS-I position paper

The stack of Gaia-X compliant technologies from Figure 26 and the knowledge gained from the project could contribute significantly to the realization of the IDS-I vision.

3.7.7 Project contribution to IDS-I

With the stack of Gaia-X compliant technologies from Figure 26 and the lessons learned. Also concepts from the IDS-I paper could be evaluated in SmartFactoryOWL.

3.7.8 Project benefit from IDS-I

Learning about different implementations and jointly working on the missing concept and integration architecture mentioned above.

3.7.9 Link to the project and relevant results

- www.ki-reallabor.de
- https://smartfactory-owl.de/cuna-realproduktion/

3.8 DOME: Digital Online Marketplace for Europe

3.8.1 Short project description

The European Commission has intensified its commitment to advancing cloud adoption in Europe, unveiling a strategic initiative to establish a comprehensive cloud services marketplace for users across the private and public sectors. In response to this initiative, the Digital Europe Programmer's inaugural open call witnessed the launch of the DOME (Digital Online Marketplace for Europe) project.

The primary goal of the DOME project is to design, deploy, and manage an all-encompassing online marketplace for cloud and edge services within the European Union. The project aims to streamline and simplify the procurement process for users by offering a unified platform, thereby enhancing the efficiency of cloud service adoption in Europe. With a focus on trust and reliability, the marketplace will play a pivotal role in facilitating the growth of the digital ecosystem in the EU, aligning with the Commission's broader strategy for a digitally resilient and competitive Europe. It will serve as the centralized hub for accessing trusted industrial services, including:

1) Cloud and Edge Services: Providing a diverse range of cutting-edge cloud and edge computing solutions tailored to meet the evolving needs of users.
2) Building Blocks from the Common Services Platform: Offering essential building blocks deployed under the Common Services Platform for Public Administrations, ensuring standardized and interoperable solutions.

3) EU Program Developed Software and Data Processing Services: Enabling access to a broad spectrum of software and data processing services developed under various EU programs, fostering collaboration and innovation.

DOME technical approach is aligned with the DSBA technology convergence recommendations [108] developed together by IDSA, Gaia-X, FIWARE Foundation, and BDVA under the umbrella of the Data Spaces Business Alliance (DSBA) [109]. Because of that, publication of product specifications and offerings defined around data and data services made accessible through a data space connector that implements DSBA Technical Convergence recommendations will work smoothly.

3.8.2 Project-relevant scenario(s)

In practice, DOME will take the form of a shared digital catalogue of cloud and edge services which are made available through the global DOME portal or any of its federated marketplaces. DOME scenarios consider three types of federated marketplaces:

- Marketplace connected to an IaaS provider, which comprises a catalogue of cloud and edge data/app services which customers can pick and then easily deploy on top of the provided infrastructure;
- Marketplace connected to a Platform provider, which comprises a catalogue of cloud and edge data/app services which customers can pick, easily activate and run integrated with the rest of data/app services already running, integrated with the provided Platform;
- Independent Marketplace, which comprises a catalogue of cloud and edge data/app services not tied to an IaaS or Platform provider.

In regard to the actors and stakeholders which give purpose to the target scenario, DOME identifies three major categories:

- Data/Application service providers which can publish their products in the shared DOME catalogue only once and benefit from making them available through all those federated marketplace services they choose, thus reducing their costs while maximizing their exposure through multiple channels in the market. This as opposed to the current situation where they have to adhere to the rules of specific marketplaces, typically run by individual IaaS/platform providers;
- Platform and IaaS providers are those which aim to benefit from enriching the portfolio of cloud applications they can import into their respective marketplaces from the shared catalogue of DOME. This accelerates the achievement of a critical mass with regards to the number of data/application services offered;
- Customer companies, in turn, will benefit from a personalized experience through each of the federated marketplaces, which may offer different user interfaces, incorporating discovery services better tailored to the kind of users or application domain, or complementing content with focused training material, match making opportunities, etc. They will also benefit from billing integrated with the billing of IaaS/platform services, potential discounts, etc.

The technical vision of DOME is summarized in Figure 27. To realize such a vision in real-world scenarios, DOME leverages a subset of TM Forum Open API recommendations, meticulously defining its foundational information model and APIs. The framework supports the storage of crucial information encompassing products, services and associated resources instantiated for specific customers. It also supports the generation of comprehensive logs detailing procurement and product usage. Product specifications and offering descriptions are made accessible through Verifiable Presentations (VPs), which are essentially sets of Verifiable Credentials (VCs) adhering to Gaia-X specifications. Some of these VCs will bring users trust about adherence of products to specific standards. As an example, customers will be able to verify that products comprising data services for management of AAS data follow a specific RESTful API standard (for example, NGSI-LD) or adhere to some concrete standard data models. Additionally, the platform utilizes VCs to articulate meaningful roles and claims assigned to service users, complemented by policy rules defined based on roles and other environmental attributes. In essence, DOME's robust architecture ensures the seamless implementation of these diverse functionalities for the realization of a reliable and trustworthy European cloud edge services marketplace which meets the needs of the envisioned scenario.

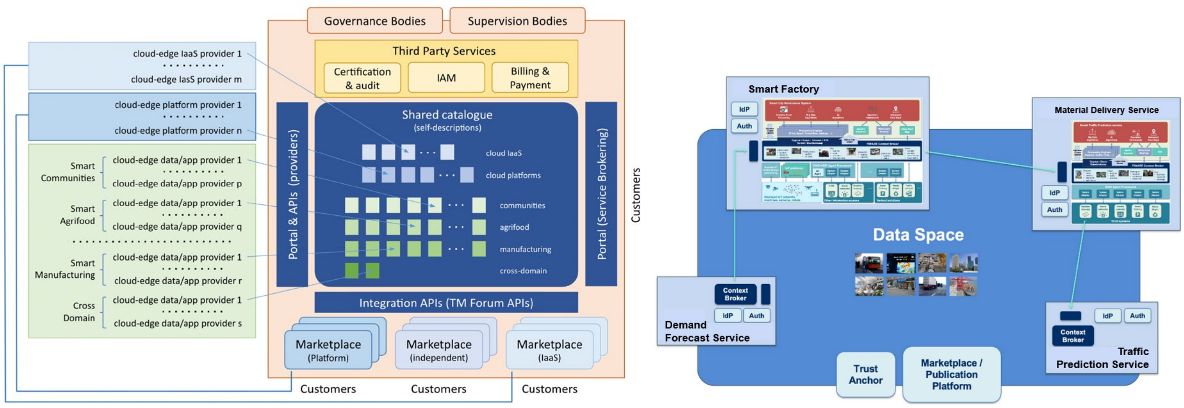

Figure 27: DOME Technical Vision

3.8.3 Architecture

DOME is putting in place and bringing together a series of key concepts in its architecture framework:

- *Products, Services, Resources.* In the context of TM Forum terminology, a Data/Application Provider is categorized as a *Product Provider*. The conception of a *Product* within this framework involves a synergistic blend of *Services* and/or *Resources*, where Services grant access to data or engage in data processing, and Resources represent the essential components needed for Service execution. The provisioning and activation of Products, along with their associated Services and Resources, are tailored for specific Customers. It is noteworthy that the provisioning and activation process may span several days, with not all aspects automated. Moreover, the ecosystem extends beyond cloud-centric operations, encompassing cloud-to-edge products, thereby acknowledging the diverse nature of service deployment across various technological landscapes. Other entities and relevant concepts which are more specific and aim to increase the applicability of these models include: *Product Catalog*, Product Inventory, Product Offering, Party, Product Order, Service Inventory, Resource Inventory, Orders, Specifications, Candidates, Usages, etc. Figure 28 integrates all these concepts along with their semantically annotated relationships in a single diagram.

