Open reference architecture for engineering model spaces

# Deliverable 6.2

# Cooperation Plan with external Bodies

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# Executive Summary

The WP6 activities (dissemination, standardisation and exploitation) pursue the objective of increasing the visibility of the developed concepts and achieved solutions of the project. Activities need to ensure protection of intellectual property for all project partners, extensive and feasible dissemination of the project outcomes and identifying and scaling up the results that can be exploited after the project period. Consortium partner memberships in different industrial networks are exploited to disseminate the results and support networking for business.

According to the specifications and expected results from WP2-5, cooperation with existing standardization bodies such as VMAP, STEP or IDSA is planned. WP6 will organise the communication and synchronisation of works within SmartEM and the related standardisation communities.

There are various standards for data formats, communication protocols and model management that are important and useful in connection with SmartEM. In most cases, SmartEM use cases can utilise these standards without modification for their planned implementation.

In this document, we focus on those standards that are still under development and for which there may still be open questions from the perspective of SmartEM. We see five areas at which SmartEM could contribute to ongoing standardization activities:

1. VMAP - Technical data from simulation, measurement, and machine monitoring
2. FMI - Solutions to combine (system) models in complex simulation systems
3. UMC4ES - Unification of meta-parameters to characterise models in a model store
4. OMG RAS - addresses the engineering elements of reuse
5. IDS-RAM - Software architecture for data and model spaces

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# 1. Introduction

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1. VMAP - Technical data from simulation, measurement, and machine monitoring
2. FMI - Solutions to combine (system) models in complex simulation systems
3. UMC4ES - Unification of meta-parameters to characterise models in a model store
4. OMG RAS - addresses the engineering elements of reuse
5. IDS-RAM - Software architecture for data and model spaces

For each of these five standardisation activities, D6.2 briefly describes

- the current state of development and the potential benefits for SmartEM
- the potential contributions and enhancements that SmartEM can make to this standard, and
- the planned interactions and communication with the bodies responsible for the standards.

# 2. Standardisation Communities

## 2.1. VMAP Standards - Data from simulation, measurement and monitoring

Weblink: VMAP Standards Community e.V. (VMAP SC)

The VMAP data standard enables the storage of data from

- numerical simulation results,
- physical measurements and experiments, and
- monitoring systems in production machines.

VMAP particularly supports data with spatial and temporal discretisation; this local resolution of information allows physical effects and their causes to be viewed and examined in detail. The uniform storage of data from virtual and physical process steps enables a global view and simplifies the exchange of data in virtual twins.

### 2.1.1. Current status of standard and its relation to SmartEM

The VMAP standard offers a robust framework for storing and exchanging simulation results across engineering domains. Its major features include comprehensive support for meta and user data, detailed representations of geometry and discretization, and consistent handling of coordinate and unit systems. VMAP also accommodates a wide range of result and state variables, ensuring that simulation outputs are captured with precision. To facilitate the integration of material models, the standard provides preformatted containers for storing relevant parameters, streamlining the modelling process.

The reference implementation of VMAP is built upon HDF5, a high-performance data management and storage suite known for its scalability and efficiency. A dedicated software library is available to read and write VMAP-compliant data files, making it accessible to developers and researchers alike. To support adoption and usability, the implementation is accompanied by tutorials and test cases that illustrate practical applications and best practices.

Current development efforts are focused on expanding VMAP's capabilities. These include specific extensions for incorporating measurement and monitoring data, as well as enhanced support for full input model descriptions. A key initiative involves the ontologization of VMAP, which aims to enable semantic search and interoperability by linking VMAP with cross-domain ontologies such as MpCCI Onto. This approach follows a "sandwich" concept for ontology structuring: at the top level, a cross-domain ontology provides broad interoperability; at the middle layer, domain- and use-case-specific ontologies offer tailored semantics; and at the foundation, a general storage ontology based on VMAP ensures consistent data representation.

### 2.1.2. Expected and potential extensions to the standard

The SmartEM project holds significant potential to enhance the VMAP standard across several strategic dimensions. One of its key contributions lies in the development of extensions tailored for combining the already supported rule-based simulation methodologies and AI-driven surrogate modelling disciplines. These additions would broaden VMAP's applicability to emerging computational paradigms and intelligent modelling approaches.

