University of Stuttgart

Institute for Control Engineering of Machine Tools and Manufacturing Units (ISW)

Digital Twins

And the Asset Administration Shell

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Presenting the Joint Work of all Five of Us

Every information about an asset in a single place

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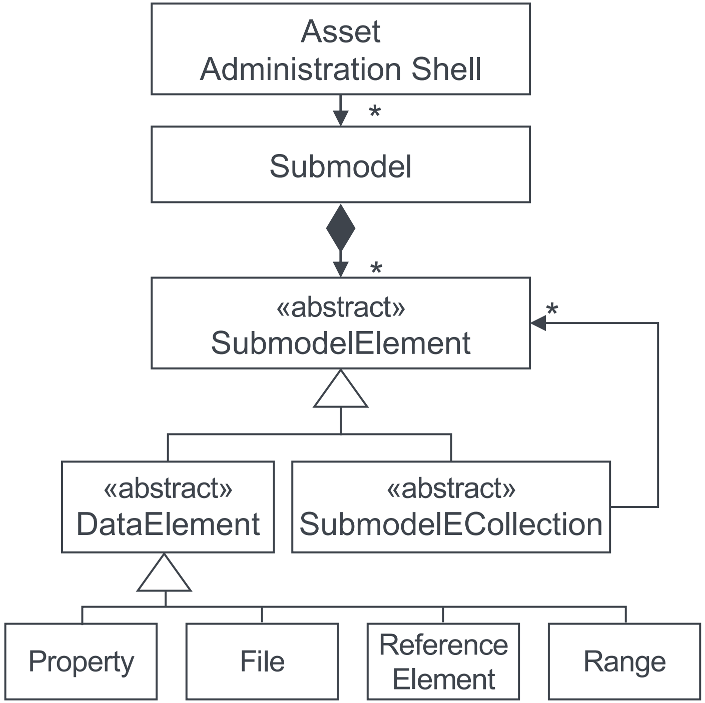
The Asset Administration Shell is an Industrial Modelling Success Story

Every information about an asset in a single place

- Essentially a metamodeling framework for asset information (including data, models, and more)
- Standardized by Industrial Digital Twin Association (IDTA)[1]
- 129 members, incl. ABB, Bosch, Danfoss, Dassault, Hitachi, Huawei, Mitsubishi, PTC; Siemens, SAP, Trumpf, VW, …
- Core metamodel[2] building on industry standards
  - Data model based on ISO 13584-42, IEC 61360
  - ECLASS[1] ISO/IEC compatible data modeling standard
- Goal: Standard for Digital Twins in Industry
- Eclipse BaSyx for implementation (among others)


Asset Administration Shell
*
Submodel
*
«abstract» SubmodelElement
*
«abstract» DataElement
«abstract» SubmodelECollection
Property
File
Reference Element
Range

1. https://industrialdigitaltwin.org
2. https://industrialdigitaltwin.org/wp-content/uploads/2023/04/IDTA-01001-3-0_SpecificationAssetAdministrationShell_Part1_Metamodel.pdf