- Verifiable Credentials (VCs). DOME relies on VCs to describe participants and products as well as to support Attribute Based Access Control (ABAC) for digital entities. The W3C Verifiable Credentials stand as a pivotal open standard, providing a secure and flexible framework for digital credentials. This innovative standard represents the information found in physical credentials while also accommodating entirely digital concepts, such as ownership of a bank account. Functioning as virtual "badges" in the physical world, these credentials are characterized by cryptographic security, tamper resistance, and instantaneous verifiability, owing to their utilization of digital signatures. Emphasizing privacy, W3C VCs uphold a peer-to-peer communication model, ensuring that sensitive information is shared with the utmost discretion. VCs are also machine-verifiable, enhancing their utility in automated processes, and they adopt the JSON-LD data format, contributing to their interoperability within diverse digital ecosystems.
- Acquisition of Product/Service Usage Rights. The organizations that undergo the onboarding process in DOME become trusted issuers of Verifiable Credentials (VCs) and can issue such VCs for users within their organizations. When an organization acquires rights to utilize a product through a provider utilizing the DOME Trust & Identity Access Management (IAM) framework, it too assumes the role of a trusted VC issuer for users within their organizational domain. In both cases, the authentication and authorization processes involve steps at multiple levels. Firstly, participants undergo a trust verification service to assess their reliability. Subsequently, the system ensures that access rights were legitimately obtained, either through a marketplace or direct acquisition, by verifying the organization's status as a trusted VC issuer linked to access policies. Finally, the presented VCs are thoroughly scrutinized to verify that they permit the requested operation, ensuring a robust and secure framework for product and service usage rights within the DOME ecosystem.
- Trust Anchor Framework and Decentralized IAM. The Trust Anchor Framework verifies the identities of organizations and authenticates credentials using multiple features. It employs ID Binding, utilizing identifiers embedded in eIDAS digital certificates issued by EU Trust Service Providers (TSP). This ensures a secure and standardized mechanism for binding identities within the framework. It implements Proof of Participation through a Decentralized Trusted Participant List, stored in the Verifiable Data Registry, offering a decentralized and tamper-resistant method of confirming the involvement of participants. Furthermore, Proof of Issuing Authority is established through one or more Decentralized Trusted Issuers Lists, also stored in the Verifiable Data Registry, confirming the legitimacy of entities issuing credentials. The Verifiable Data Registry, a crucial component of the Trust Anchor Framework, is implemented using Decentralized Ledger Technology (DLT) based on the European Blockchain Services Infrastructure (EBSI). In turn, The Decentralized Identity and

Access Management (IAM) Framework is characterized by eliminating centralized identity providers and empowering all participants to securely transmit identity data. It relies on W3C Verifiable Credentials and leverages OpenID Connect for Verifiable Presentations (OIDC4VP) and Self-Issued OpenID Provider v2 (SIOPv2), this framework incorporates proven, standardized mechanisms to transport Verifiable Credentials/Presentations within OpenID Connect flows, ensuring a secure and established approach. Furthermore, the framework aligns with EBSI APIs, enhancing interoperability and integration with Trust Services. The diagram in Figure 29 integrates the aforementioned building blocks in the context of an organization onboarding process.

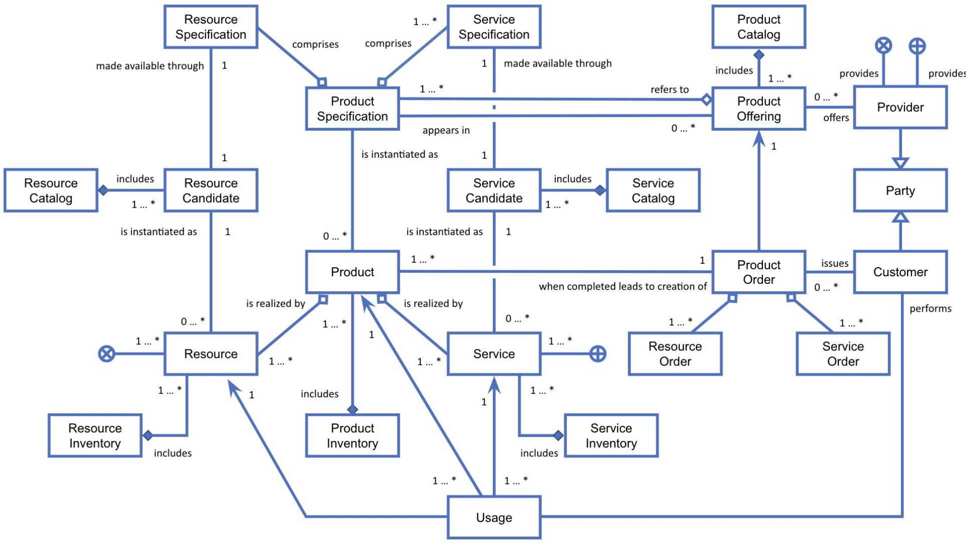

Figure 28: TM Forum APIs for Marketplaces - Model (more details [here](#))

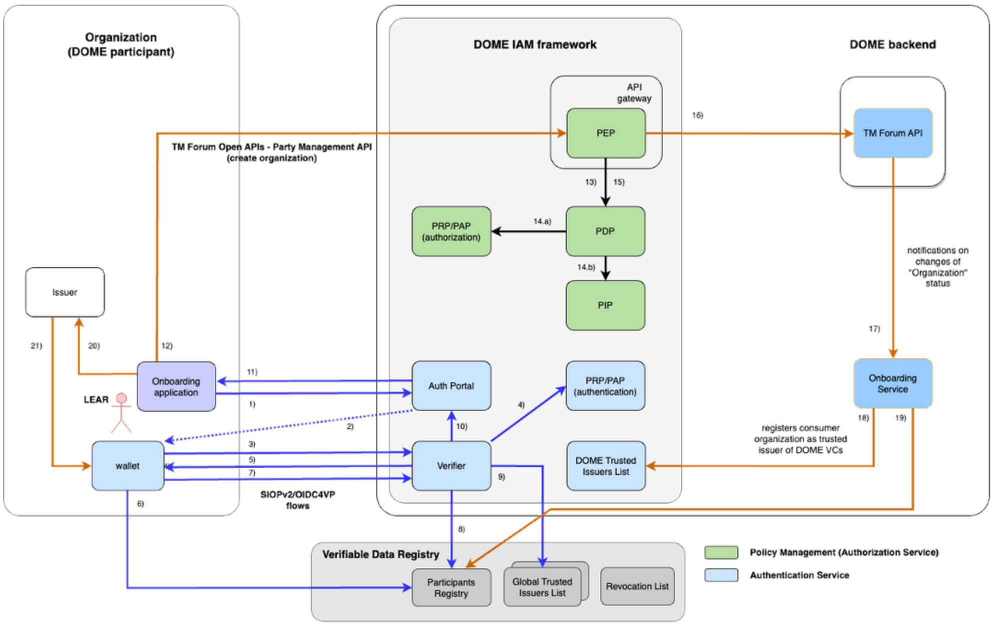

Figure 29: Organization onboarding through the DOME portal

3.8.4 Usage of I4.0 & IDS concepts/components

DOME technical approach is aligned with DSBA Technology Convergence recommendations [108] developed together by IDSA, Gaia-X, FIWARE Foundation, and BDVA under the umbrella of the Data Spaces Business Alliance (DSBA) [109]. Because of that, publication of product specifications and offerings defined around data and data services, enabled by data space connectors implementing DSBA Technical Convergence recommendations, will proceed seamlessly. Data and data services may be exposed following a digital twin approach. In this respect, DOME provide the means for describing how the interface to data and data services based on digital twins is implemented for a particular system, bringing to users the tools for verifying what standards have been implemented.

Readers interested on how the vision of these organizations and components fit together may read Chapter 2 in the DSBA's Technical Convergence Discussion Document [93].

3.8.5 Lessons learned from the joint use I4.0 & IDS concepts/components and recommendations for improvements

DOME is making considerable efforts towards achieving technical alignment within the extremely heterogeneous landscape of concepts, technologies, and components in this emerging domain. Certain aspects, such as Identity Management mechanisms employing Decentralized Identifiers (DID) and Verifiable Credentials/Presentations (VC/VP), are well-defined and recommended for adoption. Other elements still require further clarification. Additional work is required to foster a common framework for data spaces and include the development of essential components as open source. Looking ahead, priority areas for future work include delineating the integration of IAM and marketplace functions within data space connectors to ease the publication of products offered through those Connectors into DOME. Furthermore, the interaction of Marketplaces with the Federated Catalog and Metadata Broker is evolving, with a focus on finalizing the mapping of TMForum, Gaia-X, and IDS-RAM, as well as defining the relationship between TMForum APIs and IDS contract negotiation sequences. Despite a comprehensive understanding of Policies for Access and Usage Control, there is a recognized need to articulate the controlled vocabularies that underpin these policies for enhanced clarity and effectiveness.

3.8.6 Project results related to the IDS-I position paper

DOME results contribute a single point of access in Europe for trusted Cloud and Edge services across different domains aligned with the conceptualization study on the European cloud marketplace [110]. The two powerful and necessary concepts, federation and decentralization, are key requirements of such cloud marketplaces. Furthermore, every contribution is built upon open standards:

- Description of cloud and edge services and service offerings based on W3C Verifiable Credentials / Presentations (VC/VP), enabling verification of standards a given product offered through the marketplace supports;
- Shared Catalogue and Marketplace functions based on TM Forum Open APIs implemented on top of EBSI-compliant blockchain;

- Decentralized Identity and Access Management (IAM) based on W3C DID – VC/VP, OIDC protocols for SSI (SIOPv2, OIDC4VP) and EBSI-compliant APIs for interfacing Trust Services
- Logs generated through the full lifecycle of cloud application service offerings stored on blockchains aligned with the European Blockchain Service Infrastructure (EBSI);
- Data services to be visible through existing Data Publication Platforms supporting DCAT/DCAT-AP.

3.8.7 Project contribution to IDS-I

DOME contributes to the position paper with the necessary framework to implement European marketplaces for cloud and edge services. It also contributes a well-curated win-win strategy aimed at accelerating the engagement and onboarding of every party involved in the emerging business models of data-driven industries. In essence, DOME contributions are cornerstone to support the required digital transformation for businesses and public organizations because they are the means to make available, affordable, and operational a comprehensive catalogue of cloud-to-edge offerings for the industry.

