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Asset Administration Shell as an interoperable enabler of Industry 4.0 software architectures: a case study

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Abstract

In recent years, the discipline of Digital Transformation in manufacturing companies turned out to be a hot topic of research debate, which allowed the design and introduction of new technologies and tools able to exploit the potential of the data produced by the shop floor assets. This increased interest in data generation and management has however highlighted a crucial issue about the lack of standardised models and structures to share these data and ensure interoperability. Among the several concepts proposed by the recent initiatives devoted to solving or mitigating this issue, Asset Administration Shell (AAS) is increasing in popularity, given its potential in providing standardised and modular information about the assets and events represented. This paper deals with a demonstration of the easiness of integration of AAS in pre-existing software architecture, allowing higher flexibility and a better understanding of the ongoing processes: a production line has been indeed entirely represented with modular AAS metamodels and it has been used to feed a Digital Model representing the line configuration. The use case proposed proves the effectiveness of the obtained solution when used for virtual commissioning operations.

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Keywords: Asset Administration Shell; Digital Transformation; Interoperability; Digital Twin.

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1. Introduction

The last manufacturing decades have been characterized by the so-called “Digital Transformation”, a discipline formalised after the introduction, in 2011, when, during the Hannover Messe, an initiative led by the German association of digital and electronics manufacturers (namely Verband der Elektro- und Digitalindustrie, ZVEI e.V.) proposed the well-known Reference Architecture Model Industrie 4.0 (RAMI4.0) [1]. This reference model addressed the topic of digitalisation in the manufacturing sector, proposing a set of reference standards and concepts that, when materialised, would have allowed manufacturing companies to add value to their operations and ease their supply chain by reframing their organisation and processes according to a data-centric perspective [2]. This initiative rapidly gained a broad consensus not only in the research environment [3], but also in the political community, as witnessed by the government initiatives aimed at easing the access to the skills and technologies addressed by RAMI4.0 [4].

However, despite the unquestionable commitment of the different national governments, several issues emerged when the acceptance of RAMI4.0 had been analysed: in particular, in the last years, some authors highlighted that the acceptance of these new technologies is significantly lower among Small and Medium Enterprises (SMEs), mainly because the intrinsic limitations given by the dimensions of these companies, which constitute a severe constraint towards the acquisition of Industry 4.0-compliant hardware and of human resources able to master these technologies [5–7].

Given the fact that several papers have been (or are) targeting the issue of skills in Industry 4.0 [8,9], the focus of this work starts from the impact that the available technology is supposed to add to the specific SME and its stakeholders. This impact is exploited by the data that shopfloor machines and informative systems can share with the different actors leveraging on the information underlying the data, but, in the context of RAMI4.0, data themselves are characterised by different issues:

- The “interoperability” problem, given by cyber-security and trust-related issues, limits significantly the adding value capabilities of data exchanged among different companies[10].
- RAMI4.0 frames its data-related considerations according to IEC 62264 [11], which formalises the information to be shared between the Manufacturing Operations level and the Business Planning one of the ISA 95 standard [12] taking for granted the availability of the information coming from the shop floor.
- Several recent works either explicitly address the lack of (uniform) data coming from the shopfloor [13,14] or develop their data pipelines under the strong assumption of data availability and uniformity [15].

To overcome these issues, the same RAMI4.0 proposed, as a concept [1], the Asset Administration Shell (AAS), which is nowadays considered one of the most promising technologies [16] to standardise the access to “each physical thing” [1] composing the shop floor.

The Industry 4.0 context has brought to the development of AAS functionalities and the virtualisation advantages of a commercial Digital Twin (DT) [17], however, they still live apart from one another. In this work, the authors want to show that the AAS can be used as an enabler to model a system in a digital environment connecting the AAS with a Digital Model (DM), as per the definition given by [18], for the virtual commissioning [19] of the assembly line of the Industry4.0Lab. This paper is structured as follows: Section 2 resumes the background knowledge about the technologies used, Section 3 describes the case study and how AAS has been used for a DM creation for virtual commissioning, and Section 4 summarises the findings and paves the way to new research works.