The AAS aims to Locate all Relevant Information About an Asset Centrally

Submodels are the main content of asset administration shells

Capabilities

- End milling
- Drilling

Maintenance

- Cutting time
- Latest service

Operational Data

- Sensor data
- Energy consumption

Technical Data

- Max. spindle speed
- Axis count

Digital Nameplate

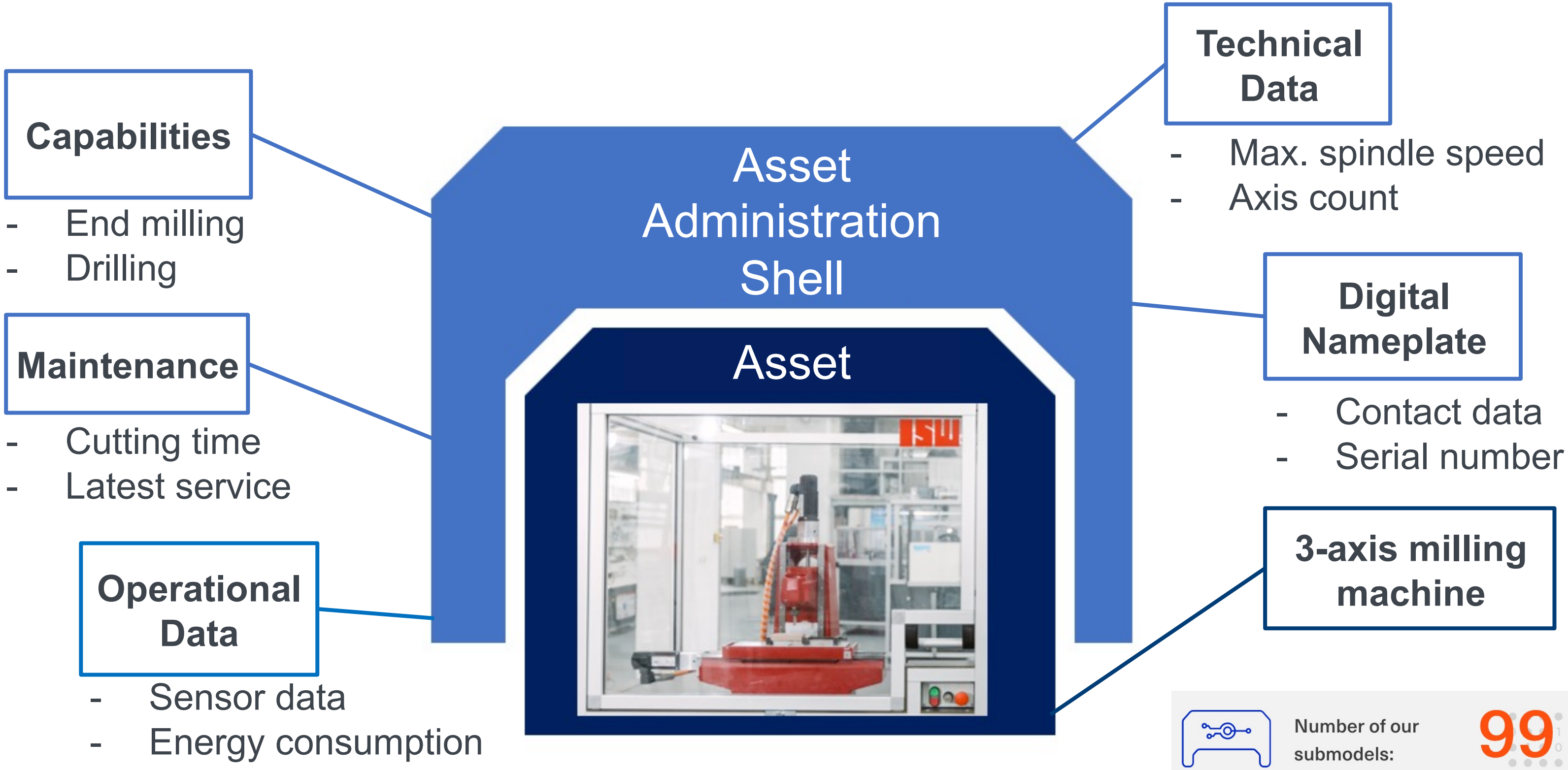
- Contact data
- Serial number

3-axis milling machine

Number of our submodels: 99

The AAS aims to Locate all Relevant Information About an Asset Centrally

Submodels are the main content of asset administration shells



- End milling
- Drilling

- Cutting time
- Latest service

- Sensor data
- Energy consumption

- Max. spindle speed
- Axis count

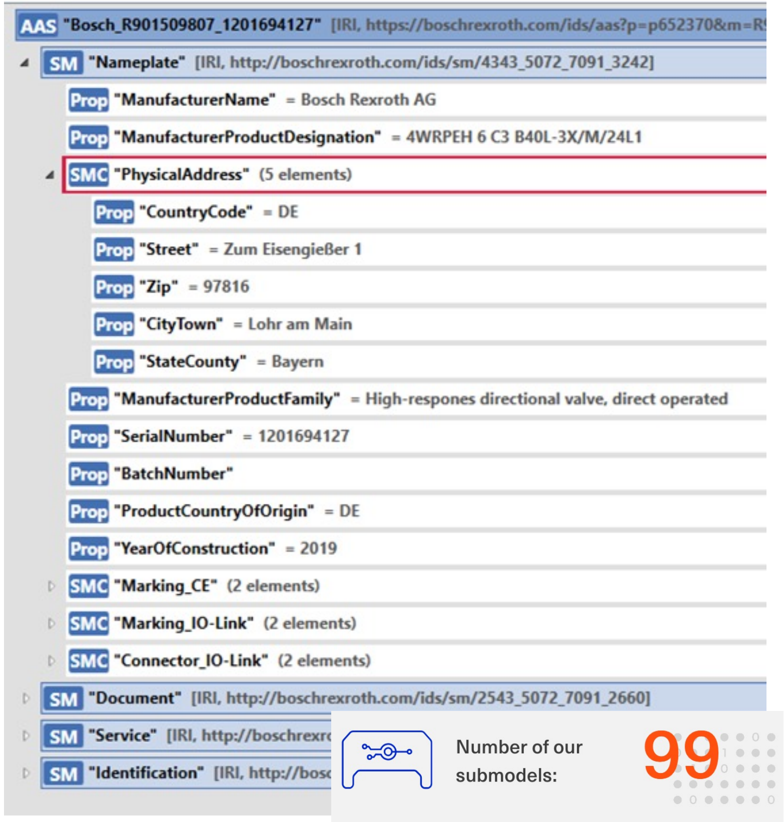
- Contact data
- Serial number

Number of our submodels: 99

AAS Submodel Templates Facilitate Structuring Asset Information

Standardizable data models within the IDTA

- Ca. 40 submodel templates published[1], incl.
  - Digital Nameplate
  - Provision of Simulation Models
  - Handover Documentation
  - Bill of Material
  - Asset Interfaces Description
- Rest under development, incl.
  - Software Bill of Materials
  - Nameplate for Software in Manufacturing
