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Asset Administration Shell in Manufacturing: Applications and Relationship with Digital Twin

Tasnim A. Abdel-Aty*, Elisa Negri*, Simone Galparoli*

* *Management, Economics and Industrial Engineering, Politecnico di Milano, Piazza Leonardo da Vinci, 32, 20133 Milano, Italy (e-mail: tasnim.ahmed@polimi.it; elisa.negri@polimi.it; simone.galparoli@polimi.it)*

Abstract: Within Industry 4.0 the communication between the physical and the cyber part of manufacturing system faces an ever-growing rise in complexity. The Asset Administration Shell (AAS) is an information framework, within Industry 4.0, that describes the technological features of an asset. It was created to present data and information in a structured and semantically defined format, allowing for interoperability. The work addresses the industrial implementation of AAS, where a systematic literature review has been carried out to investigate the features of the implemented AAS metamodel, and the tools used for the realization of the models. A study of the convergence present in literature between the AAS and Digital Twin (DT) has also been carried out. This paper presents a reference of AAS tools and information for industry practitioners, as well as suggestions for research gaps in the standardization of AAS information modelling.

Keywords: Asset Administration Shell; Digital Twin; Manufacturing; Industry 4.0; RAMI 4.0.

1. INTRODUCTION

One of the core concepts of the current Fourth Industrial Revolution (Industry 4.0) is the Cyber-Physical System (CPS) which provides the infrastructure to support the integration of the physical and virtual worlds, in which networked embedded devices monitor and regulate physical processes while also impacting information processes (Lins and Oliveira, 2020; Liu and Jiang, 2016).The cyber part of the CPS hosts the Digital Twin (DT) that is a digital representation of a physical system, with the ability to link the digital information to the physical system through-out its whole life cycle (Grieves and Vickers, 2017). The DT has a specific role in the manufacturing field: it uses simulation and mathematical models, sensed data, and real-time data to mirror the physical system in order to forecast and optimize production process activities at each life cycle phase (Cimino et al., 2019; Kritzinger et al., 2018). The DT concept is still in infancy stage and has not yet received a common definition. Following this gap a stream of literature focuses on proposing framework structures and identifying the key features that make up a DT in an attempt to standardize the architectural layers and transform DT from a theoretical concept to a vital tool in smart factories.

The Asset Administration Shell (AAS) was introduced in 2016 as a core element of the Reference Architectural Model for Industry 4.0 (RAMI 4.0). The Industry 4.0 component has been described within RAMI 4.0 to be made up of an asset, its corresponding AAS, and a connection between them (Wagner et al., 2017). The frequent variations introduced by dynamic changes in business environments, and the growing diversity in manufacturing systems is encouraging multiple academic studies to build AAS-based methods as an attempt for interoperability and standardization (Sakurada et al., 2021). Hence, the increasing interest of manufacturing and automation industries is visible within the published research efforts that have been growing by the year.

Both the AAS and DT appear to have overlapped definitions, however the relationship between the AAS and the DT has not yet been clearly defined, and a study of literature exemplifies the potential synergy. Bradac et al. (2019) and Wagner et al. (2017) discuss the difference and similarities between the AAS and DT. Bradac et al. (2019) demonstrates the importance of adopting Industry 4.0 technologies and, specifically, argues that the term AAS should be used instead of the term DT within the Industry 4.0 context. Wagner et al. (2017) also agrees that there is an overlap between the term AAS and DT, however, while the authors believe there is a convergence in the definition of the two concepts, they add that DT is not yet equivalent to an AAS. On the other hand Kuhn et al. (2020) used the AAS as an implementation of the DT.

More work needs to be done on the standardization of the AAS information model and on understanding how it can be utilized in manufacturing in relation to other digital technologies. Following this gap this paper aims to analyze the features of the present implementations of AAS within literature and investigate the applications that mention DT and AAS together to analyze how the two concepts interact with each other in manufacturing, aiming to present an exhaustive reference towards standardization for future research efforts.

