Asset Administration Shell Generation and Usage for Digital Twins: A Case Study for Non-destructive Testing

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Abstract: In a real manufacturing site, containing non-destructive testing machinery components and sensors, we have implemented and validated Asset Administration Shell, using different tools and technologies. The tools included emerging technologies-related tools, such as Administration Shell IO, Eclipse BaSyx, and low code programming software for event-driven applications, namely Apache StreamPipes and Node-RED. We have also developed International Data Spaces connectors for data exchange using previously created Asset Administration Shells. All of the implementations in the case study have been implemented by the same developer, the first author, while the developed outputs have been verified and validated by different various testers. In this paper, we present the emerging digital twin technologies, and share different solution architectures using these technologies for the purpose of secure, standard and interoperable digital twin solutions, and data exchange between different International Data Spaces connectors. We conclude that the presented designs are easy to implement. We found Admin Shell IO to be easier to use than the Eclipse BaSyX. Our future studies will contain the use of Fraunhofer Advanced Asset Administration Shell Tools for digital twin development in the same environment, and a comparison of the implementations using different methodologies and tools.

1 INTRODUCTION

With the evolution of technology, changes in smart manufacturing and society are accelerating at unexpected paces (Boss, et. al. 2020). Industry 4.0 brings new challenges regarding the automatization of IoT networks to perform information exchange in a timely, reliable and uniform way (Alonso, et. al. 2018). Digital twins are known to be key enables for various IoT and Industry 4.0 use cases (Boss, et. al. 2020, Albayrak and Ünal, 2020, Unal, et. al., 2022).

IoT focuses on connecting physical devices to the internet, and collecting telemetry data, while Digital Twins focus on organizing the collected data and representing it in a standard way to enable the application of Artificial Intelligence and business rules on this data (Jacoby, et. al, 2022). Internet of Things (IoT) devices could utilize communication protocols compliant with Industry 4.0 (such as MQTT, REST, and AMQP).

Without their interoperability, integrating all of these protocols with various data structures would require significant effort, and their potential would not be fully exploited (Pribiš, et. al., 2021). Plattform Industrie 4.0 made interoperability one of its strategic fields for 2030 (Boss, et. al. 2020). Interoperability enables cooperation and open ecosystems that permit plurality and flexibility. In order to realize interoperability, standards, decentralized systems, integration, and a uniform regulatory framework, are needed (14 in Boss, et. al. 2020).

Asset Administration Shell appears to be the key concept of Platform Industrie 4.0 in order to enable interoperability. The AAS can directly be adopted to implement Digital Twins. As a result, all industries may benefit from an open and standardized meta-model, standardized data models with homogenized

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semantics and standardized APIs and infrastructure services.

It is also a fact that Industry and Non-Destructive Evaluation (NDE) are growing together with the fourth industrial revolution. It will eventually lead to improved awareness of NDE (Vrana, et.al. 2021). This article aims to implement the key emerging technologies regarding Digital Twins and apply them in a real manufacturing site's non-destructive testing environment. The technologies validated are AAS and IDS.

The organization of the rest of the paper is as follows: Section 2 presents background information related to the emerging technologies that are associated with Digital Twins. The technologies/tools used and presented in this study are Asset Administration Shell (AAS), Eclipse BaSyx and International Data Spaces (IDS). Section 3 summarizes the case study conducted by describing the environment of the case study and the work performed by using the already briefed technologies and tools. Finally, Section 4 concludes the study, and presents future research to be conducted

2 BACKGROUNDS

Being the digitalization of manufacturing, Industry 4.0 integrates processes, devices, workers, products, and all other relevant assets in one unified digital system, and defines the domain of smart manufacturing (Eclipse BaSyx). For Industry 4.0, the term asset refers to any object that has value for an organization. Assets in Industry 4.0 can be a production system, a product, a software installation, intellectual properties or human resources (AAS, 2022).

Assets have a logical representation in the "information world", and they are managed by information technologies systems. Hence, an asset has to be identified as an entity, has a specific state within its life, has communication capabilities, is represented by means of information, and is able to provide technical functionality. This logical representation of an asset is called Administration Shell (AAS, 2022). The combination of asset and Administration Shell forms the so-called Industry 4.0 Component. In international papers, the term smart manufacturing is also used for the term Industry 4.0.