  - Digital Battery Passport
- Or build your own submodel templates



```
AAS "Bosch_R901509807_1201694127" [IRI, https://boschrexroth.com/ids/aas?p=p652370&m=R
◢ SM "Nameplate" [IRI, http://boschrexroth.com/ids/sm/4343_5072_7091_3242]
    Prop "ManufacturerName" = Bosch Rexroth AG
    Prop "ManufacturerProductDesignation" = 4WRPEH 6 C3 B40L-3X/M/24L1
  ◢ SMC "PhysicalAddress" (5 elements)
      Prop "CountryCode" = DE
      Prop "Street" = Zum Eisengießer 1
      Prop "Zip" = 97816
      Prop "CityTown" = Lohr am Main
      Prop "StateCounty" = Bayern
    Prop "ManufacturerProductFamily" = High-respones directional valve, direct operated
    Prop "SerialNumber" = 1201694127
    Prop "BatchNumber"
    Prop "ProductCountryOfOrigin" = DE
    Prop "YearOfConstruction" = 2019
  ▷ SMC "Marking_CE" (2 elements)
  ▷ SMC "Marking_IO-Link" (2 elements)
  ▷ SMC "Connector_IO-Link" (2 elements)
▷ SM "Document" [IRI, http://boschrexroth.com/ids/sm/2543_5072_7091_2660]
▷ SM "Service" [IRI, http://boschrexr
▷ SM "Identification" [IRI, http://bosc
```

Number of our submodels: 99

[1] https://industrialdigitaltwin.org/en/content-hub/submodels

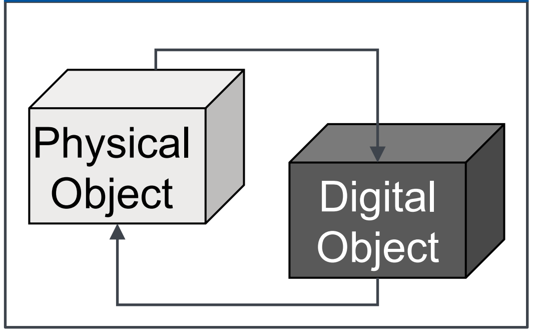
Question

Is the Asset Administration Shell a Digital Twin?