2. OBJECTIVE AND METHODOLOGY

The present paper aims at analyzing the ongoing research within AAS relating to manufacturing systems. The main objective is to evaluate the potential emerging uses of AAS implementations within production systems, along with

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highlighting the various technologies used to implement and realize AAS. Specifically, this literature review studies the practical uses of AAS in industrial or laboratory settings, and compares the tools used. Additionally, the study investigates the relationship between the proposed AAS applications and DT. A systematic literature review methodology has been followed where literature studies have been critically appraised, and the findings synthesized qualitatively. The search has been done on Scopus, for the years of 2017-2021 as there are no published papers relating to the aim of the research before this date. As the objective of the paper is to study the implementation approaches of the AAS, the literature search has been executed with the keywords "asset administration shell".

The literature research has resulted in 143 articles. The methodology followed to filter the articles according to their relevance to the objectives presented follows a "funnel like" structure and can be divided into two distinctive phases: "Primary Selection" and "Critical Analysis".

In the "Primary Selection" phase all the literature articles that resulted from the keyword search have been either accepted or rejected depending on their relevance to the study. 45 papers have been excluded, by studying their title and reading the abstracts, due to the following reasons: (i) the language was not English; (ii) The article could not be accessed/downloaded by the authors; (iii) The article does not hold the searched key words in the title or abstract.

In the "Critical Analysis" phase, the remaining articles have been thoroughly read: those that presented a methodology or an architecture without implementation of AAS have been rejected. The output has been 29 papers accepted for appraisal. The accepted papers have been also reviewed for the mention of DT and its relationship to AAS, and the findings are discussed.

3. REVIEW OF AAS APPLICATIONS IN LITERATURE

Plattform Industrie 4.0 (www.plattform-i40.de) specified a metamodel of the AAS (Bader et al., 2020) that is made up of AAS data, asset data, and submodels. Standardization efforts of information models and services are crucial to create interoperability within manufacturing resources (García et al., 2020). Hence, the columns of Table 1 have been chosen to investigate the modelled assets along with the chosen submodels, the purpose of the implemented AAS, the communication protocol used for data exchange between the physical asset and AAS, the modeling solution used for creation of the model, and the mention of DT within the article. The aim is to analyze the relationship between the application purpose and the modelled information of the AAS and DT. Table 1 presents the articles analyzed with their reference in the first column, and the publication type in the second column. The fact that most of the published papers till now are conference articles gives an indication on the level of infancy of the topic, however the growing number of publications is a proof that the AAS is a research area with increasing interest. In Table 1 the articles are further analyzed according to various aspects described in detail below.

3.1 Modelling Solution

The 'Modelling Solution' column specifies the tools used by the authors for the creation of the AAS. The tools could be grouped into editors that have a specific implementation for the AAS, which are easier to use for non-developers in a manufacturing company, like:

- AASX Package Explorer: An open-source software with a friendly graphical user interface available on git-hub (https://github.com/admin-shell-io/aasx-package-explorer).
- Basyx: Eclipse BaSyx is an open-source platform that has an implementation for the AAS and also supplies C++, C#, and Java software development kits.

Automation ML, OPCUA information, and JavaScript Object Notation (Json) have been also mentioned as modelling solutions that provide a level of higher flexibility for the creation of AAS, yet require experienced users.

3.2 AAS Implementation

The 'AAS Implementation' column reports the features of the implemented AAS, specifically regarding the 'Asset' modelled and the 'Submodels' included in the AAS. The 'Application Purpose' column report the intended purpose for the development of the AAS. The information extracted from these three columns demonstrate that the AAS can be used to model a variety of assets for varying purposes. The 'External Communication Protocol' column investigates the protocols used for the data integration between the physical asset and the AAS.