Another promising area is the integration of model meta (characterisation) parameters into the VMAP framework. By embedding these descriptors, VMAP could offer richer context and improved traceability for simulation models, facilitating better interoperability and reuse.

Furthermore, SmartEM supports the evolution of VMAP into a semantic framework through the development of a dedicated 'model management' ontology. This transformation - essentially a direct translation of the VMAP format into a semantic context taxonomy - would enable advanced capabilities for managing, searching, and combining data and models across domains.

Finally, the project could contribute to the implementation of the VMAP format and ontology, paving the way for structured model representations such as UMC4ES (Unified Model Characteristics for Engineering Simulation) or RAS (Reusable Asset Specification) for Simulation) as formal ontologies. These efforts align with the broader goal of establishing a semantically enriched, interoperable ecosystem for engineering data exchange.

### 2.1.3. Communication with the standardisation bodies

Fraunhofer SCAI plays a central role in the VMAP Standards Community, with Klaus Wolf serving as the chair of the VMAP Steering Committee. This leadership position ensures strong coordination and strategic direction for ongoing standardization efforts.

Communication within the VMAP community is actively maintained through several key channels. One important avenue is the regular VMAP Assembly meetings, where SmartEM-specific challenges related to model management are presented and discussed. These sessions foster collaboration and help identify shared needs across different stakeholders. To further support this dialogue, a dedicated VMAP Working Group on Model Management is being proposed. This group would operate similarly to existing working groups such as those focused on Additive Manufacturing, Full Model Storage, and Sensor Data, providing a structured forum for technical exchange and development.

In addition to these collaborative efforts, concrete proposals for VMAP Model Extensions are being developed, accompanied by reference and demonstration implementations. These contributions aim to enhance the VMAP standard's capabilities and usability across various applications.

The standardization work has already yielded tangible results. Notably, VMAP version 2.x introduces advanced features for model management, reflecting the community's evolving needs. These developments are supported by demonstrators and real-world use cases that showcase the practical benefits of the standard. To ensure broad dissemination and engagement, findings and innovations are regularly presented at industry conferences such as the annual VMAP UserMeetings and NAFEMS Conferences, reinforcing VMAP's role as a leading initiative in simulation data interoperability.

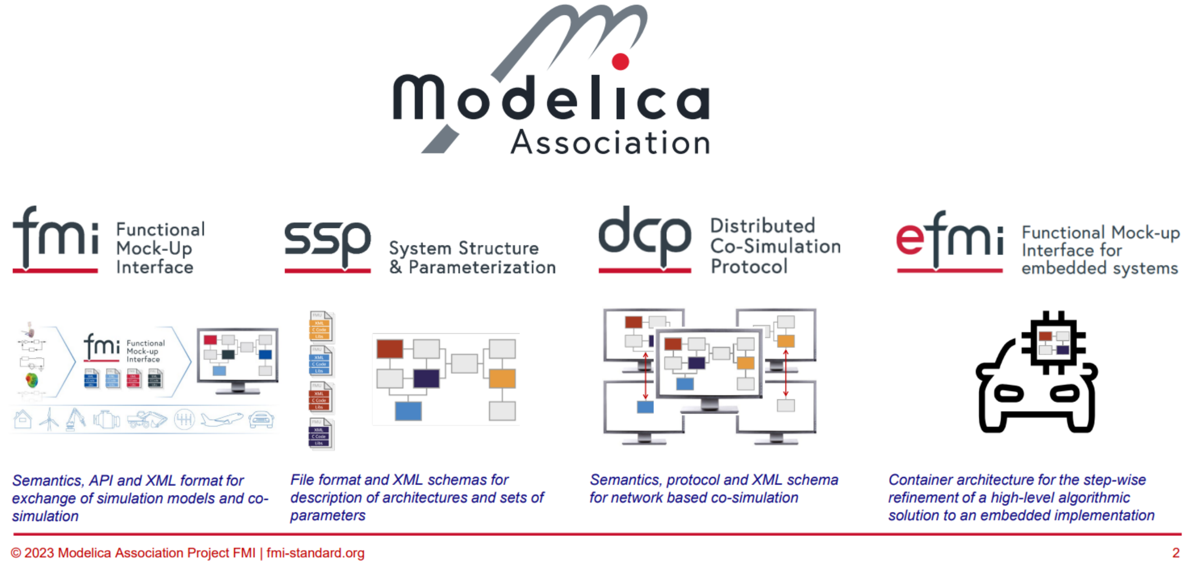
## 2.2. FMI Functional Mockup-Interface – Model extraction and co-simulation

[Functional Mock-up Interface](#)

The Functional Mock-up Interface is a free standard that defines a container and an interface to exchange dynamic simulation models using a combination of XML files, binaries and C code, distributed as a ZIP file. It is supported by 250+ tools and maintained as a Modelica Association Project.