2. Background

2.1. Asset Administration Shell (AAS)

AAS is a standardized digital representation of an asset to support Industry 4.0, which provides uniform access to information and functions and interoperability capability among the assets [20]. According to the Platform Industry 4.0 guidelines, AAS leverages several functions which are supposed to make this technology an actual interoperability enabler for the manufacturing domain. Each AAS entity can indeed count on a series of functions to ensure interoperability [21]:

- Reference: an ordered list of keys which, key by key, defines the represented element.

- Kind: level of “embodiment” of an asset, which can identify the asset as a type (e.g., a specific tool part of a manufacturer’s catalogue) and is named as *type*, or can embody a type in a specific object in the shopfloor and is named as *instance*.
- Referability and Identifiability: since “every physical thing” [1] should be univocally identifiable and referable, AAS provides global identifiers that can unambiguously point to a certain asset type independently from the context, and other attributes (i.e., *idShort*, *category*, *description*, *parent*) which make the entity referable in a defined namespace and explicit its relations with eventual parent referable entities.
- Semantics: structured references to external entities.
- Data Specification: a set of additional attributes to the ones already defined in the default class. Thanks to the Semantics functionality, Data Specification can be referenced to existing global templates.
- AssetAdministrationShell: is the main element of the metamodel and contains references to the Asset, eventual Submodel(s) and concept Dictionary.
- Asset: an identifiable entity containing all the metadata about the related asset.
- Submodel: an entity listing specific attributes of a subsystem of the metamodel. It is usually used to decompose a complex object into its components (e.g., a machine into its subsystems) and being identifiable it is usually referred to as a specific AAS metamodel describing the subsystems (which can be, in turn, further decomposed into submodels, e.g., describing its components in terms of sensors, actuators, structures…). Submodels rely on their own Data Specification, Semantics, allowing them to model the subsystem in terms of characteristics of interest: these attributes can be descriptive metadata, when the Kind of the metamodel is *type*, but can also be a sampled signal when the Kind is *instance*.

All these characteristics, in particular the identifiability, contribute to the overall objective of interoperability, in the sense that the same metamodel, with a Kind defined as type, can be univocally represented in a different context, easing, for example, the standardisation of bill of materials of machines, or the supply request for spare parts.

Another important aspect is the laying of AAS over IEC 61360 [22] for what concerns the Submodel attributes, which makes the semantic structure of AAS easy inflectable into data exchange protocols relying on tree structures, such as OPC UA [21,23].

2.2. Data pipelines

The opportunity to lay on existing communication protocols is indeed a significant advantage for AAS, since manufacturing companies often rely on structured data exchange formats such as OPC UA [24] to handle the communication between machines and software tools devoted to the data gathering and analysis. The overall concept of Industry 4.0 lays indeed on the opportunity to generate added value from manufacturing data, so leveraging on evolved protocols able to handle complex and pre-processed information is aligned with the general trend of the market. The issue of integrating processes across the entire organization, via networking of smart production systems, smart products and smart logistics, is academically referred to as “Vertical integration”[25] and has been addressed throughout several tools [26], such as Enterprise Service Buses (ESBs) [27] and integrated Platforms as a Service (iPaaS) [28], but in recent years more the majority of solution relied on middleware-based architectures [29], which offer the advantage to adopt usually a “publisher-subscriber” policy, which saves the client interested in any information from continuously polling the server, preventing the network from congestion. Furthermore, by decoupling client and server, this technology allows buffering data in the middleware itself, avoiding data losses due to server updates faster than polling frequency.

2.3. Digital environments

As said above, one of the motivations for this work is the advantages given by the spread of DT technology within the employment of digital environments for simulation. This concept has evolved over the years and these environments were used in the literature for different purposes, with different functions depending on the case study considered. The interested reader can refer to the reviews on the subject [30], among which different classifications of the existing DT applications can be found [31]. In summary, they can be classified according to usage, they can be used offline and/or online, or they can be classified according to their nature, they can be based on both models and/or data [32]. Also, they can be divided by their interaction with the real system, as well explained in [33]:

- the DM is the single model created and used for offline analyses;
- the Digital Shadow (DS) can be used for both online or offline analyses and it is also updated with real-time data from the real system;
- a proper DT can be used as a DS with the additional capability of updating in real-time the real system about the analyses computed in the digital environment.