- *Asset:* The AAS can be structured to model various kinds of assets, the modelled solutions within Table 1 can be classified into: *Resources* within a production line, for example the most common modelled resources are the 'Robot', 'Robot Arm', and the 'AGV'. *Operator/Human* as an asset where the Human Administration Shell (HAS) can be used to virtualize the industrial workforce's capabilities (Assadi et al., 2020). *Product* as an asset has been used to visualize/control the production process. *Management level* assets for example, Manufacturing Execution System (MES) and Enterprise Resource Planning (ERP) System. *Data Acquisition* assets like Supervisory Control and Data Acquisition (SCADA) system and Programmable Logic Controller (PLC). The wide range of modelled assets demonstrate the modelling flexibility of the AAS and the potential for use.

- *Submodels:* This column investigates the submodel selection. Efforts are being invested into the standardization of submodels by the working group in Plattform Industrie 4.0. They have published templates for the Digital Nameplate, Technical Data, and Contact Information (which can be found on: www.plattform-i40.de). However, the study of literature un-earths the plethora of submodels presented within research articles and can be seen in Table 1. Two obvious groups can be deduced from the presented choice of submodels: *Submodels relating to the application purpose:* for example 'Maintenance', 'Troubleshooting', 'Energy', and 'Configuration'. *Standard (also named Generic (Ye and Hong, 2019)) submodels:* for example 'Documentation' submodel which has been used in seven articles, ‘Identification’ submodel is present in five articles, and ‘Index data item’ used in two articles.

Some other submodels with frequent occurrences have been ‘Communication’ submodel used in three articles, ‘Operational data’ in four articles, and ‘Technical Data’ in two articles. More work is needed in the standardization of these submodels due to their importance for AAS implementation.

- *Application Purpose:* Eleven articles presented a methodology or architecture for Information Modelling within the AAS, Maintenance has been addressed by Tantik and Anderl (2017), while specifically Predictive Maintenance (PdM) has been investigated by Cavalieri and Salafia (2020a) and Predetermined preventive maintenance by Lang et al. (2019), and two articles addressed Human Machine Interface (HMI).

- *External Communication Protocol:* Communication of the AAS with the modelled asset is an important characteristic for information sharing and interoperability. Not all articles have mentioned the communication protocol used. OPCUA is by far the most used data exchange protocol, present within 18 articles. REST, HTTP protocol, and MQTT have also been used.

3.3. AAS and DT

The articles have been studied for the mention of the term ‘Digital Twin’ or ‘DT, to analyze the existing relationship in literature between AAS and DT. Ten papers, out of 29, have recognized and discussed this relationship, out of which four articles have validated their model in a company setting (Inigo et al., 2020; Platenius-Mohr et al., 2019; Schnicke et al., 2021; Ye et al., 2021a). As the AAS is a relatively new concept, the correlation with DT has been presented in literature in various different formats; the AAS has been used as synonym term to the DT in Industry 4.0 (Lang et al., 2018) where a troubleshooting solution is proposed using AAS, HMI, and Machine Learning (ML). Deuter and Imort (2021) and Vogel-Heuser et al. (2021) also use the AAS as a synonym for DT, where the former investigates Product Lifecycle Management (PLM) data integration through AAS and the latter demonstrates the potential of DT for Multi Agent Systems (MAS) using AAS metamodel. On the other hand, Inigo et al. (2020) adds a specification that only a fully developed DT in the future can be used as a synonym for AAS.

Cavalieri and Salafia (2020a) used the term AAS throughout the article to propose a model for PdM that uses the AAS as a standard abstraction layer for the asset, however when presenting the relation between the AAS and DT the authors mentioned that the AAS is within the boundaries of RAMI 4.0, while in other architectures the term DT is used. Ye et al. (2021b) proposed a method for data exchange between software assets, specifically MES and ERP, utilizing AAS, where they specified that the AAS is used to execute certain functionalities of DT, while Ye et al. (2021a) and Pribiš et al. (2021) add to this idea that the AAS could also be used to implement DT as a whole.