A Digital Twin is a Software System using Data, Models, and Services

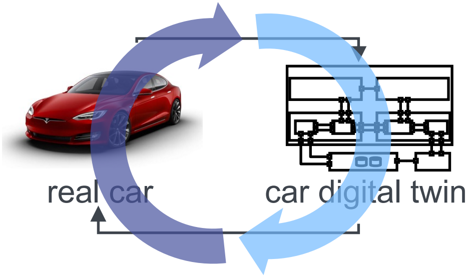
That can represent and control its (cyber-physical) counterpart

Flow-Based DT Model[1]



Physical Object

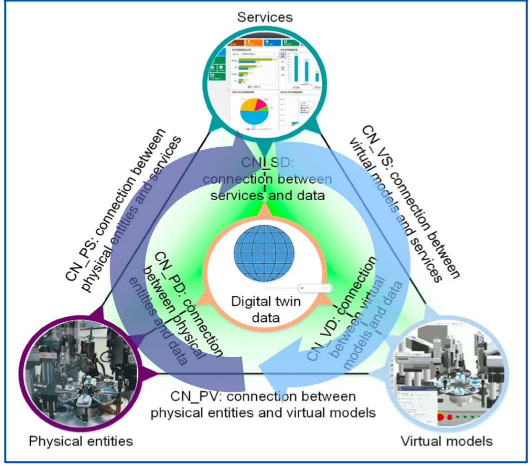
Digital Object



real car

car digital twin

5D Digital Twin Model[2]



Services

CN_SD: connection between services and data

CN_PS: connection between physical entities and services

CN_VS: connection between virtual models and services

CN_PD: connection between physical entities and data

Digital twin data

CN_VD: connection between virtual models and data

CN_PV: connection between physical entities and virtual models

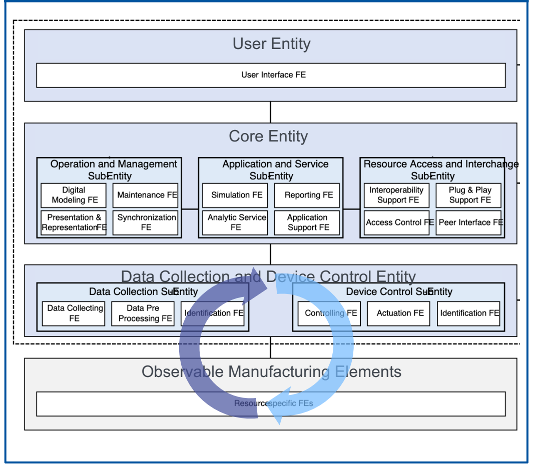
Physical entities

Virtual models

5 Dimensions

(1) CPS, (2) Data, (3) Models, (4) Services, (5) Connections

DT for Manufacturing[3]



User Entity

User Interface FE

Core Entity

Operation and Management SubEntity: Digital Modeling FE, Maintenance FE, Presentation & Representation FE, Synchronization FE

Application and Service SubEntity: Simulation FE, Reporting FE, Analytic Service FE, Application Support FE

Resource Access and Interchange SubEntity: Interoperability Support FE, Plug & Play Support FE, Access Control FE, Peer Interface FE

Data Collection and Device Control Entity

Data Collection SubEntity: Data Collecting FE, Data Pre Processing FE, Identification FE

Device Control SubEntity: Controlling FE, Actuation FE, Identification FE

Observable Manufacturing Elements

Resource specific FEs

Observable Manufacturing Elements:

Physical, biological, chemical, virtual, …

[1] Kritzinger, W., Karner, M., Traar, G., Henjes, J., & Sihn, W: Digital Twin in manufacturing: A categorical literature review and classification. IFAC-PapersOnLine, 2018.

[2] Qi et al.: Enabling technologies and tools for digital twin. In: Journal of Manufacturing Systems, Elsevier, 2019

[3] ISO 23247. Digital Twin Framework for Manufacturing, 2021.

There are Three Types of Asset Administration Shells

At different levels of maturity

Type 1 AAS

- Shells are serialized files
- Contain static information
- Data model governed by AAS meta model
- Describe types and instances of assets as-designed
- No automated dataflows from/to asset

Type 2 AAS

- Runtime instances: may contain static and dynamic information from asset
- Interact w. other components
- Ex: frontend for device services, live sensor data, …
- Properties, operations, events via generic runtime interface
- Automated dataflows only from asset

Type 3 AAS

- Extend type 2 AAS
- Have active behavior
- Can start to communicate & to negotiate on their own
- Well-defined language and message structures (VDI/VDE 2193)
- Automated dataflows from/to asset

Question

How Much Digital Twin do the Three Asset Administration Shell Types Support?

