Whitepaper

Joint Integration Architecture Approach of Catena-X & OPC UA

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Introduction

Improving supply chain and shop-floor integration is a business imperative in today's hyper-connected world. Bringing shopfloor and corporate IT information together in an automated information flow is mandatory, as, for example, the Digital Product Passport (DPP) demonstrates. The Ecodesign for Sustainable Products Regulation (ESPR) and the European battery regulation mandate the creation of an EU-wide IT approach that will allow the massive field collection of technically specific information from each battery instance greater than 2.0kWh that is placed in the EU market. Such a DPP IT system is expected to come into effect in 2027.

The Catena-X Automotive Network has been established to address critical challenges in the automotive supply chain — namely resiliency, sustainability, and efficiency. It does so by enabling collaborative data sharing, based on the principles of data spaces. These data spaces offer trusted environments for cross-company data exchange, grounded in both multi-organizational, multi-policy agreements, and a technical infrastructure that ensures secure, sovereign data sharing — even between unknown participants.

Catena-X leverages a suite of core technologies to realize this vision, including:

- Decentralized data spaces using the Eclipse Dataspace Components (EDC) Connector
- Semantic interoperability through standardized data models
- Identity, Access & Policy Management (IAM) for trusted, secure, policy-driven data access
- Traceability and compliance frameworks to support regulation and quality assurance

These capabilities enable trusted, sovereign data exchange, while maintaining participant autonomy.

The OPC Foundation is the world's largest, international industry organization that develops and maintains open, vendor-independent standards - most notably, OPC Unified Architecture (OPC UA) - for secure and semantically interoperable information exchange in industrial automation and beyond. OPC UA has been available since 2006, addressing the use cases of factory automation and process automation, all the while scaling from field to cloud. Over the last 20 years, the OPC Foundation has partnered with many domain experts, consortia, and associations to "digitalize" actionable manufacturing knowledge via Companion Specifications (CS). Over 160 Companion Specifications have been released, such as those for machine tooling, plastics, energy, wood working, oil & gas, food & beverages, and many more industry verticals. The CSs are information models, which can be used in applications or services, or be embedded in industrial assets like machines, controllers, and robots providing "controllable" interfaces to the asset. OPC UA provides client/server-type communication and deterministic mission critical communication with OPC UA FX (OPC UA PubSub over UDP/TSN). In addition, transmitting OPC UA data and metadata to the cloud has been standardized with OPC UA PubSub over MQTT and AMQP (and more recently also over Kafka). Furthermore, OPC UA can be used as a modelling language for Asset Administration Shell (AAS) submodels.

Bringing both concepts together into a joint reference architecture will complement interoperability of data exchange from shopfloor processes up to horizontal supply chain integration.

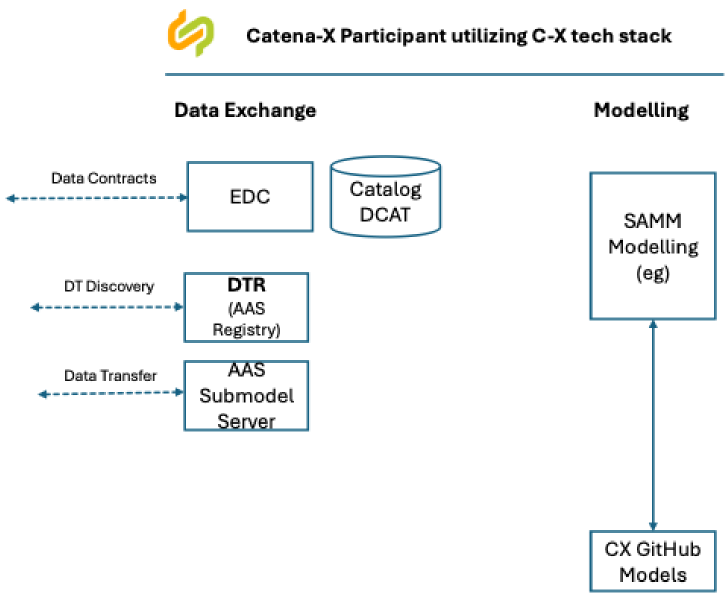
In order to achieve interoperability, the following concepts will be used in this whitepaper:

- Tractus-X Eclipse Dataspace Components (Eclipse Tractus-X Component)
- Asset Administration Shell (AAS) HTTP REST interface from the Industrial Digital Twin Association (IDTA) and Platform Industry 4.0
- Open Platform Communications Unified Architecture (OPC UA) modelling language

We assume the reader has a general understanding of the concepts mentioned above.