3.8.8 Project benefit from IDS-I

The position paper serves as an excellent opportunity to delve deeper into the ongoing technical convergence involving IDS, Gaia-X, FIWARE and BDVA concepts and components. Furthermore, it offers a chance to broaden its scope by initiating convergence with those concepts and components which are relevant to the paper but may currently have weaker connections to the ongoing technical convergence efforts.

3.8.9 Link to the project and relevant results

- Website: https://dome-marketplace.eu/
- FIWARE Dataspace Connector: https://github.com/FIWARE/data-space-connector
- FIWARE Implementation of TMForum-APIs: https://github.com/FIWARE/tmforum-api

4 Analysis of the integration possibilities between the technical components of IDS and I4.0

4.1 The role of digital twins in a data space

A data space is a "federated data ecosystem within a specific scope of use, based on common policies and rules" [71]. Access and usage rights are granted by those authorized to publish this data.

Based on the definition and design principles for data spaces, there are several approaches that have led to similar building blocks for data spaces, e.g., [71], [72], etc. These building blocks enable interoperability, trust, data value creation, and governance within the data space.

Data spaces are typically focused on a specific sector (e.g., manufacturing, mobility, energy, etc.). This raises the question of what the sector-specific requirements are and how they are reflected in the data space building blocks. Since IDS-I focuses on the industrial sector, where standardized DTs play a crucial role, in this section we analyze how AAS standard-compliant digital twins could be used for/by data spaces.

In [55], the authors explored the potential of combining DTs with data spaces to enable data-sovereign sharing with DTs as the data sources and data sinks. They discussed the possible role of DTs in different data space components and described an approach for integration based on the IDS and AAS. The focus of this approach was to enable end-users to benefit from both DTs and data spaces while reducing barriers to entry due to complexity and onboarding effort.

The relevant data space building blocks that must be considered when releasing a data space based on DTs are shown in Figure 30 with a red rectangle. The other building blocks are designed and should be implemented in such a way that they are not specific to a particular application domain or use case and therefore do not address specific requirements for DTs.

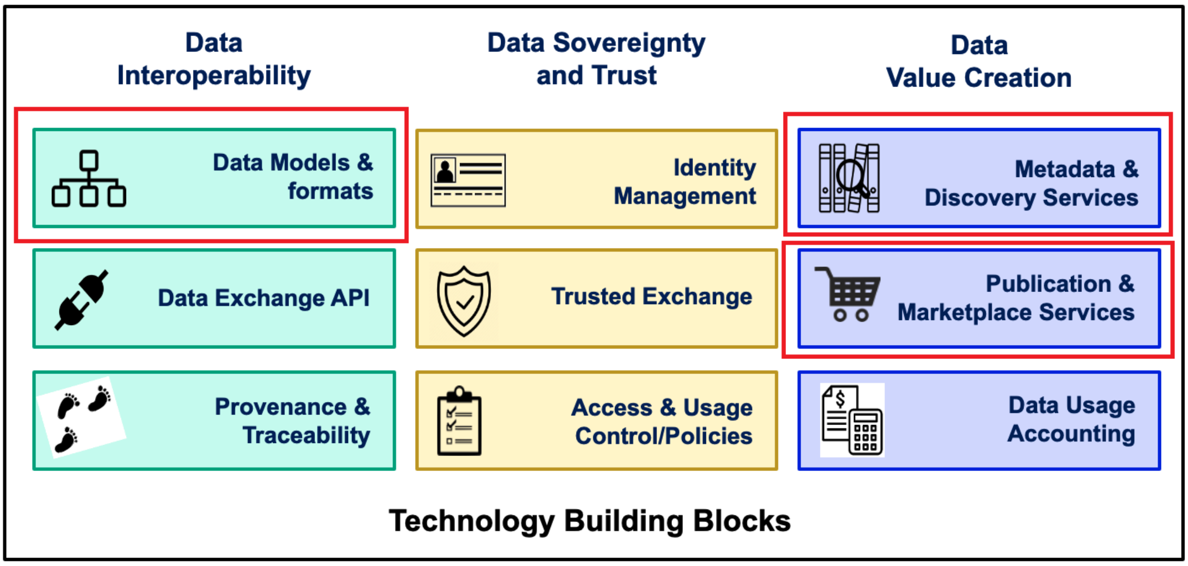

Figure 30: DTs in data space building blocks [55]

In the subsequent part of this section, we summarize the results described in [55] by clarifying the purpose of each relevant building block and by explaining the role of a DT in it.

4.1.1 Data Interoperability

4.1.1.1 Data Models and Formats

To enable interoperable exchange for participants in a data space, standards and specifications for data models and data formats are required. It is necessary to agree on the models that will be used for the data, since the meaning and semantics of the data should be understood by all participants. The formats or models can be chosen freely, but agreeing on the smallest possible subset of formats and models minimizes the need to convert and map between them.

The AAS-compliant DTs are based on the AAS specification [7], [8], a standardized information model that defines how information about industrial assets can be structured and exchanged between different systems and organizations. Part I of the AAS specification [7] defines the metamodel of a DT, which means that the entities that can be used for modelling are explicitly defined and standardized.

The AAS specification goes one step further by defining the so-called AAS submodel templates [73]. While the AAS submodels describe content or functional aspects of an asset (e.g. product carbon footprint), an AAS submodel template is a predefined structure or schema that defines the format and content of an AAS submodel. It is intended to provide a standardized way to represent a particular aspect of an asset or system and to facilitate the creation and management of AAS.

AAS submodel templates are an important means for defining the structure and semantics of an AAS, which is crucial for achieving interoperability and consistency in I4.0 applications. As of November 2023, there are 80 submodel templates, ~20 have been published, ~40 are under development and ~20 proposals have been submitted. More information can be found in [73].

In terms of formats, the AAS specification currently offers support for JSON, XML, RDF and AASX [7]. In the past, AutomationML and OPC UA Node Set were also supported as a way of (de)serializing an AAS, but this is no longer the case. Additionally, an AAS relies on other domain-specific ontologies and vocabularies. As such, the data formats and models are clear for all participants of the data space.

4.1.1.2 Data Exchange API

We would like to note here that we do not consider the Data Exchange API building block to be relevant for DT-related aspects in a data space, although the AASs also have a standardized API as defined in Part II of the AAS specification [8]. The reason for this is that communication and interaction should be based on the IDS protocols, as this ensures uniform, interoperable data exchange between the participants in a data space. This is aligned with the published results e.g. [53].

On the other hand, the AAS are mainly seen as data providers or data consumers for the data space (see Figure 31). The standardized AAS API not only facilitates the integration between an AAS and an IDS connector. It also relieves an IDS connector from the direct integration of the physical assets, which is very complex due to different communication protocols (e.g. OPC UA), different interaction patterns (e.g. execution of operations in addition to the frequently used request/response or pub/sub interaction patterns) and also non-functional requirements.

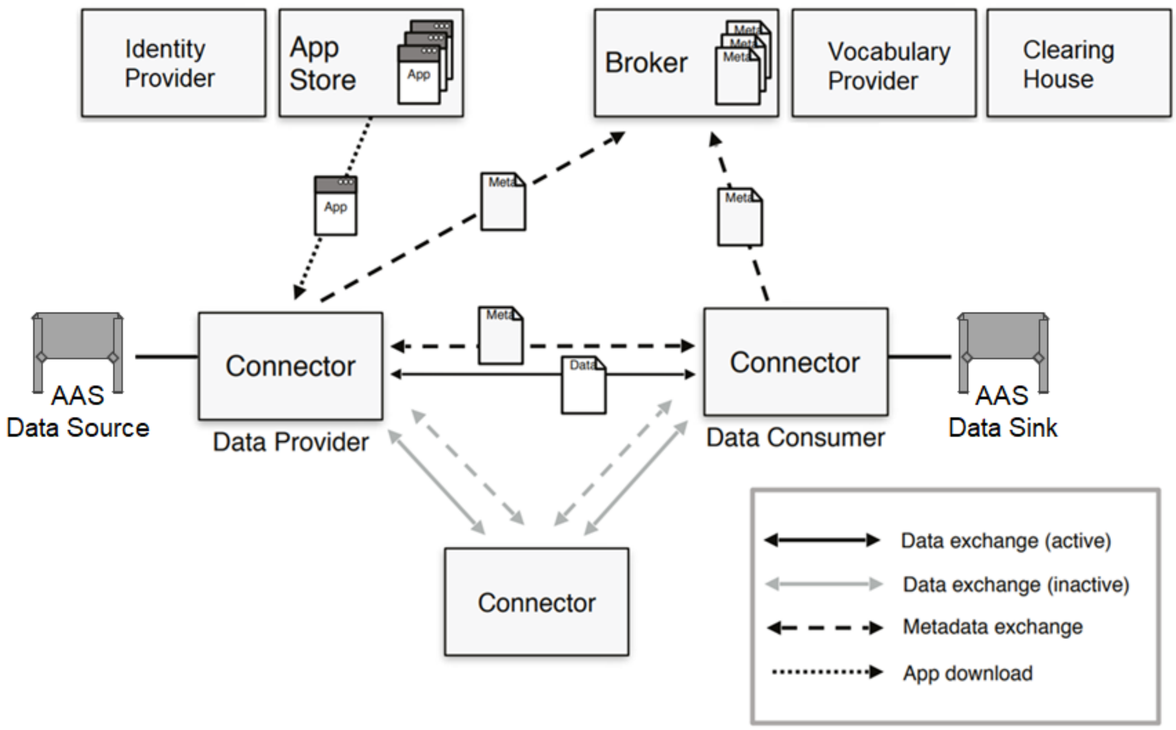

Figure 31: Data Space by IDSA [74] adapted to DTs as data providers and data consumers

4.1.2 Data Value Creation

4.1.2.1 Metadata and Discovery Services

The Metadata & Discovery Services building block is mostly concerned with enabling participants to find each other and the corresponding data through a given protocol. For the metadata, data resources must be described with an information model, for example the IDS Information Model [74]. Otherwise, the data space participants will not be able to understand their data descriptions.

