




# From Multiple Digital Twins to a Multi-Faceted Digital Twin: Towards an AAS-Based Approach

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**Abstract**—Digital Twin, the technological advance that has emerged in the Industry 4.0 era, will become one of the six technological pillars forming Industry 5.0, according to the vision of the European Commission. This promotion relies on the fact that digital-twin technologies are getting more mature and widely adopted in both the public and private sectors. Besides the progressions, a new challenge has arisen: harmonizing multiple digital twins in a single digital twin system. Indeed, digital twins built on different technologies addressing different aspects of an asset are not interoperable by default, making the interaction between them uneasy. Moreover, as an asset must have a connection with each digital twin for data exchange, its multiple connections with multiple digital twins may cause the asset itself and the involved network infrastructures to be overloaded. Regarding the above challenge, this paper proposes an approach based on the Asset Administration Shell (AAS) standard to harmonize multiple digital twins as a single digital twin with multiple facets.

**Index Terms**—Industry 4.0, Digital Twin System, Papyrus, Asset Administration Shell, Interoperability,

## I. INTRODUCTION

Even just into the fourth industrial revolution (Industry 4.0) in the past decade, the world is preparing for the fifth one (Industry 5.0). While Industry 4.0 is about adopting the new and greatest technological advances, such as the Internet of Things (IoT), Artificial Intelligence (AI), and Autonomous Robots, to increase production performance, automation, and productivity, Industry 5.0 frames and directs technologies to reinforce its human-centric, sustainable, and resilient focuses [1]. Digital Twin (DT) is a technological concept that has just emerged during Industry 4.0 but is projected to be one of the six technology pillars forming Industry 5.0. DT refers to *"the digital representation of a target entity with data connections that enable convergence between the physical and digital states at an appropriate rate of synchronization"* [2]. It embodies a *"set of digital models representing a real-world entity"* and implies *"advanced operating tools, including the ability to understand, analyze, predict, and optimize the operation and management of the real entity"* [3]. Note that from now on in this paper, the term asset will replace the term entity as insisting on the manufacturing scope.

DT has meaning when it is a part of a digital twin system (DTS). DTS is defined as a system-of-systems in which multiple DTs integrate with other systems, such as AI data analytics, to address determined goals and increase value creation [4]. One key challenge of building DTS is harmonizing multiple

DTs. Indeed, depending on technology, different DTs can perform different aspects of an asset. For example, on the one hand, a 3D model running on a 3D engine can represent the visualization aspect of a robotic arm; on the other hand, an Asset Administration Shell (AAS) model deployed on an AAS executor can expose its functional aspect [5]. Unfortunately, these technologies are generally not interoperable by default, so their build-upon DTs cannot collaborate natively. A second problem of having multiple DTs is the number of connections between an asset and its DTs. Literally, each asset has a connection with one DT to exchange data. When the number of DTs increases, the number of connections also increases. Consequently, the asset must work harder to send data, and the network infrastructures that maintain the connections is getting busier. The above drawbacks reduce the performance and augment the cost of deploying and maintaining a DTS.

This paper presents an approach based on AAS, an industrial-grade standard for digital representations of assets [6], to harmonize multiple DTs into a single DT with multiple facets. In detail, an AAS DT acts as the synchronization point between an asset and its multiple DTs. The multiple DTs, instead of connecting directly to the asset, will exchange data with it indirectly via the AAS DT. Each DT is considered a facet of the multi-faceted DT. This approach relies on the potential of the AAS standard to offer a unified and standardized interface for each asset, thus providing semantic interoperability for other applications and DTs to connect to the asset through its AAS DT. Moreover, our tool—Papyrus for Manufacturing (P4M)—can complement this approach with its rich support for technical and syntactic interoperability. To the best of our knowledge, this approach might be new since other research jobs normally focus only on the main feature of AAS, that is, to implement AAS DTs, but none of them use this standard as a solution for harmonizing other DTs [7].