2.1 Asset Administration Shell

The Asset Administration Shell (AAS) is the standardized digital representation of the asset, and also is an important element of the interoperability between the applications managing the manufacturing systems. AAS proposes a standardized electronic representation of industrial assets enabling Digital Twins and interoperability between automated industrial systems and Cyber-Physical Systems (CPS) (Iñigo, et. al. 2020). AAS, the concept was introduced to provide data and information in a standardized, and semantically described manner, in order to enable interoperability and easy interaction (Fuchs, et.al. 2019). Thus, AAS is considered as being one of the key components of Industry 4.0 (Tantik and Anderl, 2017a, Bader and Maleshkova, 2019, Marcan, et. al., 2018, Ye, et. al., 2021).

AAS needs to provide a minimal and sufficient description according to the different application scenarios in Industry 4.0 (AAS, 2022). Different standards, consortium and manufacturer specifications can contribute to this definition. Capturing the information about the AAS itself, AAS can be taken as the digital representation or Digital Twin of the Asset (Bader and Maleshkova, 2019).

The AAS is composed of a series of sub-models (AAS, 2022). Each of these sub-models represents a different aspect of the asset under consideration. The sub-models may contain a description relating to safety or security and also outline various process capabilities such as assembling and process control.

AAS does not prescribe what content it contains. Content is modelled by means of sub-models. Implementation of the Administration Shell security has to be together with the implementation of other components. Each sub-model of AAS contains a structured quantity of properties that can refer to data and functions. A standardized format based on IEC 61360-1/ ISO 13584-42 is envisaged for the properties. Data and functions may be available in various complementary formats. The properties of all the sub-models result in a constantly readable directory of the key information of the Administration Shell.

In order to enable binding semantics, Administration Shells, assets, sub-models and properties must all be identified. Global identifiers that can be utilized are IRDI (e.g. in ISO TS 29002-5, ECLASS and IEC Common Data Dictionaries) and URIs (Unique Resource Identifiers, e.g. for ontologies). It should be possible to filter elements of the Administration Shell or sub-models according to different given views.

There are three types of AAS specified:

Type 1 or Passive AAS is a static file serialized as JSON, AXML or AASX. In order to exchange information, the file needs to be passed by manually.

Type 2 or Reactive AAS is a software component where information exchange is realized automatically by means of external software that communicates with the AAS by means of API utilization. Finally, Type 3 or Proactive AAS is a software component that supports communication via I4.0 languages, where information exchange is realized via direct communication among AASs (Jacoby, et.al., 2022).

Every AAS must be secure (Boss, et. al. 2020). Access permission rules can be defined to describe the permissions an authenticated subject has on which object.

Tantik and Anderl wrote the potential of AAS for Service Oriented businesses, and concluded that future use cases which include applications for monitoring and remote control of the entity would not be challenging (Tantik and Anderl, 2017a). The authors also stated that with AAS using a standardized external interface, seamless interoperability would be possible. Mohr, et. al. conducted a case study with AAS to present interoperable digital twins in the IIoT system (Mohr, et.al., 2019).

A semantic AAS was developed (Bader and Maleshkova, 2019). Information provided by an AAS can be adopted during the whole life cycle of a production system (Cavalieri and Salafia, 2020). The authors presented the use of AAS metamodel in order to represent an IEC 61131-3 program and its relationships with the real plant controlled (Cavalieri and Salafia, 2020). AAS integrated with PLM/ALM was demonstrated (Deuter and Imort, 2020).

While some researchers presented a methodology of AAS implementation into an embedded system, showing dramatically reduced system requirements (Pribiš, et. al., 2021), and Casado and Eichelberger (2021) presented resource monitoring with micrometer and AAS. Park, et. al. 2021, proposed Virtual REpresentation for a DIgital twin application (VREDI): an asset description for the operation procedures of a work-center-level digital twin application.

Having briefed what AAS is, and provided an overview of some of the ASS related studies conducted, the next subsection list two of the AAS tools that are utilized in the case study: Administration Shell IO, and Eclipse BaSyx. The selection of the tools was based on the authors' subjective estimation of the tools' level of recognition in the community and the projects' maturity levels.

2.2 AAS Tools

The top-level project "Digital Twin" of the Eclipse Foundation is the home of many projects that are related to the AAS (Eclipse Digital Twin, 2022). The Eclipse Digital Twin Top-Level Project provides a space for open-source projects to produce implementations, and increase the adoption of solutions, prototypes and supporting software to build and consume information from digital twins (Eclipse Digital Twin, 2022). The Top-Level Project supports the ecosystem orchestrated by the Industrial Digital Twin Association (IDTA) (Eclipse Digital Twin, 2022).

As stated by Tantik and Anderl (2017b), the Industry 4.0 components can be enabled to manage the production process autonomously, and additional applications will be implemented into the AAS to increase their functionality.

Within the scope of this study, developments have been conducted using Admin-Shell-IO and BaSyx open-source projects. As low-code software development tools Apache StreamPipes and Node-RED have been utilized (Apache StreamPipes, Node-RED).