We opted to Analyze very Popular and Important Digital Twin Definitions

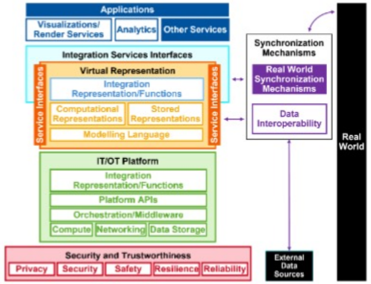
Omitted many less useful defintions[1]

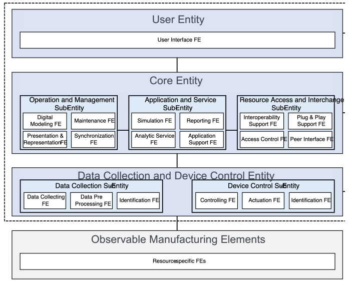
ACADEMIC DEFINITIONS

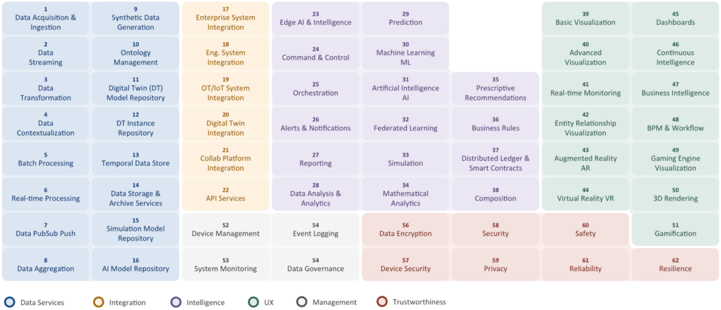
- Based on data flows[2] (Kritzinger et. al)
- Based on dimensions[3] (Qi et. al)

INDUSTRIAL DEFINITIONS

- ISO DT framework for manufacturing[4]
- Digital Twin Consortium (DTC) platform stack architecture for digital twins[5]
- DTC digital twin capability periodic table[6]







1 Data Acquisition & Ingestion	9 Synthetic Data Generation	17 Enterprise System Integration	23 Edge AI & Intelligence	29 Prediction		39 Basic Visualization	45 Dashboards
2 Data Streaming	10 Ontology Management	18 Eng. System Integration	24 Command & Control	30 Machine Learning ML		40 Advanced Visualization	46 Continuous Intelligence
3 Data Transformation	11 Digital Twin (DT) Model Repository	19 OT/IoT System Integration	25 Orchestration	31 Artificial Intelligence AI	35 Prescriptive Recommendations	41 Real-time Monitoring	47 Business Intelligence
4 Data Contextualization	12 DT Instance Repository	20 Digital Twin Integration	26 Alerts & Notifications	32 Federated Learning	36 Business Rules	42 Entity Relationship Visualization	48 BPM & Workflow
5 Batch Processing	13 Temporal Data Store	21 Collab Platform Integration	27 Reporting	33 Simulation	37 Distributed Ledger & Smart Contracts	43 Augmented Reality AR	49 Gaming Engine Visualization
6 Real-time Processing	14 Data Storage & Archive Services	22 API Services	28 Data Analysis & Analytics	34 Mathematical Analytics	38 Composition	44 Virtual Reality VR	50 3D Rendering
7 Data PubSub Push	15 Simulation Model Repository	52 Device Management	54 Event Logging	56 Data Encryption	58 Security	60 Safety	51 Gamification
8 Data Aggregation	16 AI Model Repository	53 System Monitoring	54 Data Governance	57 Device Security	59 Privacy	61 Reliability	62 Resilience