For the discovery, participants want to query a central component like an IDS Metadata Broker [75] to discover suitable data sources. A broker is a component where all connectors can register to publish their data offerings to a broader audience. It is also the component used to search for suitable data offerings. We note here that this component is part of the data value building blocks, namely it uses the Metadata & Discovery protocol building block. However, it is also part of the publication services.

In order for the data space participants to find a correct DT, the DTs must be taken into account when describing the metadata and catalogues in the data space. The metadata should originate from the DTs themselves. For an AAS-compliant DT, it is possible to describe an AAS entity semantically, e.g. by using the so-called semantic IDs. These semantic IDs could refer to external ontologies, external standards (e.g. ECLASS) or be defined within the AAS. There is therefore a need for a solution to "link" the AAS semantics with the IDS information model.

In order for a DT to be found, a DT catalog is required that provides the registration and search functionalities. The AAS specification also specifies an AAS registry that provides functionality such as storing metadata and searching for an AAS. The registry is based on the AAS descriptor, which also contains an AAS endpoint that is used to access an AAS.

The registration and search functionalities are also provided by an IDS Metadata Broker. However, the IDS Metadata Broker is a central point for searching for IDS connectors and filtering data offerings. It is not tailored to the AASs and their registration. Therefore, there is a need to integrate the complementary concepts of an AAS registry and an IDS Metadata Broker to ensure that AAS can also be found and used in a secure and interoperable way via a data space. To this end, the various options for linking an AAS registry with an IDS Metadata Broker should be investigated and implemented. This is illustrated in Figure 32.

In addition to a concept and architecture for the integration of an AAS registry and an IDS Metadata Broker, there is a need to extend the existing search of the AAS registry and the IDS metadata broker to combine both information sources and to extend the "integrated" search to include semantic information and reasoning based on the IDS information model mentioned above.

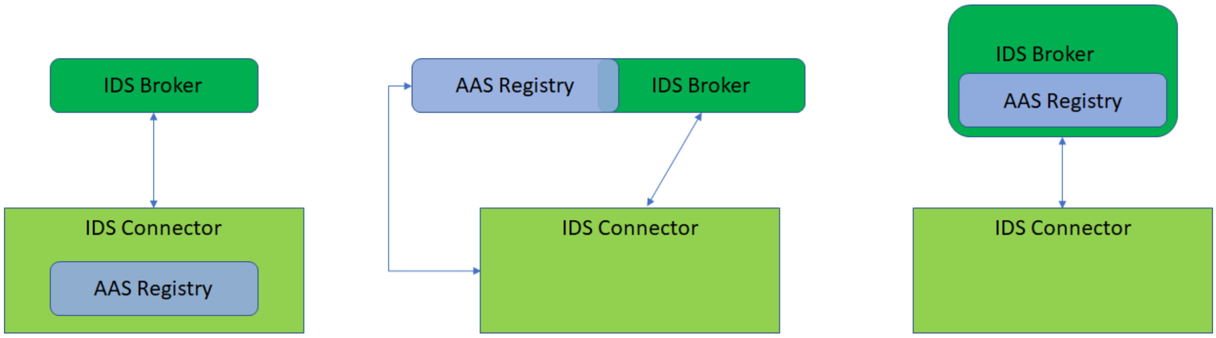

Figure 32: Various options for combining an AAS registry and an IDS metadata broker

Consequently, in both the DT and data space domain, there needs to be software components enabling discovery and publication of data sources. In the case of the IDS, an IDS Broker provides a list of IDS connectors with their available data offerings. However, the broker only understands the IDS Information Model and cannot resolve DT requests, such as the AAS queries found in the AAS Registry API. It is vital for participants to register their connector in a broker, since the participants in a data space might not know each other before data transfer. Likewise, it is vital to register the DT in a registry so that other DTs can find and interact with each other. In the AAS specification, a component called AAS registry is used to keep track of all registered AAS instances. Like the IDS Broker, the AAS registry provides a list of available AAS and their submodels.

An example on how to combine the functionality of IDS brokers and AAS registries in a single component is explained in the section "FDS Project "Synergy between AAS Registry and IDS Broker". This allows users to make use of the AAS API to look for available AASs even if they are protected by IDS connectors. This makes sense in cross-company scenarios where AASs need to find and interact with each other while not being aware of IDS connectors but leveraging data sovereign data transfers. The task of finding other AASs to communicate with is then handled by the customer AAS or external systems using the AAS API. However, data transfers are still required between the connectors in order to negotiate a valid usage contract. This means that the customer AAS or an external system still needs a connector to handle the data transfer. More information can be found in [76].

4.1.2.2 Publication and Marketplace Services

The Publication and Marketplace services building block is concerned with the publication of data offerings and marketplace services enabled by data sharing. The previously mentioned IDS Metadata Broker publishes the metadata of participants in the data space.

To support the publication services in publishing metadata of participants, the semantic meaning of descriptions of data offerings can be requested. As shown in Figure 31, a data space could include a component called the IDS Vocabulary Provider [77]. The IDS Vocabulary Provider is a central IDS component for managing all vocabularies (ontologies, reference data models, etc.) and can annotate and describe metadata of datasets, applications/services and resources. However, the current implementation of the IDS Vocabulary Provider is limited to metadata only.

After querying the Metadata Broker, the data consumer has enough information to request the data from the data provider connector. However, in many real-world use cases, the AAS data provided by the AAS servers is defined using specific terminology, conceptualization and representation that data engineers need a lot of time to understand and is perhaps used in various use cases, such as collaborative condition monitoring. In manufacturing, for example, products and assets are described using the AAS, but still require a thorough understanding of the specific terms and values if the semantic IDs are not provided.

As described in [55], there are several concepts to establish syntactic and semantic interoperability in the context of the AAS. Semantic IDs are used to link a semantic specification to a submodel or submodel element. This specification provides meaning to the element, for example through an ontology or a formal specification describing the element in detail [8]. It is possible to define own dictionaries in the AAS that contain semantic definitions of the submodel elements. These semantic definitions are called concept descriptions and are mainly used for attributes and data types in the AAS [78].

While the meta model of the AAS creates a rough syntactic structure, the aspects of an asset can be split across several submodels and elements in any way the company sees fit. Submodel templates define the aspects of the asset to be represented in a specific structure and with specific elements. They are created and standardized by PI 4.0 working groups allowing for better interoperability between different systems and devices, if companies implement them [79].

Vocabularies and ontologies are usually provided by the IDS Vocabulary Provider. They are needed to achieve a common shared understanding in a domain. Such ontologies could be either used to semantify AASs (see section FDS Project “IDS Vocabulary Provider - AAS Semantification”) or could be instantiated based on the semantic ID of AAS entities.

On the topic of marketplace services, an example in a circular economy is carbon footprint emission trading enabled by offering permits on a marketplace. DTs can also be reflected in marketplace services that enable, for example, manufacturing-as-a-service [91], where the capabilities of a machine are offered to all data space participants. These services depend on the business model of the data space and would profit from using AAS standard submodel templates.

4.2 Integration options between an IDS connector and an AAS

Data spaces and digital twins are two different concepts, but they can complement each other to enable interoperable, secure and standardized data exchange in industrial ecosystems. The key technical components of an IDS data space are IDS connectors, which should be used by data providers and consumers to participate in the data space.

The connector is the gateway for an organization to participate in the data space. It is a central component that is required by data providers and consumers. It is part of several technical building blocks:

1) interoperability building blocks to provide Data Exchange API and store Provenance logs;
2) trust building blocks to enable trusted exchange and
3) data value building blocks to store metadata and log data usage.

A connector is primarily used for data transfer and the negotiation of data policy.

One of the most important technical results of I4.0 are AASs, which are considered as industrial digital twins. An AAS is a logical representation of an asset (e.g. products, devices, machines, facilities, etc.), it identifies the asset unambiguously and is used to integrate the asset into I4.0 communication. It provides the standardized interfaces to all information of the asset and covers the complete life cycle of it.