The AAS metamodels can be used as a dataset for the creation of each digital environment. This paper starts following this objective by providing offline data, hence static data, for the creation of a DM in a use case.

3. Case study

In order to examine the practical implications of AAS, a case study has been set up in a laboratory environment, and the Industry4.0Lab [34] has been selected as an ideal test bed, given the real-like industrial environment embodied in the assembly line (Figure 1) constituting the core of the laboratory. The production line assembles a prototypical mobile phone, with the following assembly steps: the "Manual Station" (7), is the load station where the production starts when an operator adds the carrier within a pallet, in the “Front Cover Station” (1) the front cover of the phone is positioned on the pallet, in the “Drilling Station” (2) the drilling operation is simulated on the cover, in the “Robotic Cell” (3) the Printed Circuit Board (PCB) and the fuses are placed inside the front cover, in the “Camera Station” (4) a camera controls that the pieces inside the front cover are positioned in the right way, in the “Back Cover Station” (5) the back cover is placed on the front cover, finally in the “Press Station” (6) a press close the two covers together. The finished assembled part returns to the “Manual Station” (7) where the operator unloads it. All those steps are customisable for different types of products, i.e. it is possible to have a product with or without a PCB and a product with a PCB with one or two fuses.

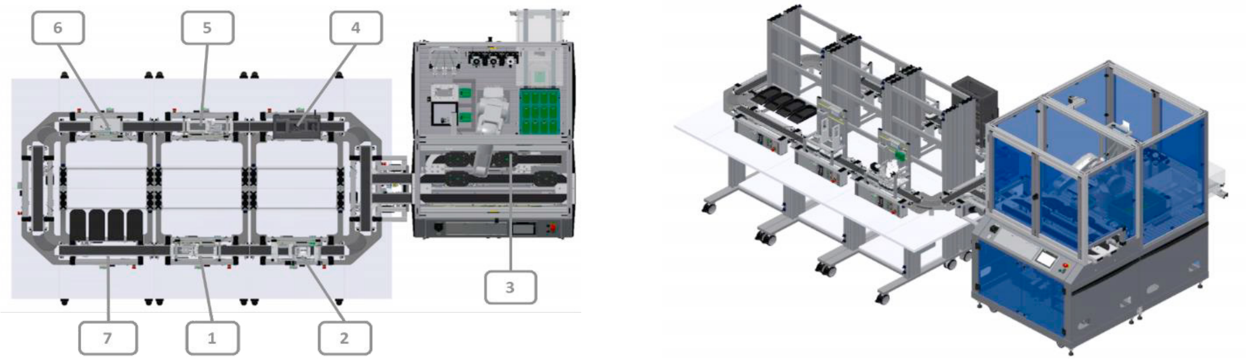
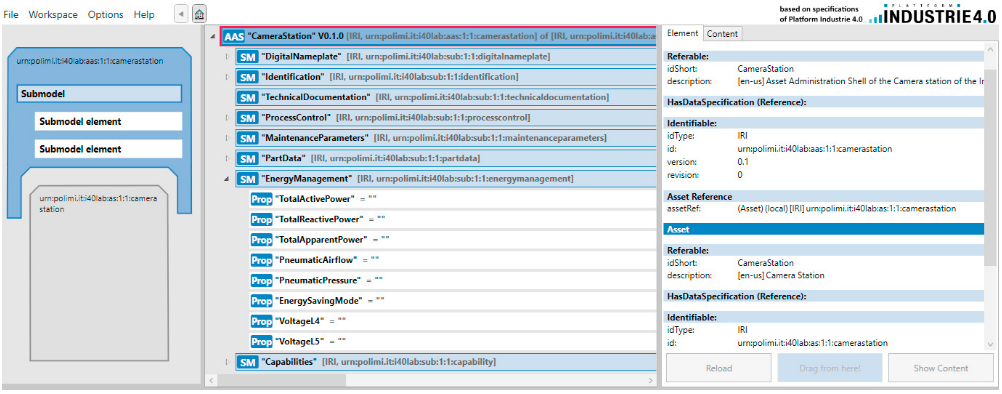