○ Data Services ○ Integration ○ Intelligence ○ UX ○ Management ○ Trustworthiness

[1] List of 112 definitions of the term digital twin: http://www.wortmann.ac/digital-twin-definitions
[2] Kritzinger, W., Karner, M., Traar, G., Henjes, J., & Sihn, W: Digital Twin in manufacturing: A categorical literature review and classification. IFAC-PapersOnLine, 2018.
[3] Qi et al.: Enabling technologies and tools for digital twin. In: Journal of Manufacturing Systems, Elsevier, 2019
[4] ISO 23247. Digital Twin Framework for Manufacturing, 2021.
[5] https://www.digitaltwinconsortium.org/2023/11/understanding-dtcs-digital-twin-platform-stack-architectural-framework/
[6] https://www.digitaltwinconsortium.org/initiatives/capabilities-periodic-table/

Common Requirements on Digital Twins

Based on popular definitions, characterizations, and architectures

Req.	The digital twin …	Sources
R1	can **receive data** from twinned counterpart	All
R2	can **send data** to its twinned counterpart	All
R3	has a **user interface**	DTC, ISO
R4	can **represent** its counterpart digitally	All
R5	can **synchronize** (selected) properties with its counterpart.	Flows, ISO
R6	can **report information** to selected recipients aside from the AAS, e.g., by sending a message to the asset's operator	DTC, ISO
R7	can communicate with **other digital twins**	DTC, ISO
R8	can interact with **third-party systems**	DTC, ISO
R9	provides **services** to act on data and models.	5D, DTC, ISO
R10	can **reason** about data from/about the twinned counterpart as well as about data obtained from other systems	DTC, ISO

What IDTA Requires for a Type 1 AAS Based on Various White Papers

Type 1 AAS are serialized files that contain static information

Req.	Evaluation	Eval	Explanation
R1	**receive data**	○	Just an XML file without any activity
R2	**send data**	○	
R3	**user interface**	○	
R4	**represent**	●	Can represent asset information statically
R5	**synchronize**	○	
R6	**report information**	○	
R7	comm. w. **digital twins**	○	
R8	interact w. **3rd-party systems**	○	
R9	**services**	○	
R10	can **reason**	○	

IDTA requires ● suggests ◐ does not require ○ that feature

What IDTA Requires for a Type 2 AAS Based on Various White Papers

Type 2 AAS are runtime things: may have static/dynamic information from asset

Req.	Evaluation	Eval	Explanation
R1	**receive data**	●	Shall receive asset data via any connection
R2	**send data**	○	
R3	**user interface**	○	
R4	**represent**	●	Can represent system statically and dynamically
R5	**synchronize**	◐	Supports unidirectional, timed synchronization
R6	**report information**	◐	Can use references between submodels to emulate
R7	comm. w. **digital twins**	○	
R8	interact w. **3rd-party systems**	○	
R9	**services**	◐	There is an API for manipulating submodels
R10	can **reason**	◐	There is an API for manipulating submodels

IDTA requires ● suggests ◐ does not require ○ that feature

What IDTA Requires for a Type 3 AAS Based on Various White Papers

Type 3 AASs encompass Type 2 and yield software modules for added-value

Req.	Evaluation	Eval	Explanation
R1	**receive data**	●	Active bidirectional communication with asset
R2	**send data**	●	Active bidirectional communication with asset
R3	**user interface**	○	
R4	**represent**	●	Can represent system statically and dynamically
R5	**synchronize**	◐	Supports unidirectional, timed synchronization
R6	**report information**	◐	Can use references between submodels to emulate
R7	comm. w. **digital twins**	●	Possible via “Industry 4.0 language”
R8	interact w. **3rd-party systems**	●	Required via “Industry 4.0 language”
R9	**services**	◐	There is an API for manipulating submodels
R10	can **reason**	◐	There is an API for manipulating submodels

IDTA requires ● suggests ◐ does not require ○ that feature

Type 3 Asset Administration Shells are Digital Twins

The others not

Type 1 AAS

- Shells are serialized files
- Contain static information
- Data model governed by AAS meta model
- Describe types and instances of assets as-designed
- No automated dataflows from/to asset

→**Idealized, static, description of an asset**

Digital Model

Type 2 AAS

- Runtime instances: may contain static and dynamic information from asset
- Interact w. other components
- Ex: frontend for device services, live sensor data, …
- Properties, operations, events via generic runtime interface
- Automated dataflows only from asset