Overall Architecture Components

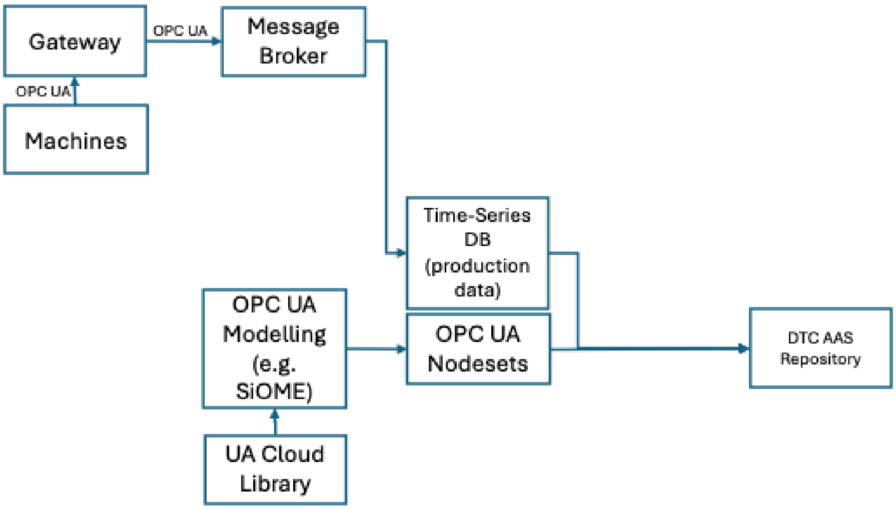
The Catena-X architecture is based on a few components that define how data is being exchanged in the Catena-X ecosystem. A data provider models the data it intends to offer to the ecosystem via the Semantic Asset Modelling Methodology (SAMM). SAMM provides a metamodel on how to define submodels that are compliant to the Asset Administration Shell (AAS) metamodel specification. These submodels describe standardized data semantics within Catena-X and are physically stored in a GitHub repository (https://github.com/eclipse-tractusx/sldt-semantic-models)



From a data exchange perspective, Catena-X utilizes 3 core components, which are typically referred to as “Enablement Services”:

1) **Eclipse Dataspace Components (EDC)**
   A mechanism to discover data offers from a catalog and to negotiate data contracts based on usage policies between provider and consumer.
2) **Digital Twin Registry (DTR)**
   A registry component, as part of the AAS specification (“AAS Registry”), that allows discovery of specific addresses (API endpoint locations) of a requested submodel.
3) **AAS Submodel Server**
   An implementation of an AAS-compliant API (AAS HTTP REST) to retrieve submodel data from various sources. Catena-X follows a decentralized approach for data sovereignty and modular distribution of data. The submodel service can be implemented as a stand-alone component or as an AAS-compliant API in an existing PLM or ERP system.

Over the last years, the OPC Foundation Cloud Reference Architecture has been enhanced to provide secure, standardized data ingestion from on-premises machine data via gateway and message broker components into a time series database in the cloud, as well as standardized data integration for data exchange along manufacturing supply chains.



With the OPC Foundation Cloud Initiative, best practices are used to create a cloud reference architecture, increasing standardized data sharing and cloud-optimized, OPC UA-enabled services. In addition, a mechanism to model Asset Administration Shells (AAS), with the OPC UA modelling language, has been created.

The OPC UA information models can be provided in an online store, namely, the UA Cloud Library. This library is operated publicly by the OPC Foundation or as a private instance by the individual manufacturers.