Figure 1 - Industry4.0Lab: on the left the line architecture, on the right the 3D representation of the line

3.1. AAS modelling

The modelling of the physical assets composing the line has been performed through a Python library, namely “PyI40AAS – Python Industry 4.0 Asset Administration Shell” v0.2.2, which has been preferred to other alternatives (BaSyx, SAP AAS, NOVAAS, RACAS Wizard [17]) for the ability to create a customized code that allows the flexible creation of the serialized AAS packages, as well as data population. A recently presented methodology [18] has been followed for the creation of the AAS models. In this environment, the AAS metamodels have been structured to represent assets as resources, products, and work order. Hence, one metamodel for the entire line has been developed, as well as seven metamodels for the seven stations (as the one depicted in Figure 2) and several ones for their subcomponents. These models contain the mechanical and electrical features of the assets from the manufacturer, as well as technical features obtained from sensors of the assembly line. Furthermore, three representative metamodels have been developed for the three different products selected to be assembled by the line (a mobile phone without fuses, with one fuse, and with two fuses), and one metamodel has been developed to describe the work order that details the production plan obtained from the Manufacturing Execution System (MES).



AAS "CameraStation" V0.1.0 [IRI, urn:polimi.it:i40lab:aas:1:1:camerastation] of [IRI, urn:polimi.it:i40lab:a
SM "DigitalNameplate" [IRI, urn:polimi.it:i40lab:sub:1:1:digitalnameplate]
SM "Identification" [IRI, urn:polimi.it:i40lab:sub:1:1:identification]
SM "TechnicalDocumentation" [IRI, urn:polimi.it:i40lab:sub:1:1:technicaldocumentation]
SM "ProcessControl" [IRI, urn:polimi.it:i40lab:sub:1:1:processcontrol]
SM "MaintenanceParameters" [IRI, urn:polimi.it:i40lab:sub:1:1:maintenanceparameters]
SM "PartData" [IRI, urn:polimi.it:i40lab:sub:1:1:partdata]
SM "EnergyManagement" [IRI, urn:polimi.it:i40lab:sub:1:1:energymanagement]
  Prop "TotalActivePower" = ""
  Prop "TotalReactivePower" = ""
  Prop "TotalApparentPower" = ""
  Prop "PneumaticAirflow" = ""
  Prop "PneumaticPressure" = ""
  Prop "EnergySavingMode" = ""
  Prop "VoltageL4" = ""
  Prop "VoltageL5" = ""
SM "Capabilities" [IRI, urn:polimi.it:i40lab:sub:1:1:capability]

Referable:
idShort: CameraStation
description: [en-us] Asset Administration Shell of the Camera station of the Ir

HasDataSpecification (Reference):

Identifiable:
idType: IRI
id: urn:polimi.it:i40lab:aas:1:1:camerastation
version: 0.1
revision: 0

Asset Reference
assetRef: (Asset) (local) [IRI] urn:polimi.it:i40lab:as:1:1:camerastation

Asset

Referable:
idShort: CameraStation
description: [en-us] Camera Station

HasDataSpecification (Reference):

Identifiable:
idType: IRI
id: urn:polimi.it:i40lab:as:1:1:camerastation

Figure 2 – Example of AAS module in the AASX Package Explorer

The different AAS metamodel modules are created separately as shown above and they are connected one to the other. In particular, for the case study, the seven metamodels created are related as follows:

- The *Work Order AAS* lists the product sequence that must be produced in the line;
- Each product in the work order has its *Product AAS*, i.e. the "ProductNoFuse" of Figure 3 refers to one of the products listed in the work order AAS;
- The Assembly Line AAS include the ordered list of stations in line (the same shown in Figure 1);
- Each station in the assembly line has its own Generic Station AAS, i.e. the "DrillStation" of Figure 3 refers to the stations of the assembly line of the case study.