2.2.1 Admin Shell IO

Admin Shell IO offers software to create AAS and display the generated AAS on the UI screen. The Admin Shell IO software is composed of: AASX Package Manager, and AASX Server. The Eclipse AASX Package Explorer application of Admin Shell IO is used to create and view AAS. While, the AASX-Server application keeps the AAS that is generated by the AASX-Server Package Manager on a server, provides the visualization of the AAS, sub-model and sub-model elements by means of the UI screen. UI provides ease of use for Admin Shell IO.

The Eclipse AASX Package Explorer is an open-source browser and editor for creating AASs as .aasx packages. The Eclipse AASX Package Explorer is a tool with a graphical user interface aimed at experimenting and demonstrating the potential of AASs targeting the different levels of users, ranging from tech-savvy to less technically-inclined users.

The Eclipse AASX Package Explorer includes an internal REST server and OPC UA server for the loaded file.AASX format (Eclipse AASX Package Explorer, 2022). The Eclipse AASX Package Explorer supports the XML and JSON serialization of the AAS. Export formats for AutomationML or server generation for OPC UA, and BMEcat are also provided by the Eclipse AASX Package Export. New features are added continuously to the software.

2.2.2 BaSyx

BaSys 4.0 defines a reference architecture for production systems that enables the transition to Industry 4.0. Eclipse BaSyx is the BaSys open source project at the Eclipse Foundation (Eclipse BaSyx, 2022, BaSyx/ WhatIsBasyx, 2022).

Eclipse BaSyx™ implements an open-source Industry 4.0 middleware that supports the digitization of production environments (Eclipse BaSyx, 2022). Essential components include the AAS as the foundation for the development of digital twins, a registry component, persistency providers, and several container applications that simplify the creation of common Industry 4.0 applications, such as dashboards (Eclipse BaSyx, 2022).

Being another open-source implementation for the AAS, BaSyx provides software development kits for commonly used programming languages: C++, C# and Java (AAS, 2022).

BaSys 4.0 addresses the changeability of production processes as one major goal of Industry 4.0. Changeable production addresses unplanned changes in production processes. Changing a production requires (manual) intervention with the production line. The major goal of BaSyx is to reduce the resulting downtime to a minimum (BaSyx/ WhatIsBasyx, 2022).

BaSyx components are structured into four layers: The field level contains automation devices, sensors, and actuators without a specific BaSys conforming interface. The device-level contains automation devices that offer a BaSys 4.0 conforming interface. Bridging devices that implement BaSys 4.0 conforming interfaces for field devices that do not provide a conforming interface by themselves are part of the device level as well. The middleware level consists of re-useable Industry 4.0 components that implement required generic, and plant-independent capabilities for Industry 4.0 production lines. Registry and Discovery services, protocol gateways, and AAS providers reside on the middleware level. Finally, the plant level contains high-level plant components that manage, optimize, and monitor production (BaSyx/ WhatIsBasyx, 2022, Basissystem, 2022).

Eclipse BaSyx includes: Server component, the Registry component and Java SDK (Implementing the Industrie 4.0, 2020). The BaSyx Industry 4.0 SDK encapsulates the BaSyx interface and communication with APIs. It enables the development of Industry 4.0 components and the integration of devices and applications into Industry 4.0 environments.

2.3 Industrial Data Spaces

With the wide application of digitalization, data become of most importance in many domains, and manufacturing is not an exception (Alonso, et. al, 2012, Nast, et. al, 2021). EC is constantly encouraging governmental-business data sharing for many topics, and EU dataspaces are commonly requested and used for various reasons (Piest, et. al., 2022).

The main objective of International Data Spaces (IDS) is to support organizations of any type to enjoy the benefits of digitalization without increasing their risks (Uslander and Teuscher, 2022, Niskanen, 2022). IDS was created in a research project involving multiple Fraunhofer institutes (Alonso, et.al. 2018). The Industrial Data Space Association (IDSA) aims at continuous development, exploitation and sustainability of the IDS (Alonso, et. al. 2018).

IDS offers participants the to exchange secure and trusted data for greater benefit while maintaining their data control (Nast, et. al., 2021, Niskanen, 2022). Within the context of IDS, IoT devices are only data providers. On the other hand, a data consumer connects to a connector to retrieve IoT data (Nast, et. al. 2021).