### 2.2.1. Current status of standard and its relation to SmartEM

**FMI - DCP - SSP - eFMI : a Coordinated Set of Standards**




The Functional Mock-up Interface (FMI)[1] is a standardized framework designed to facilitate the exchange and simulation of dynamic models. At its core is the Functional Mock-up Unit (FMU), a ZIP archive that bundles together XML files, binaries, and C code. This archive allows simulation environments—known as importers—to instantiate and simulate models, often in combination with other systems.

FMI supports three distinct interface types: Co-Simulation (CS), Model Exchange (ME), and Scheduled Execution (SE). In Co-Simulation, the FMU includes its own solver or scheduler, enabling it to manage its internal computations. Model Exchange, on the other hand, relies on the importer to handle numerical integration. Scheduled Execution allows the importer to trigger specific model partitions, offering fine-grained control over execution timing.

Despite their differences, these interface types share a foundation of common concepts. Central to FMI is its Application Programming Interface (API), which uses standardized C functions to initiate computations within the FMU. The FMU can also communicate back to the importer using callback functions. C is chosen for its portability and compatibility with embedded systems, and while FMUs may use operating system services, they are encouraged to minimize platform dependencies for broader applicability.

The FMI Description Schema, defined in XML, outlines the structure and content of the modelDescription.xml file. This file includes all exposed variables, their interdependencies, and the FMU's capabilities. By separating variable descriptions from the C API, importers can efficiently manage these definitions in their own internal formats without incurring performance penalties.

[1] https://fmi-standard.org/docs/3.0.2/)

FMUs are distributed as ZIP files that contain everything needed for simulation: the modelDescription.xml, platform-specific binaries (.dll or .so), source code for FMI functions, documentation, and any auxiliary data such as tables or maps. This packaging ensures that FMUs are portable, self-contained, and ready for integration into diverse simulation environments.

The Functional Mock-up Interface (FMI) offers two key approaches for integrating and simulating models: Model Exchange (ME) and Co-Simulation (CS).

In Model Exchange (ME), the FMU provides a system of equations—differential, algebraic, and discrete—that describe the model's behaviour. These equations include various types of events such as time, state, and step events. The importer, typically equipped with an ODE or DAE solver, is responsible for managing the simulation process. This includes advancing time, updating states, and handling events, making ME ideal for environments that already have robust solvers.

Co-Simulation (CS), on the other hand, is tailored for scenarios where models are exported along with their own solvers. These FMUs are self-contained and can be run independently, allowing for the integration of entire simulation tools or subsystems. CS is particularly useful for coupling different simulation environments or pre-solved model components into a unified simulation workflow.

### 2.2.2. Expected and potential extensions to the standard

The Functional Mock-up Interface (FMI) standard, particularly through its Functional Mock-up Units (FMUs), provides a structured approach for deploying extractable models - typically packaged as libraries - across various execution platforms. However, its descriptive capabilities are relatively limited, relying primarily on XML schemata. This constraint becomes evident when compared to more expressive frameworks such as UM4CES or RAS, which offer richer semantic and structural descriptions.

In contrast, the SmartEM use-case environments embraces a broader spectrum of implementation strategies and execution environments. There is a strong need for diverse modelling approaches, although certain subsets of SmartEM models could still be effectively encapsulated within FMUs. This opens up opportunities for mutual learning: SmartEM can benefit from the modular principles and interoperability strengths of FMI, while FMI could evolve by learning from SmartEM's divers modelling concepts.

A particularly promising direction involves extending FMI to support AI-based surrogate models. Enabling these models to be packaged and executed as FMUs would significantly enhance the standard's relevance in data-driven simulation workflows, bridging the gap between traditional numerical models and modern machine learning techniques.

Finally, the notion of “co-simulation” within the SmartEM context warrants a more nuanced interpretation. Rather than simply coordinating execution across platforms, co-simulation in SmartEM implies a dynamic interplay between rule-based logic, surrogate intelligence, and semantic model integration. It reflects a collaborative simulation ecosystem where diverse model types and ontologies interact to produce coherent, context-aware results.