→**Well-informed Dashboard**

Digital Shadow

Type 3 AAS

- Extend type 2 AAS
- Have active behavior
- Can start to communicate & to negotiate on their own
- Well-defined language and message structures (VDI/VDE 2193)
- Automated dataflows from/to asset
- **Software interfacing asset**

Digital Twin

Challenges and Opportunities for Future Research

Also exploitation

1. **Deriving Twins.** Engineering model, e.g., AutomationML or SysML, comprise vast asset knowledge (connectivity, sensors, actuators, error modes, …) , yet much of this needs to be re-developed for the digital twins → needs means to derive parts of digital twins from engineering models
2. **Component Reuse**. Digital twins have many components to process data, interact with models, communicate to the asset, and run services, yet reusing these components between digital twins is hardly possible → needs digital twin reference architecture with well-defined component interfaces
3. **Digital Twin Reuse.** Systems often comprise subsystems, hence their twins should comprise sub-twins. The composition of digital twins is far from solved → needs systematic method to compose smaller digital twins into larger ones.
4. **Low-Code Configuration**. Digital twins will be configured, used, and understood by domain experts with little programming knowledge. Expecting them to grasp OO data models or stack traces is futile → needs DSLs and interfaces to properly configure and represent cross-cutting twin concerns.

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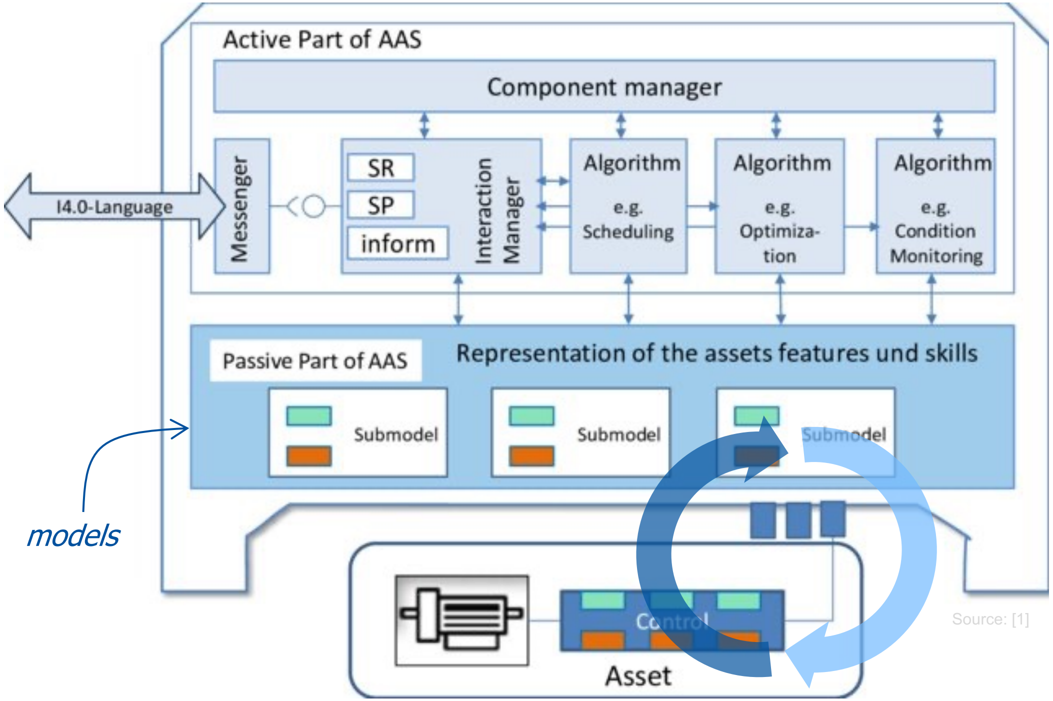
A General Architecture of Type 3 Asset Administration Shells[1]

A potential blueprint for digital twins

- Component manager orchestrates AAS behavior
- Service requester/provider interact with environment
- Algorithms perform computations
- Interact with models and asset
- Reference implementation, e.g., with BaSyx
- A lot of JSON…



Source: [1]

[1] Belyaev, A., Diedrich, C. (2019). Aktive Verwaltungsschale von Industrie 4.0 Komponenten," in Automationkongress 2019, Baden-Baden.