The same procedure has been followed for each product considered and for each station of the assembly line in the Industry4.0Lab, to obtain a modular AAS.

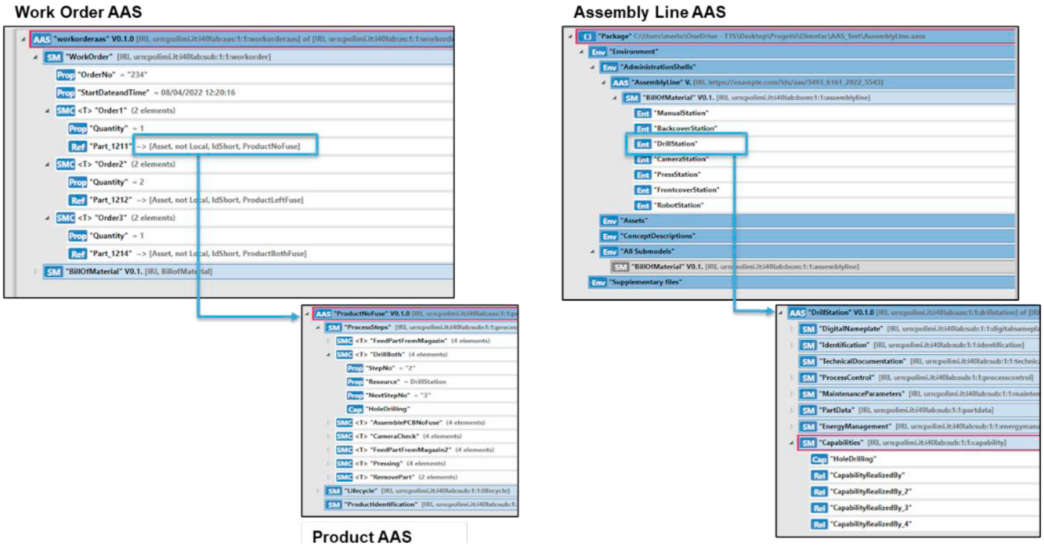


Figure 3 - Connection of the modular AAS metamodels

3.2. Data architecture

The developed metamodels have been deployed in an existing data pipeline, namely SHIELD [35], designed to handle data flows in Learning Factories and used for industrial use cases [36]. In a nutshell, SHIELD allows returning a sets of customised signals of interest to the user, retrieving them from shopfloor machines at customised frequencies.

The pipeline, depicted in Figure 4, lies on several functional modules, such as a certain number of connectors (one for each protocol to interface, e.g., OPC UA [23] and MQTT[37]), an orchestrator module which calls and configures the internal services to fulfil the users' requests, a topic manager which gathers, integrates and dispatches the data streams from the machines to the users and a static database, where the users can find the information about the data shareable by the machines, their addresses and their physical meaning. All the communication among the different module – apart from the ones involving the users – are mediated by an Apache Kafka middleware [38].

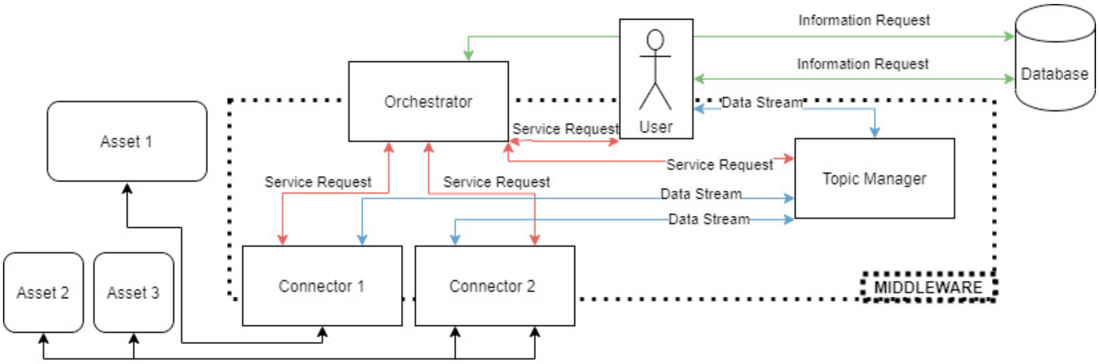


Figure 4 - SHIELD architecture [29]

The AAS metamodels created are herein used as the static database to be filled with the information acquired by SHIELD replacing the existing Orient DB [39]. The latter, given the graph-based structure of elements, was lacking in "querability" of the database providing instead "surfability". The AAS modules created do not constitute a proper database, but data structures and representations are better interpretable by the users, containing all the additional information about the real system.