### 2.2.3. Communication with the standardisation bodies

The FMI initiative is guided by a dedicated leadership team, with Christian Bertsch from BOSCH serving as Project Leader and Torsten Sommer from Dassault Systèmes as Deputy (projectleader@fmi-standard.org).

Once a clearer and more generalized understanding emerges around how a typical SmartEM model is generated, annotated, extracted, stored, combined, and coupled, the SmartEM plans to present these insights at one of the regular Modelica or FMI meetings. This would serve as a starting point for broader discussions on how SmartEM concepts can be integrated into future FMI developments.

On the standardization front, several promising outcomes are anticipated. These include proposals for extensions or adaptations to existing model description formats, helping to better accommodate the needs of SmartEM and similar applications. Demonstrators and use cases will be developed to illustrate the practical benefits of these enhancements. Furthermore, the results and methodologies will be shared with the broader community through presentations at key industry events, such as Modelica conferences, ensuring visibility and fostering continued engagement.

## 2.3. UMC4ES – Model meta parameter definitions

NAFEMS - Unified Model Characteristics for Engineering Simulation - Draft 4.0

UMC4ES is a specification of unified model characteristics defined by NAFEMS' ASSESS (Analysis, Simulation, and Systems Engineering Software Strategies) initiative. The ASSESS initiative defines engineering simulation as "the use of physics-based mathematical (numerical) models and/or logical models, including relevant data derived from physical tests of a conceptual or real-world system, phenomenon, or process in studying its technical requirements and/or operational behavior." The physics-based mathematical models are used to perform behavioural response simulations of a system, whereas logical models are used to capture descriptive representations of a conceptual or real-world system, phenomenon, or process in studying its technical requirements and operational behaviour.

UMC4ES proposes model characteristics metadata that unifies metadata proposed by other, typically purpose-specific, initiatives. The most prominent of these other initiatives are INCOSE's Model Characterization Pattern (MCP), ISO 10303-243 Modeling and Simulation information in a collaborative Systems Engineering Context (MoSSEC), SystemX's Model Identity Card (MIC), and the LOTAR NAS9300-520 standard. UMC4ES is an attempt to define a comprehensive set of characteristics for the complete range of engineering simulations.

UMC4ES started from the hierarchical INCOSE MCP structure and incorporated characteristics from MoSSEC, MIC and NAS9300-520 and establishing a mapping between UMC4ES' characteristics and the other initiatives' characteristics. UMC4ES involves 28 features divided over 6 feature groups: Model Identity and Focus (5 features), Model Scope and Content (7 features), Model Representation (2 features), Model Utility (2 features), Model Assessment (7 features), Model Lifecycle Management (7 features). Each feature has multiple attributes, instances and instance attributes.

### 2.3.1. Current status of standard and its relation to SmartEM

UMC4ES focuses on the definition of a unified set of model characteristics that may be used across multiple implementations or as the basis of a standard definition. These characteristics are assigned to an ES Model to support processes, activities, business purposes, and higher-level models. Processes and activities can be treated as other types of ES Models. However, further investigation may be needed to map all appropriate process & activity model characteristics.

UMC4ES will undergo an iterative development process that includes:

1. Definition of the initial metadata structure.
2. Review/revision of the metadata structure based on the data structure of other metadata implementation approaches.
3. Mapping to/from the reviewed implementation perspectives.
4. Repeat Steps 2 & 3 for all implementation perspectives of interest.

UMC4ES is not a proposed standard and it is unknown whether or when it will become one. The latest working draft, version 4.0, was released in 2023.

UMC4ES does not involve an implementation technique. A possible technology to implement UMC4ES' characteristics is OMG's Reusable Asset Specification (RAS). RAS is discussed in Section 2.4.

UMC4ES' characteristics provide a candidate characterisation to be used in SmartEM's model store. Its unified nature makes that it is applicable for a general application. Its unified nature is also a drawback for usage in specific domains: as it involves many elements, it may be deemed too heavy for specific applications.