As shown in Figure 33, there are the following options for integrating an IDS connection and an AAS:

- AAS for IDS connector: In principle, it is possible to "wrap" each IDS connector with an additional AAS to make it I4.0 compliant. The modeling of the connector is based on the submodels. Nevertheless, corresponding interfaces for messages must be provided. Such interactive end points have not yet been defined for the AAS.
- IDS connector for AAS:
    - Bottom: For asset integration into an AAS, i.e. protecting sensor data transmitted to the AAS in the cloud;
    - Top: On the AAS interface itself, i.e. protecting and data sovereignty control between AAS and its clients, e.g. other AASs.

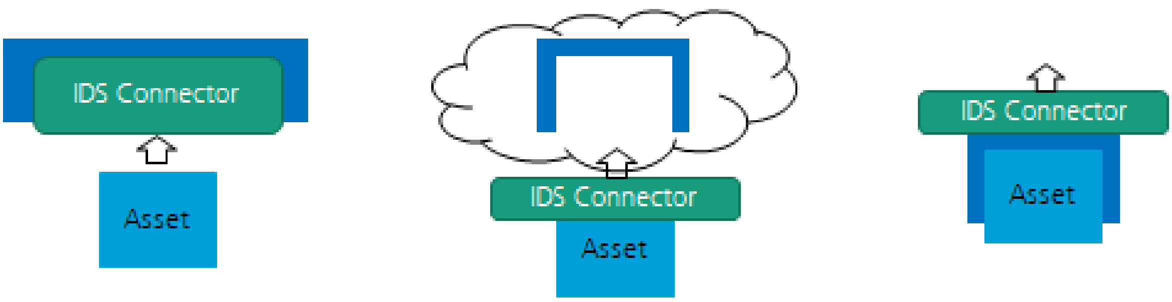

Figure 33: Options for integrating an IDS connection and an AAS

Based on the analysis of existing tools and projects, some of which were mentioned in sections 2 and 3, it seems that all approaches converge on the last solution. This means that the AASs can communicate with each other and with other components in a secure and data-sovereign manner via IDS specifications and their implementation. The idea is to continue using the standard AAS protocols and message formats, but to enrich them with IDS components to increase the level of trust and thus control the use of the data [81].

In the rest of this section we focus on the last option. It could be abstracted as shown in Figure 34. The AAS service on the data provider side and the AAS client on the data customer side are connected across sites via IDS.

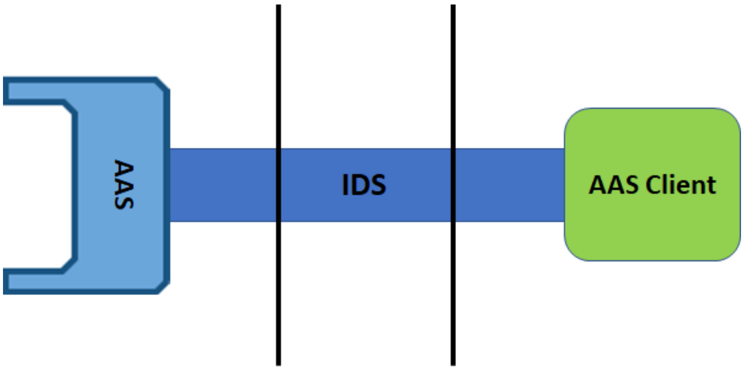

Figure 34: High-level integration architecture

The high-level architecture shown in Figure 34 is further elaborated in [81] by proposing a generalized approach for use and integration of AAS-compliant DTs across company borders. The proposed approach should ensure security and confidentially of exchanged information. Figure 35 shows a conceptual integration of a DT with the IDS. From inside the company that owns/hosts the DT (i.e., Company A), an actor, which can be either human but typically an application, can interact directly with a DT via the DT API. A DT exposes a well-defined DT API offering access to properties, services and events. Actors from outside the company, i.e. from Company B, will have to use the IDS API to interact with the DT. This requires both Company A and B to each provide a (properly configured) IDS connector.

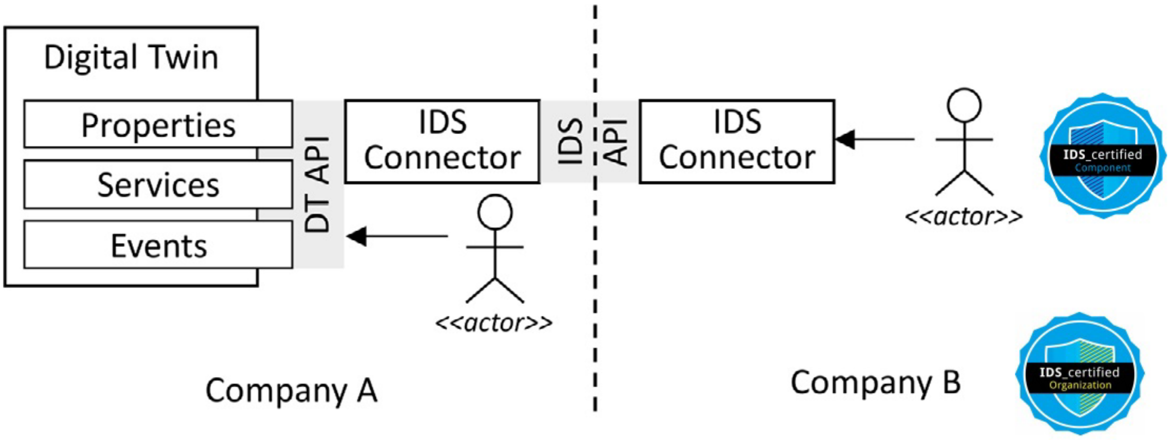

Figure 35: DT integration with IDS [81]

A similar approach is proposed in [53]. DTs and IDS connectors can both be deployed inside a company or on a cloud infrastructure and used independently. However, DTs usually represent a physical asset found in the company while IDS connectors are gateways to data spaces across company borders. As such, the combination of both concepts is shown in a simplified way in Figure 36.

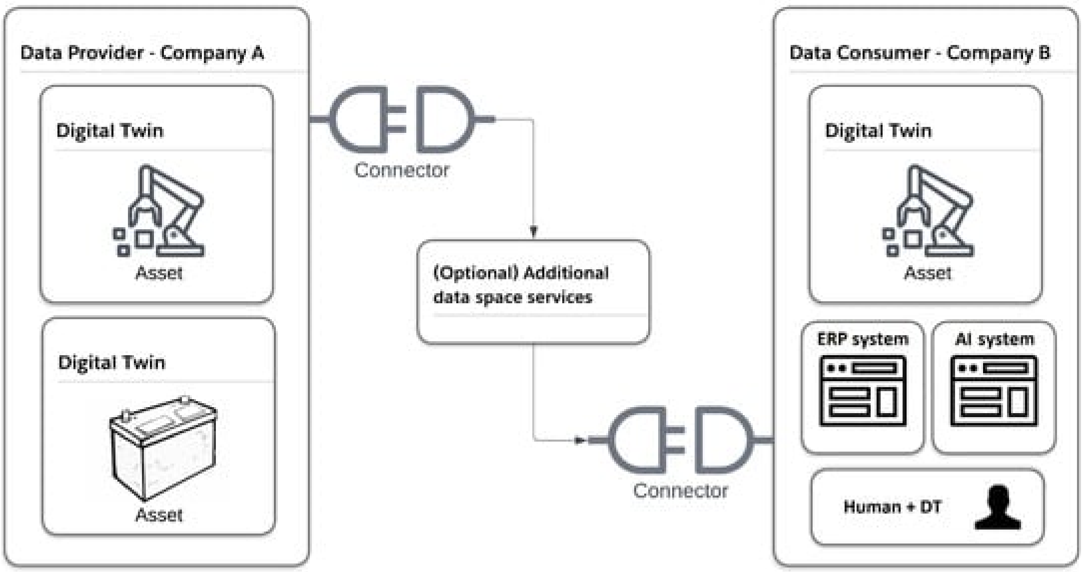

Figure 36: Combination of DT and DS (simplified) [53]

4.3 Discussion

Although the integration between the IDS and PI4.0 initiatives is very important, there are few papers that address this topic at a technical level. In this section, we summarize the results of several papers, e.g. [81], [53], [83], etc., by considering the description of tools and projects in the section “Tools” and section “Projects”.

In all these papers, AASs serve as a common data model and IDS facilitates secure communication and integration between different AAS-based systems. The papers differ mainly in the following aspects:

- the types of IDS connectors considered;
- the generalization of the approach to use any implementation of the AAS specification;
- supporting an AAS provider and an AAS consumer in integrating an AAS with an IDS connection in an automated way.

4.3.1 Type of IDS connectors

There are many types of IDS connectors, as shown by the IDSA Data Connector Report [83]. The following section describes how some of them are used for integration with AASs. In particular, Section 4.3.1.1 explains AASs and Base Connectors, 4.3.1.2 AASs and Trusted Connectors, 4.3.1.3 AASs and Dataspace Connectors, 4.3.1.4 AASs and EDC-based Connectors. Please note that these are example cases and this section is not exhaustive.