3.3. Digital Model

The modular AAS metamodel created, filled with the data through SHIELD, is used to build the DM illustrated in in a digital environment in Figure 5. The software tool used as the digital environment is designed and intellectually owned by a software house, it can render and animate each system based on the machine's status. The DM natively lays on a simulation engine, which represents the products flowing in the assembly line as XML file that is updated every time a work-in-progress product undergoes an operation.

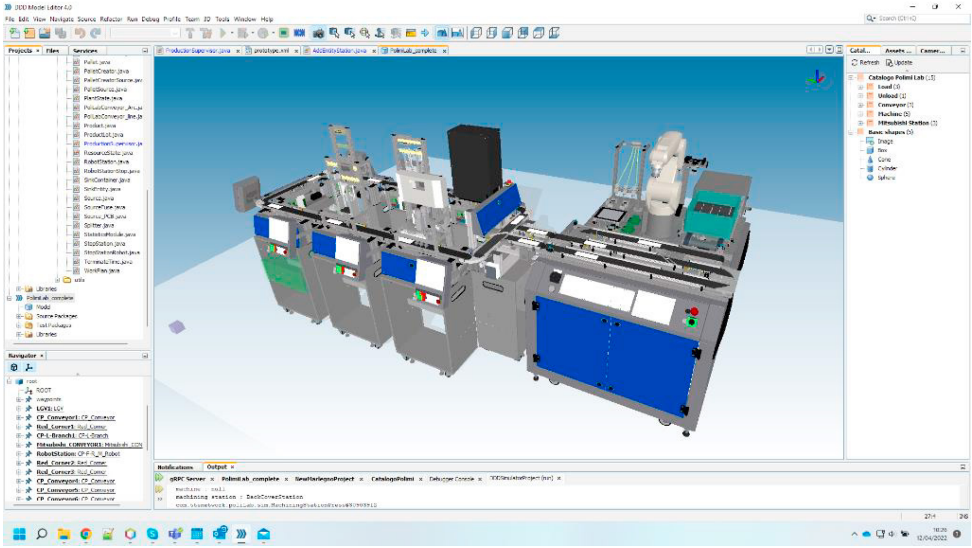


Figure 5. Digital Twin fed by AAS packages

The AAS is then the metamodel of the line and the stations – within all the addresses and descriptors of every reachable sensor of the line – and it is used to feed the DM, while the software provides the CAD drawings of the stations. Being the AAS modular and standard, a relevant feature is the "interchangeability". It is possible to easily alter the configuration of the line by changing, adding or removing some modules and visualising different possible scenarios in the DM, i.e., in the case study if the work order of the line changes there is no need to change the whole structure. This feature allows to save time on the set-up and proves the DM feasibility to be used for virtual commissioning.

4. Conclusions and future works

The case study has briefly summarised the employments of modular AAS metamodel for DM creation, demonstrating the feasibility of the DM to be easily used for virtual commission. Each AAS is a metamodel that collects all the static data about the assets which are obtained using the SHIELD architecture. Thanks to this application, AAS demonstrates its role in supporting the virtual commissioning of an entire production supply chain performed by different DM owned by the respective stakeholders, leveraging on the exchange of the work-in-progress work order AAS instance among the supply chain actors.

A challenge to be addressed in future work focuses on enabling the AAS for the dynamical data acquisition from SHIELD in real time. This would help the DM to become a DS as per the definition given by Negri et al. [40], and go forward into the use of AAS to enable a proper DT.

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