The rest of this paper is organized as follows. Section II presents the technical background: AAS principles and the P4M tool. Section III details the AAS-based approach; then, Section IV presents a real case study potentially improvable with this approach. Finally, a brief conclusion summarizes this paper and outlines future works.

## II. BACKGROUND

This section presents the technical background: the principles of the AAS standard and the P4M tool.

### A. Asset Administration Shell

The Industrial Digital Twin Association (IDTA)<sup>1</sup> develops and maintains the AAS standard to create standardized DTs in industrial environments. In this standard, an AAS or AAS DT is referred to as "a standardized digital representation of an asset" [6]. The standard offers a structured meta-model dedicated to DTs in manufacturing to support data format interoperability. Based on the meta-model, the Administration Shell part of an AAS DT represents digital models of various aspects (Submodels) of an asset and describes its related technical details (e.g. the identities of the AAS DT and the asset). Elements of a submodel (Submodel Elements) can be product properties, process variables and parameters, events for observing properties, references to external data sources or files, capabilities, operations, and composite entities.

Technically speaking, an AAS DT is composed of three major elements. The first is an AAS information model held by its Administration Shell part. The second is a network interface for data synchronization with the asset. Third, another network interface for data access and information management.

Many research groups have put effort into the AAS DT implementation to make it more competitive to dominate the domain. For example, Eclipse BaSyx<sup>2</sup> is one of the first implementations that provides various connectivity options, including MQTT, OPC UA, S3 cloud technology, and PLC4X, enabling seamless integration from edge devices to PLCs, and to cloud-based systems.

### B. Papyrus for Manufacturing

P4M [8] is a toolset developed and maintained by the laboratory LSEA of CEA List for the AAS DT implementation with the Model-Driven Engineering (MDE) approach. This toolset bridges the theoretical aspects of MDE with the practical functionalities of AAS, leading to more efficient industrial DT creation and deployment. The main features offered by P4M are as follows.

- **AAS graphical modeling environment:** This graphical modeling environment is developed based on Papyrus. The P4M has integrated the AAS meta-model as UML profiles that provide a mechanism for semantic-compliant modeling. Its various diagram editors provide multiple perspectives for illustrating DT models. The AAS design diagram (ADD) extends the UML class diagram. This diagram displays all information associated with an asset. The BOM diagram visualizes the composite structure of an asset, which is a customized UML composite structure diagram. The BPMN diagram allows the design of production processes.
- **Interoperability with other AAS-compliant environments:** The P4M provides the functionality of importing and exporting AAS models in AASX or JSON formats. It ensures seamless integration and communication with ecosystems that follow the AAS standard.

- **AAS REST server code generator:** The code generation mechanism in P4M simplifies the AAS DT implementation over the BaSyx library, which neatly handles the deployment to the AAS HTTP server. When running, the server hosts an AAS DT. The AAS information model of the AAS DT can be easily accessed via the HTTP REST protocol with the schema BaSyx API proposed by Eclipse BaSyx. The other IT applications, such as AI data analytics and supervision dashboards, can seamlessly connect to the AAS server, then to obtain real-time data and invoke methods directly from the AAS DT. The P4M's current version also supports OPC UA and WebSocket, besides HTTP REST.
- **Data synchronization with multiple supported network protocols:** P4M extends the BaSyx's communication method with new ones for the data synchronization between an AAS server and an asset. Technically, it adds more network protocol adapters. The P4M's current version supports HTTP REST, OPC UA, MQTT, WebSocket, ROS, and ROS 2.