4.3.1.1 AASs and Base Connectors

Work on the integration of AAS and IDS connectors was launched a few years ago as part of the Fraunhofer Data Space project [76]. The first attempt was based on an AAS in the form of an OPC UA server, which was developed on the basis of the I4AAS companion specification for AAS-OPC UA integration [84]. The Factory Connector[2] was developed based on the Base connector[3] to provide important IDS functionalities for factories. It requests live data from the OPC UA server with the OPC UA client and returns it in a HTTP response. The asset connection implements the means to read and write, as well as initiating operations on the physical asset via an OPC UA server. In the industrial context, OPC UA is a widespread data model and communication protocol for factory plants. Therefore, by supporting AASs in OPC UA format the Factory Connector combines the advantages of I4.0 and IDS.

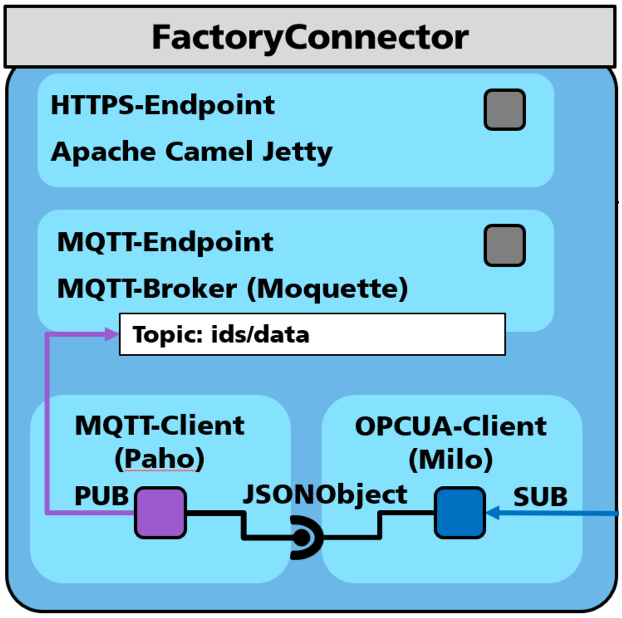

Figure 37: OPC UA-extended AASs and Base Connectors

[2] https://gitlab.cc-asp.fraunhofer.de/volzfr/opc-ua-factory-connector-with-aas/

[3] https://github.com/ids-lab/base-connector (deprecated)

4.3.1.2 AASs and Trusted Connectors

In order to comply with security and trust requirements, the Base connector was replaced with the Trusted Connector[4], which is the reference implementation for a security gateway (DIN SPEC 27070) in IDS. The extensions included data usage control with the IDS Framework “MYDATA Control”, connection to factory assets over OPC UA, MQTT and proprietary asset connections, support for additional AAS serialization formats and types of sources, integration and usage of an AAS registry as well as support for stream analytics by modelling event-based patterns.

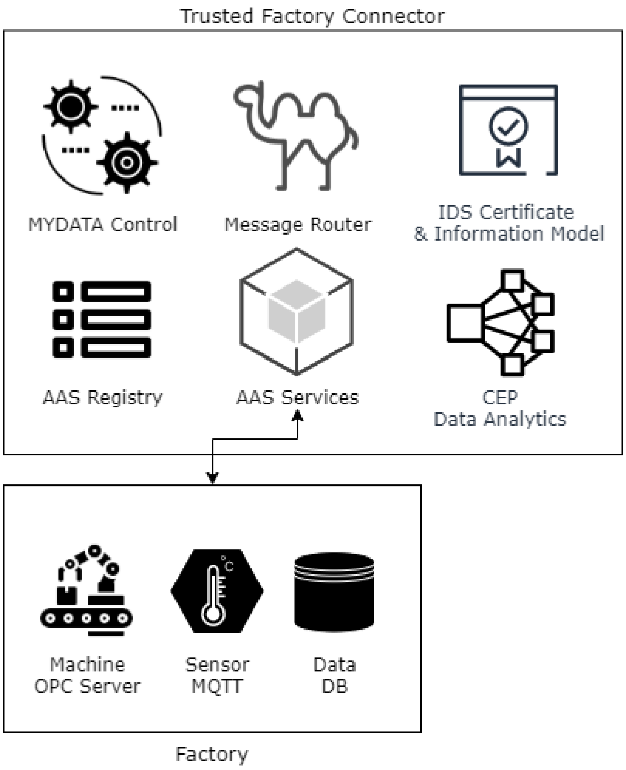

Figure 38: Different types of AASs and Trusted Connector

4.3.1.3 AASs and Dataspace Connectors

Both the AAS specification and the IDS specification are still under development and are attracting the attention of more and more developers. This leads to new developments of IDS connectors and consequently to improvements in the integration between AAS and IDS connectors.

The next step in the evolution was the use of the Dataspace Connector[5] [85] by integrating an AAS into the IDS architecture as an IDS app. Access and usage control, as well as all

[4] https://github.com/Fraunhofer-AISEC/trusted-connector

[5] https://github.com/International-Data-Spaces-Association/DataspaceConnector

security aspects, such as authentication, certificates, and identity management, are then handled by the IDS connector, but not by the AAS. However, IDS connectors communicate over the IDS API, requiring users to deploy an IDS connector for all communication. Data users without IDS knowledge would then be excluded from interacting with the AAS protected by IDS. This will limit users without IDS infrastructure by blocking their access to usage-protected data. The details are described in [86].

Additionally, if data owners require the AAS to implement usage rules, the AAS has to be part of the IDS connector. In the related work, “Shared Digital Twins” [80], based on the RIOTANA® demonstrator, a proprietary DT was put inside the IDS core container while an IDS data app translated the data according to the AAS REST API. Another possibility is that the DT is an independent service (not part of the IDS connector) and where critical data processing tasks are completed by IDS apps inside the IDS connector.

Some examples of the use of the Dataspace connectors are explained in sections “Tools“ and “Projects”.

4.3.1.4 AASs and EDC-based Connectors

In the last two years, the EDC connector has been developed and has attracted an open-source community. There are several versions of it, e.g. one developed as part of the Catena-X project [27]. As could be concluded from sections “Tools“ and “Projects”, more and more partners are using it to realize scenarios that include AASs. We expect that in the future there will be even more tools to support the integration between AASs and EDC connectors and more projects using these tools. One possible solution is shown in Figure 39.

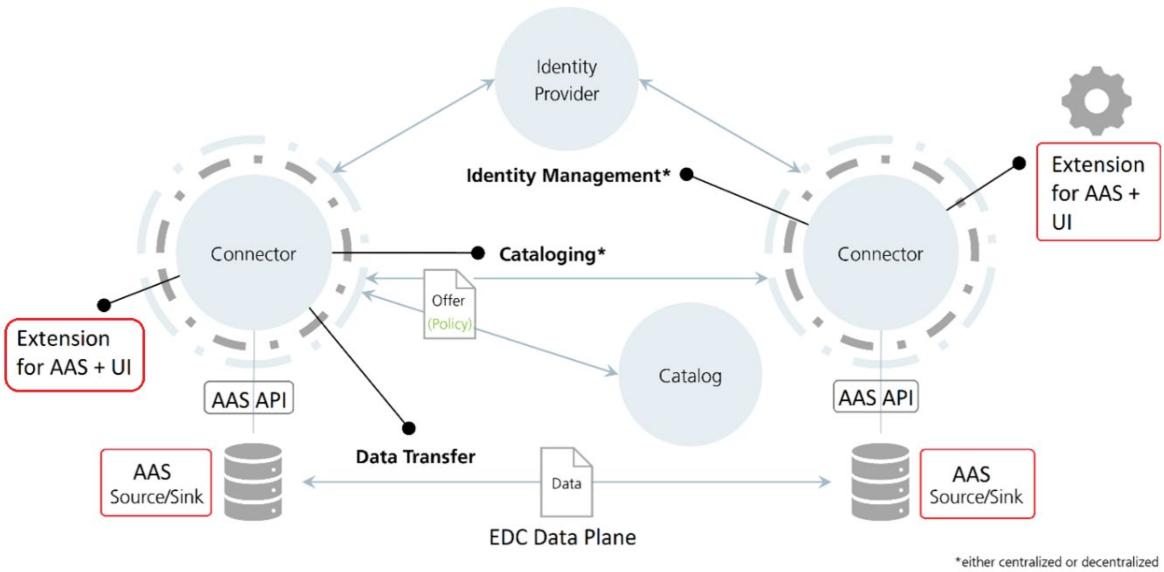

Figure 39: An approach for the integration between the AAS and the EDC connections

We believe that the next step in the improvement of the integration between AASs and EDC connectors would include adaptations to the data-plane of the EDC as this might be necessary or beneficial in different data space use-case and applications. For example, the data- and control-plane in Catena-X [27] was modified with OAuth tokens to incorporate a central authentication system. For the integration of DTs and AAS data sources, the REST data-plane of the EDC can be re-used. However, this has several implications for the consumer:

- The AAS is handled like any REST data source or sink and therefore calling AAS operations or extracting specific datasets is not possible or requires complex configuration of the REST API call;
- The consumer needs to specify the endpoint for each data-transaction, which is a tedious task on submodel-element level. On submodel level, all data values from all the properties are sent and the consumer needs to split up or handle this data in his endpoint.