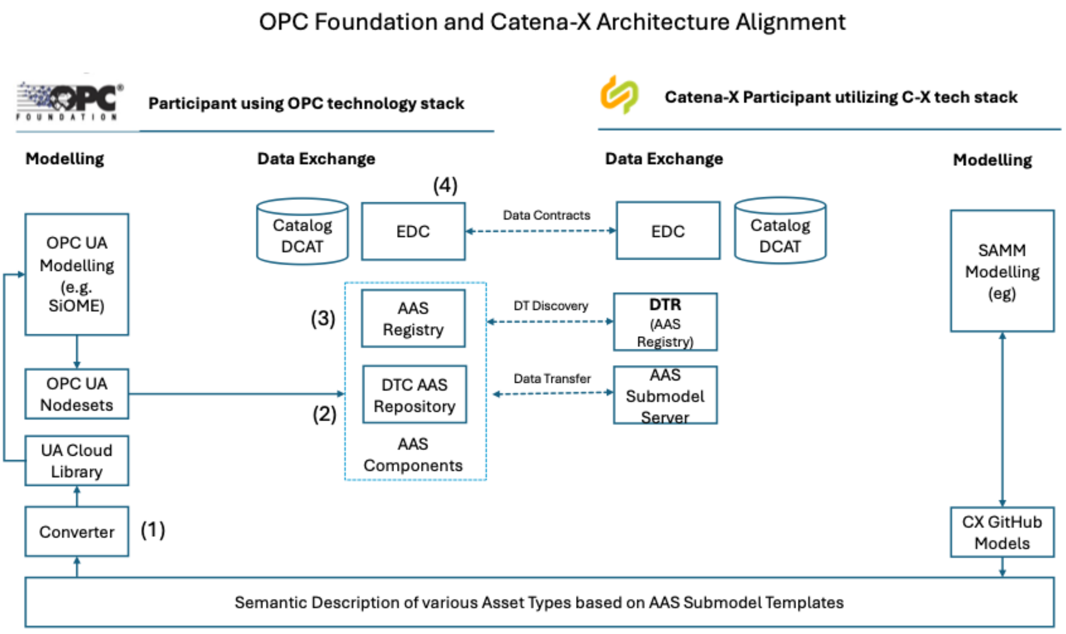
To combine the power of the OPC Foundation and Catena-X in an interoperable fashion, the following components are relevant:

1) **UA Cloud Library**
   A query-able online store of OPC UA information models
2) **Time series DB**
   Retrieved telemetry data from the production lines
3) **DTC AAS Repository**
   Supports loading AAS shells modelled with OPC UA and provides OPC UA APIs as well as AAS APIs

Bringing it all together

Combining both approaches provides the opportunity to model shop floor data in the same way as supply chain data. In addition, Digital Product Passports (DPPs) can more easily combine data from classical ERP systems, but also from MES systems or production line components.

The schematic below shows how an enterprise that has already invested in OPC UA technology can now easily integrate with Catena-X technology.



From a modelling perspective, AAS compliant submodels can be utilized. Via a converter component (1), these models can be converted into OPC UA Nodesets, stored in the UA Cloud Library, and maintained with OPC UA modelling tools, like BeeondEdgeXStudio or Siemens OPC UA Modelling Editor (SiOME).

Via the DTC AAS Repository (provided by the Digital Twin Consortium), data can be made accessible through OPC UA in an AAS compliant way (2).

The discovery of digital twin submodels will be provided by respective AAS Registry components (3).

Finally, data offerings can be created in EDC and published in a catalog via Data Catalog Vocabulary (DCAT), which is a well-established W3C standard (4).

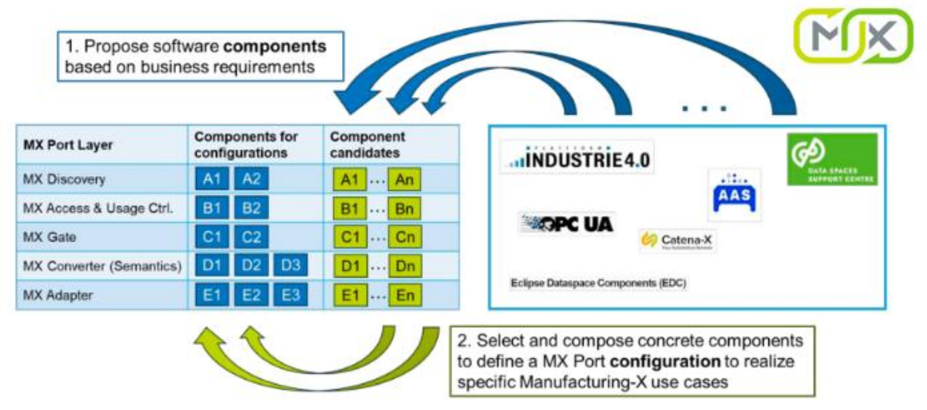
In a nutshell, the communication in a dataspace like Catena-X, may then be executed in the following way:

- EDC manages the discovery and usage control aspects of the data exchange
- DCAT describes data sets semantically for discoverability via EDC
- AAS Registry manages the links to available digital twins and their submodel URLs
- AAS Submodel Server (a.k.a. AAS Repository) provides the actual data via REST APIs (e.g. product carbon footprint, telemetry data)

Alignment with other initiatives

Even though Catena-X, which is focused on the Automotive industry, was a front runner, there are various other dataspace-oriented initiatives catering to other industry verticals like Aerospace-X, Semiconductor-X or Factory-X. All these initiatives collaborate on common concepts under the Manufacturing-X umbrella to foster interoperability across the different "-X" programs.

In Factory-X, an integration concept was developed to cater to different integration scenarios and use cases, which is called "MX Port". It conceptually describes five layers in any given integration that shall be implemented: Discovery, Access & Usage Control, Gate, Converter, Adapter:



These layers can be implemented by using different protocols & technology components. Each defined combination of components is called a configuration (Hercules, Orion – see below).

Layer	MX-Port "Hercules"
MX Discovery	Data Space Protocol / Decentral Claims Protocol
MX Access & Usage Ctrl.	
MX Gate	AAS-REST
MX Converter	AAS sub model
MX Adapter	application specific

Layer	MX-Port "Orion"
MX Discovery	Data Space Protocol / Decentral Claims Protocol
MX Access & Usage Ctrl.	
MX Gate	UADP, OPC UA TCP, HTTP(S), NetConf
MX Converter	OPC UA Companion Spec, OPC UA Meta Model
MX Adapter	application specific

These configurations utilize the same components this whitepaper has described.
By applying the concepts outlined in this whitepaper, the currently-implemented Catena-X architecture will be complemented by rich OPC UA functionality, in line with the concepts outlined in Manufacturing-X.

Summary

The increasing complexity of global supply chains and manufacturing ecosystems demands robust, scalable, and standardized data integration frameworks. Regulatory mandates, such as the EU Digital Product Passport (DPP), underscore the necessity of interoperable, end-to-end data architectures that span from shopfloor operations to enterprise-level supply chain networks.

Catena-X addresses these needs by enabling sovereign, decentralized data sharing across the automotive supply chain and beyond. Built on principles of trusted data spaces, Catena-X ensures secure and policy-compliant data exchange between partners, even in multi-organizational, multi-policy environments.

Simultaneously, OPC UA offers a mature, widely adopted framework for industrial interoperability, providing consistent information models across diverse manufacturing domains. Through the OPC Foundation Cloud Initiative, OPC UA now extends its reach to cloud-native architectures.

The integration of Catena-X and OPC UA delivers a comprehensive reference architecture that bridges the gap between standardized data generation and standardized data utilization. This joint architecture enables:

- The transformation of AAS-compliant submodels into OPC UA NodeSets via dedicated converters
- Publication and management of OPC UA information models through the UA Cloud Library
- Seamless interoperability using the DTC AAS Repository, providing both OPC UA and AAS-compliant APIs

Together, these components facilitate the creation of rich, cross-domain digital twins that unify production data with lifecycle and supply chain information. Enterprises that have already deployed OPC UA can leverage this existing knowledge to rapidly onboard into Catena-X ecosystems, preserving existing investments while extending interoperability.

This integrated framework marks a significant milestone but also represents only the starting point. As regulatory, sustainability, and business pressures continue to evolve, the fusion of Catena-X and OPC UA provides a scalable foundation for the future of data-driven, resilient, and sustainable manufacturing ecosystems.