## III. AAS-BASED APPROACH

The core idea is to use an AAS DT as the synchronization point in the middle between an asset and its multiple DTs. Figure 1 illustrates the architecture. This approach has four advantages. First, multiple DTs can exchange data through the synchronization point with the standardized interface proposed by the AAS DT and profit from the AAS standard's semantics. Second, each DT can communicate with the synchronization point with an Information Technology (IT) communication, then avoid the complexity of directly connecting to the asset at the Operation Technology (OT) layer. It is worth noting that communication between the IT and OT layers is inherently a difficult problem in the industry. Third, the AAS concept of representing aspects of an asset as submodels is flexible and extensible, allowing modifications and enrichments to meet the requirements of all involved DTs. Fourth, AAS is an industrial-grade standard compatible with the manufacturing environment and easily accepted by industrial partners.

The four principles of this AAS-based approach are as follows. First, the AAS DT in the middle must support all network protocols and data formats required by all involved DTs. Second, the information model of the AAS DT must represent all the aspects required by the DTs. Third, the AAS DT must maintain the data exchange with the corresponding asset to keep all data up-to-date. Fourth, the AAS DT allows the DTs to query and view its information model and then access data.

P4M is a recommended tool for this AAS-based approach since it supports several highly demanded network protocols in the market. An AAS DT generated by P4M has two interfaces: one interface for connecting to an asset at the OT layer and another interface for connecting to involved DTs at the IT layer. Moreover, the friendly graphic user interface of P4M eases the AAS information model design.

<sup>1</sup><https://industrialdigitaltwin.org/en/>

<sup>2</sup><https://eclipse.dev/basyx/>

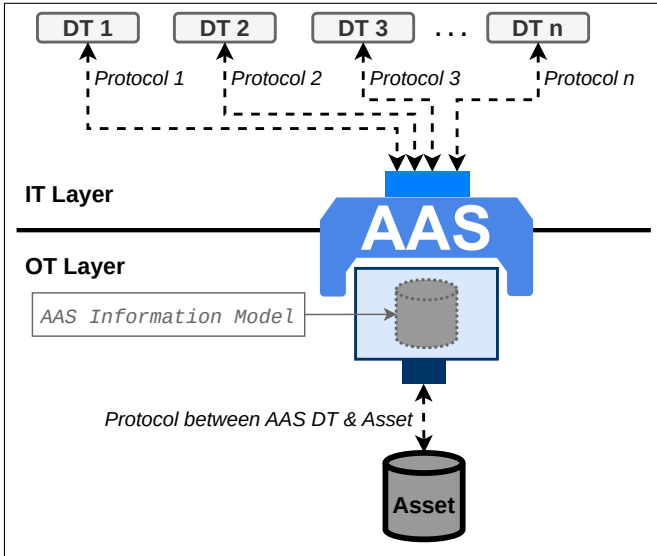


Fig. 1. Architecture with an AAS DT in the middle for the communication (1) between an asset and its DTs and (2) between the DTs

#### IV. CASE STUDY

Production-Assembly-Line (PAL) Feasibility Checking is a case study presented at the CEA List Tech Days 2023 event [5]. The objective is to introduce a new approach to practice feasibility checking in manufacturing using the DT technologies developed by CEA List's laboratories. Figure 2 is a photo of our display stand at the event.



Fig. 2. Display stand of the PAL Feasibility Checking case study

The manufacturing context is a PAL system where a human worker at one workspace on the shopfloor receives parts from a mobile robot to produce final products. Since this job is repetitive and boring, a robotic arm should replace the human worker. However, a new requirement emerges: to position the robotic arm in the appropriate position in the workspace so that the productivity of the production process is unchanged. The solution is to test the position of the robotic arm in a simulation environment before installing it on the shop floor. This test, in this case study, is called feasibility checking. In this sense, two DTs are integrated: a Geometric DT to perform the PAL system in a 3D simulation, and a Functional DT to represent the production process and the operational side of the PAL system. Technically, the Geometric DT includes several 3D DT instances mimicking the assets of the PAL system. Likewise, the Functional DT consists of AAS DT instances corresponding to the assets. The Functional DT can monitor

and control the PAL system's assets on the shop floor for the assets management mission and the 3D DT instances inside the 3D simulation for the feasibility-checking mission.