The AAS has been used as a standardized ‘data format’ or ‘data model’ for DT by Platenius-Mohr et al. (2019) who presented a mapping model that enables interoperable DT by transforming information to the AAS meta model, as well as Schnicke et al. (2021) who provided for distributed DT an “architecture blueprint” using AAS for implementation.

Within Table 1, in DT column, the discussed articles are classified according to the relationship between the AAS and DT presented:

- ‘S’ for articles that mentioned or implied that the AAS is used as a synonym for DT
- ‘I’ for the articles that used the AAS as implementation of DT as a whole or certain functionalities
- ‘IM’ for articles that used the AAS as an information model for DT

It is apparent that the relationship between the AAS and DT is complex and not yet fully developed. Half of the papers use AAS as a synonym for DT, while the other half is split between AAS as implementation and as an information model. The authors agree with Platenius-Mohr et al. (2019) and Schnicke et al. (2021) in the current use of AAS as a data model for DT, supported by the fact that the majority of applications used the AAS for information modelling purposes. The DT requirements are summarized as Bi-directional data communication, real-time data, fidelity, horizontal and vertical integration, and simulation (Al-Sehrawy and Kumar, 2021; Durão et al., 2018). Comparing these requirements with the analyzed literature shows that almost all articles addressed real-time data within their AAS models as seen from the external communication protocol column of Table 1, however the other requirements have not been actively validated, for example bi-directional data communication has been considered only by Platenius-Mohr et al. (2019) as one of the proposed eight requirements for interoperable DT using AAS, also no demonstration was present of how the AAS can be used for simulation purposes.

4. CONCLUSION

Given the growing attention AAS has been receiving from industry and researchers, this article aims at providing a reference for researchers and practitioners on the deployment of AAS within manufacturing. A systematic literature review has been performed of the implemented AAS models within manufacturing and the modelled information has been analyzed to investigate the relationship presented between the AAS and DT, as well as provide a support for AAS industrial implementation. The results of the review can be summarized as follows: the process of creation of a AAS requires individuals with IT skills, a few tools like the AASX Package Explorer and Eclipse BaSyx exist for the non-technical practitioners. The flexibility of the AAS information model allows the modeling of a wide variety of Industry 4.0 assets, however most of the analyzed articles focus on Resource as assets. The most investigated application purpose of the applied AAS is Information Modelling which emphasizes the fact that the AAS is in infancy stage and needs to be further investigated in manufacturing use cases. There is a correlation present within the submodels and the application purpose where the choice of submodels can directly stem from the intended application. A correlation is also present between modelling a Product as an asset for Production purposes. Future work might concentrate on standardizing individual submodels in connection to specific application scenarios, allowing for future technological implementations and modifications of AAS in companies. The review supported the use of AAS as a data/information model for DT, however future works needs to deeper investigate quantitively and qualitatively the progress of these two intersecting Industry 4.0 concepts. The systematic review also presented a clear gap within the modelled AAS for simulation purposes and bi-directional data exchange with the physical asset.