Industrial Data Space Reference Architecture Model (IDS-RAM) was developed in order to achieve a reliable exchange of data between organizations and platforms that are developed by different vendors (Gan, et. al. 2021). IDS-RAM emphasizes technical and organizational security, integrity and authenticity of data transactions for sovereign data exchange (Wortel, et. al. 2020). The standards materialize in the IDS-RAM and DIN SPEC 27070:2020-03 (2020) define methods for secure data exchange between the various IDS connectors (Gan, et. al. 2021, Barnstedt, et. al., 2021).

Alonso et. al and Arcentales et. al. implemented IDS structure-related components using FIWARE (Alonso, et. al., 2018, Arcentales, et. al. 2020).

Digital Twins play critical roles in many sectors, hence, data exchange across company borders becomes more and more important resulting in interoperability, transparency and openness being key success factors. IDS has an important role in these factors (Curry, et. al., 2021). Non-destructive systems have high potential utilization for digital twins.

3 THE CASE STUDY

This section presents the environment that has been used to conduct the case study. The section also presents the associated work performed by using different tools and technologies that are related to AAS and IDS generation and utilization at the real manufacturing site's testing facility. When implementing an AAS for non-destructive testing, the assets modeled are special.

3.1 Case Study Environment

The implementation of the AAS in real industrial scenarios is not common (Iñigo, et. al. 2020). However, the work associated with this case study has been conducted at a real manufacturing plant. The plant produces spirally welded steel pipes. The case study was performed on the Non-Destructive Testing (NDT) machinery of the plant where X-Ray technology is being utilized for testing purposes.

The AAS has been implemented by integrating an NDT ecosystem with X-Ray machinery and a sensor. The implementation in this case study facilitates the utilization of the X-Ray machinery components with sensor data or machines in a real steel pipe manufacturing plant, validating the AAS use in a manufacturing environment for non-destructive testing scenarios.

3.2 Work Performed using Admin Shell IO

In this study, using the AASX Package Manager software, AAS has been created for four different components of an X-Ray machinery: X-Ray Generator, X-Ray Tube, X-Ray Motor Execution, and X-Ray Motor Rotation.

The created AASs have been exported in .aasx format to be uploaded to AASX Server. Exported files have been uploaded to AASX Server. When AASs are uploaded to the server, data can be written and read from outside with REST/API.

In this application, the data from MQTT has been written to AAS with a Python script. Thus, AAS has been created by Admin Shell IO and data including dynamic sensor data can be written and read.

In addition, a data source has been written on Streampipes, which reads the data from the AASX Server and transfers it to the Apache StreamPipes environment. MQTT incoming data is written to AAS, and AAS data is transferred to Apache StreamPipes thanks to the Apache StreamPipes data source (Apache StreamPipes, 2022). Enabling low code, even close to no-code, application development, Apache StreamPipes is a self-service IIoT toolbox to enable non-technical or novice users to connect, analyze and explore IoT data streams. The architectural diagram of the study is given in Figure 1.

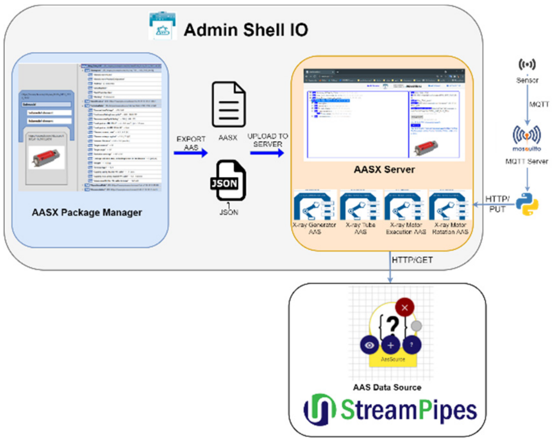

Figure 1: The architecture using Admin Shell IO.

3.3 Work Performed using Eclipse BaSyx

Using Eclipse BaSyx and Node-RED (Node-RED, 2022), architecture has been designed and implemented based on AAS.

Built on Node.js, Node-RED is a programming tool for bringing APIs, hardware and online services. The generated architecture is shown in Figure 2.

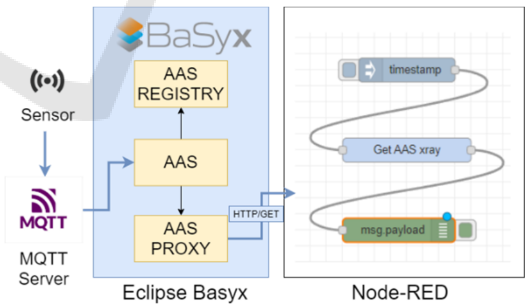

Figure 2: The architecture using Eclipse BaSyx.

An AAS has been created for the X-Ray machine using the Eclipse BaSyx Java SDK, and a sensor has been added as a Sub-model. The generated X-Ray AAS has been registered in the Eclipse BaSyx AAS Registry component.