Regarding the communication between the two DTs and the PAL system, the development team proposes two solutions as in Figure 3. The first solution is to let each DT communicate independently with the PAL system through the OPC UA communication protocols. Note that the robots in the PAL system use ROS or ROS 2; thus, this solution also requires a bridge for OPC UA, ROS, and ROS 2 [9]. The two DTs can exchange data with an OPC UA server as a data-sharing point.

The second solution is to use AAS DT instances both as the Functional DT and the synchronization point between the Geometric DT and the PAL system. In other words, it follows the multi-faceted DT approach. Thus, the AAS DT instances in the middle can communicate with their corresponding assets via either ROS or ROS 2. The AAS DTs exchange data with the Geometric DT using HTTP REST network protocol and JSON data format with the schema defined by Eclipse BaSyx. The information model of each AAS DT includes the variables and operations related to its asset at the shop floor and the corresponding 3D DT instance in the 3D simulation. Figure 4 shows the AAS information model's simple version of the mobile robot TurtleBot3 Waffle Pi as a sample. The three submodels Skills, TechnicalProperties, and Load include all the properties and operations needed to monitor and control the mobile robot. For example, the two properties connected and load respectively verify whether the mobile robot is available and whether it carries an object; the operations moveToDeposit and moveToStorage respectively control the mobile robot to two workspaces. The submodel SimulationTurtleBot3WP includes the same list of properties and operations dedicated to the 3D DTs in the 3D simulation. Note that this submodel is an extension available only in the multi-faceted approach that allows enables controlling the PAL system on the shop floor and its 3D version in the 3D simulation simultaneously or separately.

The second solution has two advantages compared to the first one. First, deploying and maintaining is simpler without OPC UA modules. Second, new facets can be added easily with no or only a few modifications to the information model at the synchronization point. However, while the first solution was fully developed and presented at the CEA List's event, the second is only a prototyped implementation.

#### V. CONCLUSION AND FUTURE WORKS

To sum up, this paper presents an AAS-based approach to resolving the interoperability challenges of multiple DTs in manufacturing. This approach proposes to use AAS DT as a synchronization point for data exchanges between assets at the OT layer and their DTs at the IT layers. Since the AAS standard is well-supported and widely accepted by the manufacturing community, this approach is a promising solution in Industry 4.0 and 5.0. Moreover, this paper suggests using P4M to facilitate the creation of AAS DTs, as it offers advantages such as support for several high-demand network protocols.