Therefore, it would be useful to incorporate a modified data-plane with the "EDC Extension for AAS" to support customers requesting AAS data from providers. The final goal would be that two AAS-compliant DTs connected to EDCs are able to communicate without complex EDC onboarding. In most use-cases, consumers request submodels or submodel-elements from a provider. With the REST data-plane, the consumer can request this data to be sent to a consumer endpoint like an AAS viewer. In more complex use-cases like product carbon footprints, it is also required to write relevant data or trigger calculations by operations. In this case, supporting the consumer with a specific AAS data-plane is beneficial. However, we must consider that modifications in the EDC limit the interoperability with other implementations of the EDC. Both the consumer EDC and the provider EDC would need to be aware of such an AAS data-plane. One solution could be backwards-compatibility of data-planes or the usage of multiple data-planes. The technical challenge is to provide maximum support and functionality to the consumer and provider while keeping interoperability and compliance to the specifications.

The usage of extensions and adaptation to the data- and control-plane allows the EDC to be deployed and used in different use-cases and data spaces. However, because of this, it is not guaranteed that two specific EDC implementations are compatible with each other. For example, because of the addition of OAuth to the Catena-X EDC, the EDC with a base control- and data-plane would not be compatible. While the base REST data-plane offers the highest interoperability, the previously mentioned drawbacks might limit AAS usage. Therefore, a reference implementation for AAS data- and control-planes should be proposed.

4.3.2 AAS-related aspects

4.3.2.1 AAS implementations

Almost all tools and projects for the integration between AAS and IDS connectors consider only one implementation to realize the AAS, viz. Basyx [23]. There is only one proposal [53], which is designed to be open to any AAS implementation that supports version 3.0 of the metamodel.

However, since almost all AAS implementations known to us are currently working on supporting the latest version of the specification, it can be assumed that they will be interoperable in the future. This would mean that in the future an AAS can be realized by any standard-compliant AAS implementation and interoperability will be guaranteed.

4.3.2.2 AAS registry

As already mentioned in sections “Tools“ and “Projects”, there are several approaches that take an AAS registry into account when realizing the integration between an AAS and an IDS connector.

For example, an AAS Registry could play an important role in discovery and publication of AASs available only over EDCs. In the case of Catena-X [27], a Digital Twin Registry [87] based on the AAS Registry specification with additions for EDC endpoints is used. This allows the discovery and publication of AAS through the Registry. However, all participants need to be aware of the additional endpoint definitions. Because of this, Catena-X in itself is a standard [37] based on AAS and IDS, but with key changes not found in other data spaces. This is also the case if the EDC Asset describing the AAS is extended with specific AAS meta-data since all participants need to understand the additional meta-data. The approach explained in [53] had no key changes to the components of the AAS or the EDC by describing each AAS element as a common EDC Asset. However, the implementation of discovery and publication of AAS could require such adaptations in either the AAS or EDC.

4.3.2.3 Where to deploy an AAS?

The next issue is where an AAS is deployed: in a connector or externally. The combination of AAS-compliant DTs with the IDS has also been tested in several projects such as RIOTANA by Fraunhofer ISST / IAIS [80]. In most cases, the DT is either placed directly into the IDS connector (service container) or an IDS app is used to act as a proxy. Since the IDS connector only understands IDS messages, specific clients (other IDS connectors or web-based GUI) are necessary to communicate with the DT. On the plus side, usage policies can be effectively applied inside of the connector. However, partners without IDS background cannot access the DT resulting in a split: data-sovereign DTs inside the IDS and DTs without usage control.

In [81], the authors focused on keeping the DT outside of the IDS connector while extracting functionality in need of usage control inside of IDS apps. For example, critical production data inside of a DT is sent to an IDS app analyzing this data and can then be viewed by partners in an IDS visualization app. This combination means that it is still possible to provide DTs without usage control for partners without IDS knowledge, while also providing critical data for IDS apps processing it according to defined usage rules.

The EDC architecture is also proposing data sources/sinks, in this case AAS, outside the IDS connector by implementing a connector data-plane directly between the AAS.

4.3.3 Usability issue

The integration between an AAS and an IDS connector still requires deep knowledge of both. There are some attempts to "automate" this process by guiding a user through the onboarding process, e.g. by providing a user interface for AAS providers/consumers, etc. Additionally, providing a connector as a service is not enough as it does not fully cover the AAS API, e.g. the AAS operations.

Therefore, the usability of existing solutions needs to be further improved. The tools must be made more accessible and user-friendly, especially for users with limited knowledge of the underlying specifications. This includes not only a better understanding of the target users, their needs and their level of knowledge and/or a simple and intuitive design of the user interface, e.g. by presenting information gradually. It is even more important that the onboarding process runs smoothly, e.g. by breaking down complex tasks into smaller, manageable steps and performing as many steps as possible (semi-)automatically.

4.4 Examples of the integration of IDS and I4.0 components other than IDS connectors and AASs

In this section, we give some examples of results already achieved with regard to the integration of IDS and I4.0 components for the data value-added building blocks.

4.4.1 FDS Project “Synergy between AAS Registry and IDS Broker”

In the Fraunhofer data space (FDS) project “Synergy between AAS Registry and IDS Broker” [76], a component was developed that combines the IDS Metadata Broker and the AAS Registry.

A triple store is used for data persistence, in which both the AASs registered in the registry and the connectors registered in the broker are stored. The broker and the registry also share a common endpoint to which both IDS messages and AAS registry messages can be sent. A reverse proxy then checks which type of message it is and forwards it to the broker or registry accordingly. Furthermore, a mapping of AAS descriptors into the IDS connector self-description is necessary, whereby on the one hand IDS-specific information is linked with that of the AAS and on the other hand AAS can be registered and searched for via the broker. By combining the broker and the registry, the following functionality is now possible, which could not be realized before:

- An AAS that is deployed in an IDS connector can register the IDS connector in the broker and the AAS in the registry at the same time with just one message and can be found both by users who have no knowledge of AASs via the broker and by users who have no knowledge of the IDS via the registry.
- The broker can now be used to search specifically for AASs and also find those that are not deployed in an IDS connector. AASs can even be filtered according to more search criteria. This is because the Registry API only allows a search for specific information that occurs in an AAS descriptor. However, as the search queries to the broker are based on Sparql, all information contained in an AAS descriptor can also be included in the search.
- The broker can be used to submit search queries that combine specific knowledge from the AAS and the IDS. For example, it is possible to search for all AASs in an IDS connector with specific usage policies that have a submodel that implements a specific submodel template.

The proposed approach is shown in Figure 40. IDS Messages are processed by the IDS Message Handler module, AAS requests by the AAS Registry. The single, consistent data storage across both specifications requires a complete mapping from one representation into the other. However, there is no need for synchronization between two worlds.

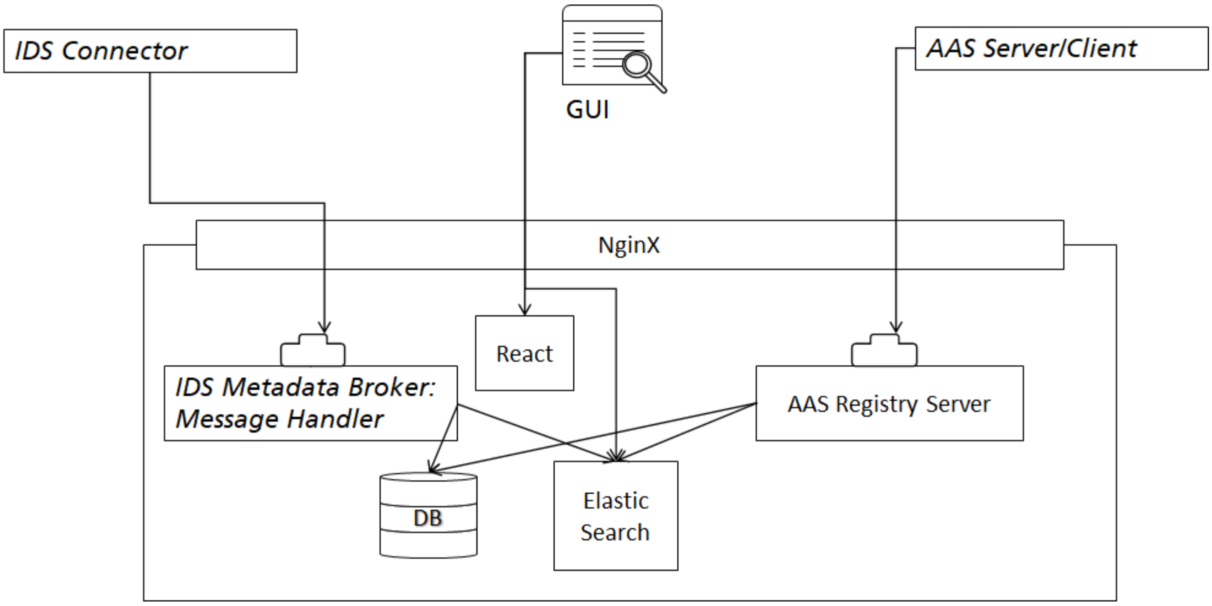

Figure 40: Metadata Broker and AAS Registry share one DB

4.4.2 FDS Project "IDS Vocabulary Provider - AAS Semantification"

In data spaces, semantics can also be described in the metadata of the offered data resources. In order to resolve the semantic description, the IDS Vocabulary Provider is a special connector that can be queried for the required semantic description. It can host several vocabularies and ontologies used in annotations and descriptions of data.