### 2.3.2. Expected and potential extensions to the standard

SmartEM could contribute to the (future) UMC4ES standard in several ways:

- SmartEM's demonstrator involves reusing and combining models. The creation of the demonstrator will reveal which model characteristics are relevant when combining engineering models. This could provide proposals to extend UMC4ES' current set of characteristics.
- UMC4ES is being developed in industries that involve large many-year projects with many stakeholders. Some of SmartEM's industrial partners work in industries, whose projects are much smaller. SmartEM could assess whether UMC4ES is also suitable in such industries, or whether it could be customized for a specific domain or company.
- UMC4ES focuses on the technical aspects of engineering models. It does not have parameters regarding IP, compliance with regulations, legal aspects, etc. SmartEM could communicate the relevance of these aspects to the UMC4ES working group and discuss possible introduction of such aspects.
- SmartEM's activities in WP4 on surrogate modelling could provide input for UMC4ES' suitability for characterising AI-based surrogate models.

#### 2.3.3. Communication with the standardisation bodies

The ASSESS initiative's website is located at nafems.org/assess. Joe Walsh (joe.walsh@nafems.org) founded the ASSESS initiative and continues to lead it within the context of NAFEMS. ASSESS' general email address is assess@nafems.org.

The ASSESS working group working on UMC4ES involves six people: Joe Walsh, Scott Shaw, Rod Dreisbach, William Schindel, Laura Michalske, and David Leal. Joe Walsh appears to be main spokesperson to the outside world; he has presented UMC4ES on multiple occasions.

## 2.4. OMG RAS – Reusable Assets

About the Reusable Asset Specification Version 2.2

The Reusable Asset Specification (RAS) is a standard of the Object Management Group (OMG) that provides a set of guidelines and recommendations about the structure, content, and descriptions of reusable digital assets. It distinguishes different categories of reusable digital assets, including digital models. It provides a standard to describe reusable digital assets to streamline their reuse

RAS consists of two main parts: Core RAS and profiles. Profiles are instantiations of Core RAS. Core RAS defines assets as having a profile, a classification, a solution, a usage and related assets (see Figure 2.1).

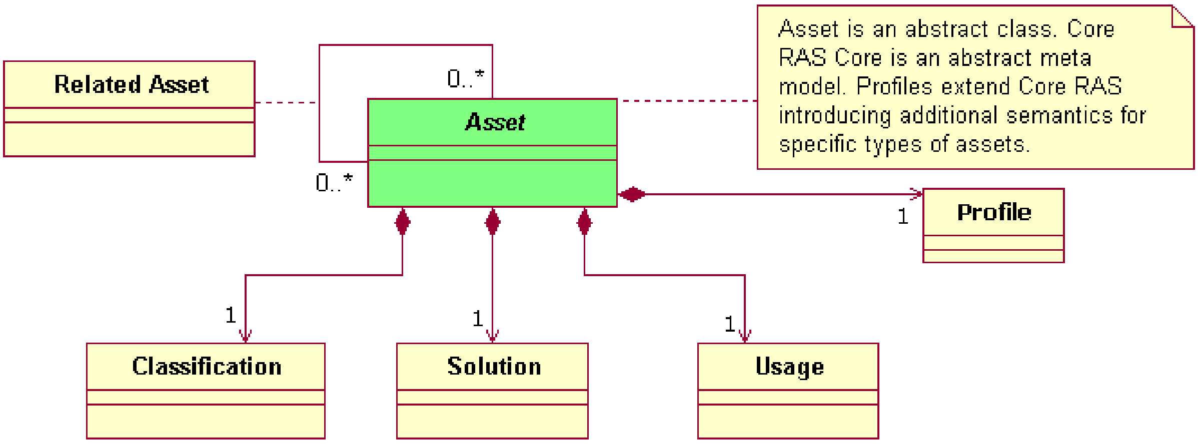



**Figure 2.1 Core RAS major sections (source: https://www.omg.org/spec/RAS/2.2/PDF)**

An asset's profile specifies the type of asset, its classification lists a set of descriptors for classifying the asset as well as a description of the context(s) for which the asset is relevant, it solution describes the asset's artifacts, its usage describes rules for installing, customising, and using the asset and its related assets describes the asset's relationship to other assets.

RAS applies XML to formally specify a reusable digital asset. It comes with a default profile XML schema, from which XML documents can be generated that describe reusable digital assets.

### 2.4.1. Current status of standard and its relation to SmartEM

RAS 2.2 was approved by OMG's Board of Directions and released in November 2005. RAS can provide an implementation technology for SmartEM. Most model characterisation standards, like UMC4ES (see Section 2.3), do not have an implementation technology. RAS' XML schemata and its API can be used to define and use model characterisations.