After creating X-Ray AAS, and registering to the Registry using Eclipse Basyx Java SDK, a proxy for AAS was created using Basyx Java SDK. Thanks to AAS Proxy; AAS, the sub-model, and the AAS data can be accessed with the REST API. For example, the Node-RED module receives data by submitting a GET request to this Proxy.

In this case study, the following actions have been performed:

- An AAS with Eclipse BaSyx has been generated,
- The generated AAS has been registered using BaSyx Registry Component, and
- A proxy for HTPP API has been created.

A new node named “Get AAS xray” has been developed for the Node-RED tool using the created API. The developed node sends a request to the proxy asking for AAS data, and the sensor data is retrieved in response to the request. Node-RED flow and sample output data developed using the Get AAS xray node are shown in Figure 3.

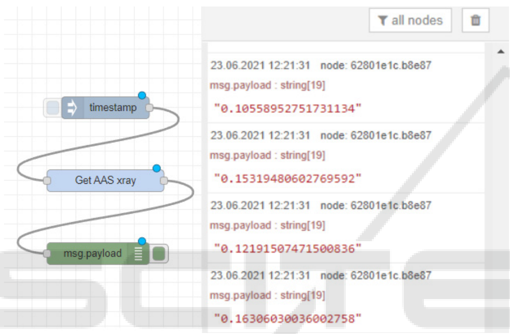

Figure 3: Data retrieval using the generated API in Node-RED.

3.4 Work Performed using IDS

In this study, International Dataspace Connector (IDS) has been installed on two different hosts. One of the connectors has been configured as a provider, and the other has been configured as a consumer. The provider aims to send the "temperature" sensor data retrieved from the previously created AAS dynamic data as the data to be installed and sent to the computer with the IP address 192.168.a.xx. The consumer, on the other hand, has been installed on the test server with an IP address of 192.168.a.yy. The consumer requests data from the provider.

As a result of the studies conducted with IDS connectors, data transfer between different servers has been achieved. The provider connector has been used as a data provider for the consumer connector. The provider connector reads data that are received from the AAS server.

The architecture that was used to send the AAS data to the IDS consumer connector using an IDS provider connector is presented in Figure 4.

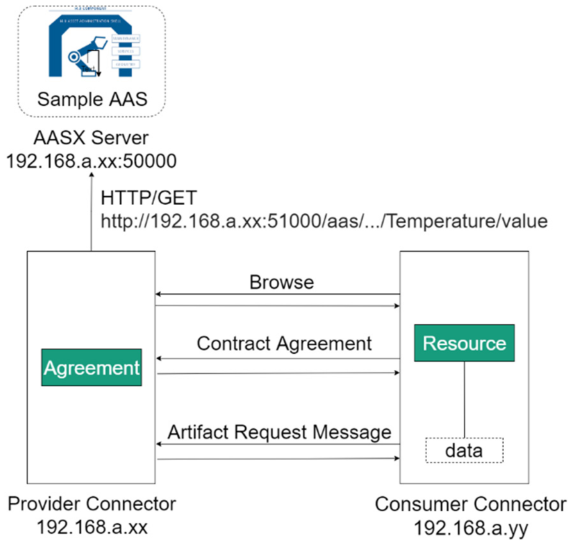

Figure 4: The architecture using IDS connectors.

4 CONCLUSIONS AND FUTURE WORK

In this case study, we have designed and implemented different technical solutions using emerging digital twin technologies/tools to generate AAS and IDS in a real manufacturing environment. The Admin Shell IO, Eclipse BaSyx, and IDS connectors have been developed and used together with Apache StreamPipes and Node-RED. The developments have been verified and validated by testers.

Digital twins are beneficial solutions for non-destructive testing systems. Being one of them, X-Ray testing systems has potential dangers, hence, it is suggested to use digital twins for these systems. To the best of our knowledge, this study is the first study conducting such a case study on non-destructive testing machinery using X-Ray technology in steel pipe manufacturing.

We conclude that with the current maturity level of the tools, it is easy to implement AAS and IDS for digital twin interoperability and to enable secure data exchanges between different organizations. In our comparison of the tools based on the ease-of-use attribute, we found that the Admin Shell IO is easier to use than the Eclipse BaSyx, because it has UI for AAS management and it generates JSON.

In the future, we will continue our studies on the generation of AAS using Fraunhofer Advanced Asset Administration Tools (FA^{3}ST). Up on successful completion of an AAS using FA^{3}ST, we aim to compare and contrast different technologies/tools, designs, and our experiences and lessons learned as part of our AAS and IDS development studies.

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