The goal of the FDS project "IDS Vocabulary Provider – AAS Semantification" [76] was to leverage this component to add missing semantic IDs in an AAS. Since the IDS Vocabulary Provider hosts several vocabularies and ontologies, it can be queried when an AAS is shared over a connector. For example, consider an AAS with an element "tire" that is shared without describing it with a semantic ID. In this case, the IDS Vocabulary Provider can be queried to find a suitable semantic ID based on the context of the AAS. The context might be the asset of the AAS or surrounding elements which are then used to find a suitable vocabulary or ontology. Following the "tire" example, the asset might be of type "railborne vehicle", allowing the resolution in the eClass vocabulary as "28-04-07-07 Wheel tire". The approach can include simple string or AI supported matching. This matching can happen before the data is offered or during data transit in the data space. However, we strongly suggest making use of submodel templates and semantic IDs before the AAS is shared to enable browsing for suitable data resources.

Figure 41 shows the use case of collaborative condition monitoring "machining process", where various machines work together according to certain rules. These machines are described in assets and with values using the AAS. Machine A requests "a temperature value" from machine B by using an IDS message on stream maybe (here we request an AAS element by sending an IDS RequestMessage to the corresponding DSC/EDS asset). IDS messages can be sent back from machine B, but machine A requests the SemanticID of the temperature field. If the semantic meaning is not present in the AAS of machine B, machine A/B or the FA³ST AAS service at the backend triggers an IDS message to the vocabulary provider, which returns a description of the temperature.

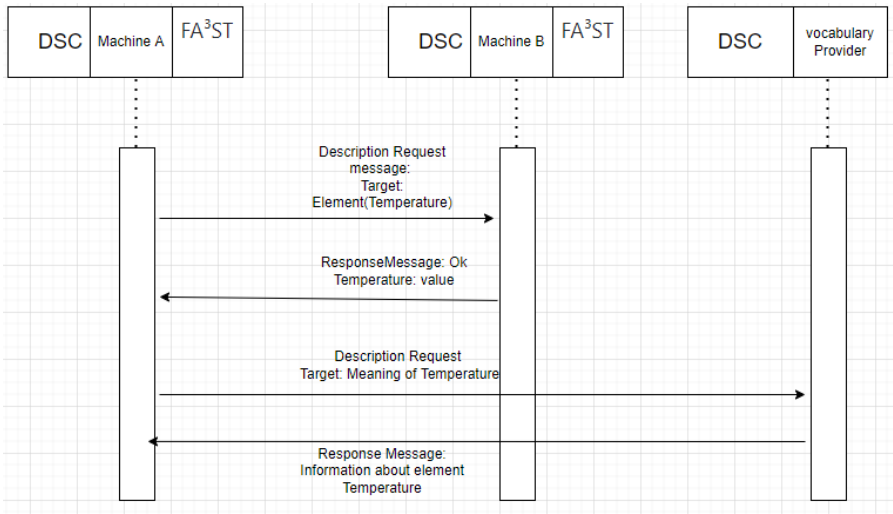

Figure 41: Use case „Collaborative Condition Monitoring"

A data consumer's connector can (programmatically) query the IDS Vocabulary Provider by issuing a QueryMessage. This can be triggered after the AAS service has checked whether semantic IDs are not available (an endpoint is required for the connector and the event is triggered by an AAS service). However, this needs to be extended to accept elements (= data set itself). This option has an advantage over REST or GUI as it takes full IDS security and confidentiality into account. It also requires a return channel for the results. Annotated result data is sent as ResultMessage to DSC/EDC and thus to the AAS service.

```
<https://admin-shell.io/aas/3/0/RC01/Submodel/submodelElement> [
    a <https://admin-shell.io/aas/3/0/RC01/Property> ;
    rdfs:label "Temperature"^^xsd:string ;
    ];
    <https://admin-shell.io/aas/3/0/RC01/Submodel/submodelElement> [
    a <https://admin-shell.io/aas/3/0/RC01/Property> ;
    rdfs:label "Temperature"^^xsd:string ;
    rdfs:seeAlso <https://saref.etsi.org/core/TemperatureSensor>
    rdfs:comment "IEC 61360 AAA110 - temperature sensor"^^xsd:string ;
    ];
```

Figure 42: Extended description

5 Summary

IDS-I comprises an international community of industrial partners that unites more than 70 organizations from around the world. It is a verticalization community of the International Data Spaces Association (IDSA).

The IDS-I objective is to analyze the mapping of IDS concepts and principles of data sovereignty to the requirements of the industrial sector. In this sense, the mission of the IDS Industrial Community is:

- To gather requirements on data sovereignty incl. data sharing, data usage monitoring and control as well as data provenance tracking by means of reference use case specifications.
- To map these requirements systematically to the standards, capabilities and recommended technologies of IDSA and PI 4.0.
- To derive profiles of IDS/Industrie 4.0 specifications that support the requirements in industrial business eco-systems based upon standards and by means of common governance models.
- To validate and demonstrate the applicability of these specifications by means of reference testbeds.
- To contribute to the outreach of the IDS architecture and specifications into the community of industrial production and smart manufacturing.

This position paper is the 3rd in this series. It aims to provide an overview of how the main IDS and I4.0 concepts and tools have been integrated so far, and to provide insights into the results of research projects related to IDS and I4.0 joint use. More importantly, this position paper makes recommendations on how different technologies can be combined in a generic way, independent of the specific implementation of IDS and/or I4.0 relevant technology components.

The approaches shown in this paper as well as the project results like e.g. Catena-X architecture will probably be reused for further initiatives. The European Data Strategy includes several acts and initiatives to foster a data economy. For instance, the European Data Act [88] "lays down harmonized rules on making data generated by the use of a product or related service available to the user of that product or service,…". It aims at any economic sector. Hence, based upon the Catena-X principles and technologies, there is an add-on initiative of the Platform Industrie 4.0 in their ambition to create a DataSpace Industrie 4.0. This initiative is entitled Manufacturing-X [89] and is a cross-industry initiative as illustrated in Figure 43. It is brought forward by a dedicated call for tender of the German Ministry for Economics and Climate Action. The first projects will start in January 2024.

Figure 43: Sectors addressed by Manufacturing-X [Source: Platform Industrie 4.0]

Although trigger by the German Platform Industrie 4.0, Manufacturing-X aims, from the very beginning, at being a global initiative. Due to the global scope of the industrial supply chains, the aspects of resiliency and sustainability can only be solved if the major global industrial sites follow the same principles and technologies for data sharing. In order to operationalize this global idea, an International Manufacturing-X Council (IM-X) was created. The collective vision for the IM-X Council is to enable open, global and cross-industry operation of cost-effective data networks. As of today, it encompassed the following countries and initiatives (alphabetical order) [90]:

- Australia (CSIRO Data61)
- Austria (Plattform Industrie 4.0 Österreich)
- Canada (Offensive de Transformation Numérique)
- France (Alliance Industrie du Futur)
- Germany (Plattform Industrie 4.0)
- Italy (Confindustria)
- Japan (RRI)
- Netherlands (Smart Industry).
- South Korea (KOSMO)
- United States of America (CESMII).

Additionally, the next step is to provide an experimental environment to test such results. The first implementation has already been performed with the FESTO demonstrator at the

Karlsruhe Research Factory for AI-integrated Production[6]. The demonstrator includes multiple AASs (e.g., for the inspection line, for the products, for the robots, etc.) and the EDC connectors that enable interoperable, secure exchange of AAS compliant DTs to support the reference use cases such as the collaborative condition monitoring and manufacturing as a service.

Additional work is ongoing to implement more AASs using various available AAS open-source implementations. Further experiments with different connectors that support easy AAS integration will also be performed.

In parallel, the demonstrator will be extended with additional hardware components and sensors to support use cases related to circularity. The goal is to provide a data space for circular economy based on AAS-compliant DPPs, including tool support for SMEs to (i) easily create AASs (e.g., for assets or processes) and AAS-compliant DPPs, (ii) exchange them via the data space for circularity, and (iii) use advanced circularity-related services based on AASs, etc. without requiring deep knowledge of the underlying I4.0 and IDS technologies.

For more information, please contact the authors or join the IDS-Industrial (IDS-I) Community by expressing your interest in an email to info@internationaldataspaces.org.

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