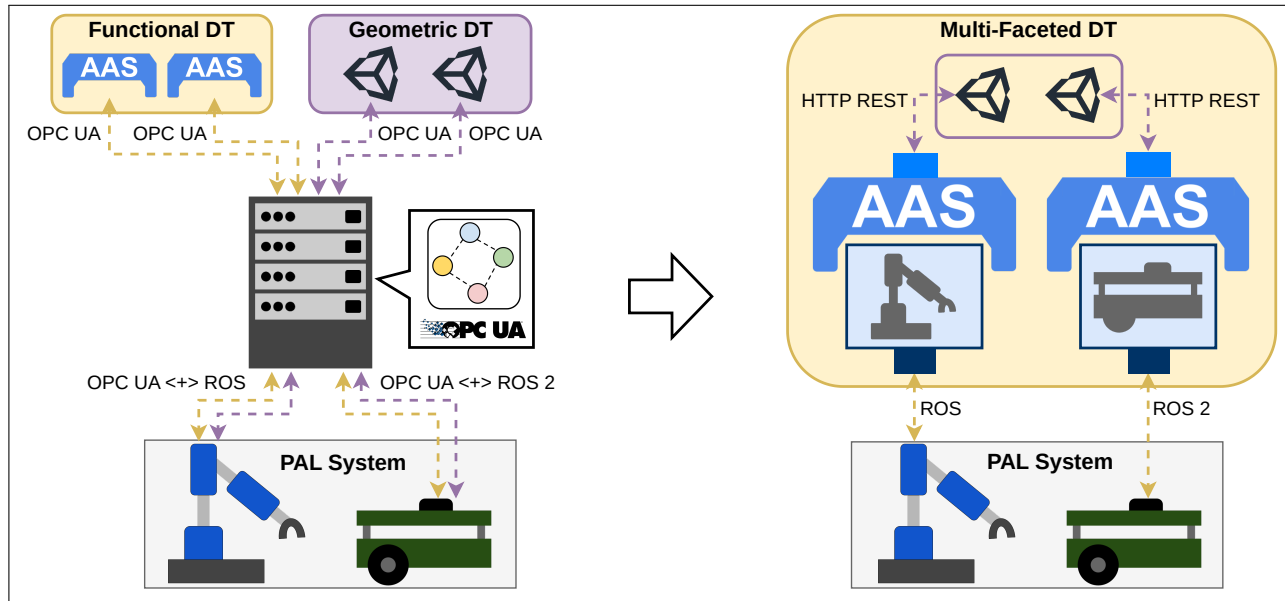


Fig. 3. Multiple DTs (left) and Multi-Faceted DT (right) approaches for the communication between the PAL system and their two DTs

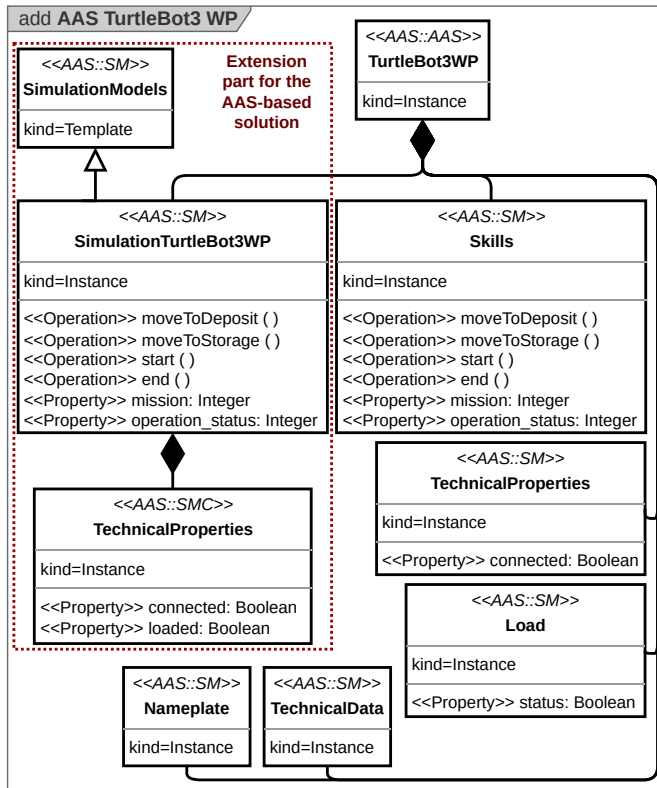


Fig. 4. Information model of the TurtleBot3 Waffle Pi's AAS DT

The case study presented in this paper shows that the AAS-based approach is realizable and beneficial. However, it has two drawbacks. First, there is a lack of quantitative evaluation and comparison between the two approaches. Second, the application context of the use case is limited and cannot show all the potential of the AAS-based approach. In the future, we plan to design and implement a complex use case with several

DT types and network protocols. This will allow us to clarify the research question regarding the effectiveness of a multi-faceted DT compared to multiple DTs. Additionally, we can evaluate the limits (the maximum number of DTs, assets, and protocols) the synchronization point can handle.

In order to support the AAS-based approach better, the development team of P4M plans to integrate more network protocols and data formats dedicated to manufacturing into the tool. Another milestone is upgrading the P4M to be compatible with the newest version of the AAS standard.

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