Table 1: Systematic Literature Review Results

Reference	Publication Type	Modelling Solution	AAS Implementation				DT
			Asset	**Submodels**	**Application Purpose**	**External Communication Protocol**	
(Tantik and Anderl, 2017)	C	P	central remote maintenance platform, robot arm		M	HTTP/REST	
(Lang et al., 2019)	C		industrial towel foldingmachine	Process data, Maintenance		OPCUA	
(Cavalieri and Salafia, 2020a)	J		Milling Machine	Condition monitoring, Identification, Maintenance			S
(Lüder et al., 2020)	C	AML	ultrasonic measurement cell	Functional, Mechanical, Electric, Automation	I/DM		
(Inigo et al., 2020)	C		Robotic Arm, Grinding Machine	Identification, Documentation, Condition Monitoring		OPCUA	S
(Cavalieri and Salafia, 2020b)	J	OPCUA	Plc, Drilling Machine	IEC 61131-3, I/O Connections, Device Connections, Configuration tool		OPCUA	
(Pribiš et al., 2021)	J	AASX	discovery board	Documentation, Identification, modelBreakDown, OperationalData		OPCUA	I
(Schnicke et al., 2021)	C	BaSyx	Oven, Sensor	Sensor data, Documentation		HTTP/REST	IM
(Lv et al., 2021)	C	AASX	AGV, Mirobot	Communication, Move, Motion, Pump,Fork		REST API	
(Ye et al., 2021b)	J	AML	MES, ERP	Manufacturing order, cost calculation.		OPCUA	I
(Ye et al., 2021a)	J	AASX	Robot, Turn table	Identification, operational data, technical data, and documentation		OPCUA	I
(Platenius-Mohr et al., 2019)	C		Motor, Motor product type, Drive, Drive product type, Powertrain system	Operational, Engineering model, Documentation, Technical data sheet			IM
(Ye and Hong, 2019)	J	AML	Robot, Sensor, Conveyor, Gateway, RaspberryPi, controller, web	Index data item, property value statement, documentation, communication, data processing, pick and place,		OPCUA	
(Cavalieri and Salafia, 2020c)	J	OPCUA	Motor controller			OPCUA	
(Marcon et al., 2019)	J		Operator		HMI	OPCUA	
(Assadi et al., 2020)	C	Json	Human			MQTT	
(Terzimehić et al., 2019)	C	BaSyx	Roller conveyor in a pallet transportation system	Initialization parameters, a topology sub- model, status variables and state machines		OPC-UA/REST/HTTP	
(Deuter and Imort, 2021)	J	AASX	SmartLight product	MQTT, OPCUA, REST, configuration, construction manual, proprietary data, operational data, production data,	PR	MQTT, OPCUA, REST	S
(Lopez et al., 2021)	C		Smart Product, Industrial Robot				
(Vogel-Heuser et al., 2021)	J	AASX	Pick and Place Unit (PPU), Stack, Work piece	Identification, Stamp1, Stamp2, Stack, Paint, Capabilities, Properties, StoredWPList, Tasks, Locations, Files			S
(Arm et al., 2021)	J	CW	3D printer, Assembly box, Supermarket Robot, Product, MES	Negotiation		OPCUA	
(Birtel et al., 2020)	C	F- OPC UA	active digital object memory model (ADOMe) products	Discharge from production, object localization, production optimization		OPCUA	

(Lu et al., 2021)	C	AML/ OPCUA	Robot, AGV, CNC		AAS P	OPCUA	
(Pethig et al., 2017)	C		pick and place work cell		CM	OPCUA	
(Barig et al., 2019)	C		diagnostic assistants systems			OPCUA	
(Lang et al., 2018)	C		Folding Machine	Troubleshooting	T	OPCUA	S
(Motsch et al., 2021)	C	Basyx	Storage and Assembly	Energy	EM	OPCUA	
(Hosseini et al., 2021)	C		Level sensor, control valve, Programmable Logic Controller (PLC), tank, and Supervisory Control, Data Acquisition (SCADA) system		SS		
(Ye et al., 2020)	J	AML/OP CUA	Robot, Turntable	Index data item, Property value statement, Documentation, Communication, PnP interaction, Pick-and-place, Object-conveying		REST API	

Legend:
J = Journal paper; C = conference paper

P = Python; AML = Automation ML; AASX = AASX Package Explorer; F- OPC UA = FreeOpcUA Modeler; Json = JavaScript Object Notation; CW = ConfigWizar

M = Maintenance; I/DM = Information/Data Modelling; HMI = Human Machine Interface; PR = Production; AASP = AAS Platform; CM = Condition monitoring; T = Troubleshooting; EM = Energy Management; SS = Safety and Security

S= Synonym; I= Implementation; IM= Information Model

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