### 2.4.2. Expected and potential extensions to the standard

At the INCOSE International Symposium 2025, plans for an update of the standard were presented. RAS 3.0 seeks to build upon and simplify the current RAS 2.2, OMG's Data Product standard (DPROD) and DoD's Modeling and Simulation Community of Interest Discovery Metadata Specification (MSC-DMS) specifications. DPROD's design principles include semantic web principles, decentralisation and data governance and MSC-DMS' include comprehensive description, discovery metadata and security and trust levels.

The technical input for RAS 3.0 has been decided. The next step in the development of RAS 3.0 is the preparation of RAS 3.0 specification documents.

### 2.4.3. Communication with the standardisation bodies

After the INCOSE International Symposium 2025, TNO has been in contact with the coordinators of RAS3.0, Matthew Hause of SSI (mhause@systemxi.com) and Sriram Krishnan of Istari Digital (skrishnan@istaridigital.com) about SmartEM involvement in the development of RAS 3.0. This contact revealed that contribution to RAS 3.0 requires a (full) membership, which is quite expensive.

## 2.5. IDS-RAM – Open reference architecture for model store architectures

IDS RAM 5 Working Draft 1

The IDS-RAM (International Data Spaces Reference Architecture Model) provides a conceptual framework for designing and implementing IDS-compliant data spaces, following the IDSA Rulebook. It defines the key roles, their interactions, the components, and the principles that govern the architecture of an IDS data space.

This working draft of IDS RAM-5 is not a complete version, but rather a preliminary draft to guide the ongoing development.

**Visions for IDS-RAM5**

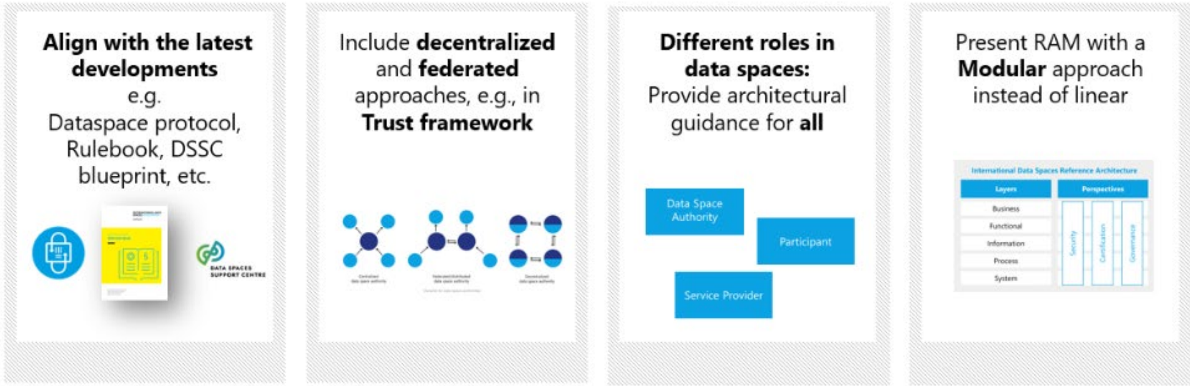



*Figure 1.1: Improvements envisioned for IDS RAM 5 at a high-level*

RAM 5 will be aligned with the latest developments in IDSA and Data Spaces. It will provide an overview for technical readers on how to create an architecture for a data space, to participate in a data space, and to provide value added services for data spaces. To do so, RAM5 will sketch architectural decision areas for different roles in data spaces.

The RAM 5 document will not be a linear document like RAM 4.0 but will contain links between parts of the layers and perspectives. Other improvements in RAM 5 will include description of decentralized approaches and updates to the information model, among other things.

### 2.5.1. Current status of standard and its relation to SmartEM

The current version of IDS-RAM (RAM 4.0) is built on a five-layer architecture and three horizontal perspectives to ensure trustworthy data sharing. The Business Layer defines the roles of stakeholders and business models within the data sharing ecosystem. The Functional Layer contains the functional services supporting these business models, such as the Connector, Broker, and Identity Provider. The Information Layer describes the semantic models and vocabularies used in data exchange. The Process Layer ensures the interoperability of functions and defines how interactions between roles are harmonized, while the System Layer provides the technical infrastructure and guarantees secure communication [1].

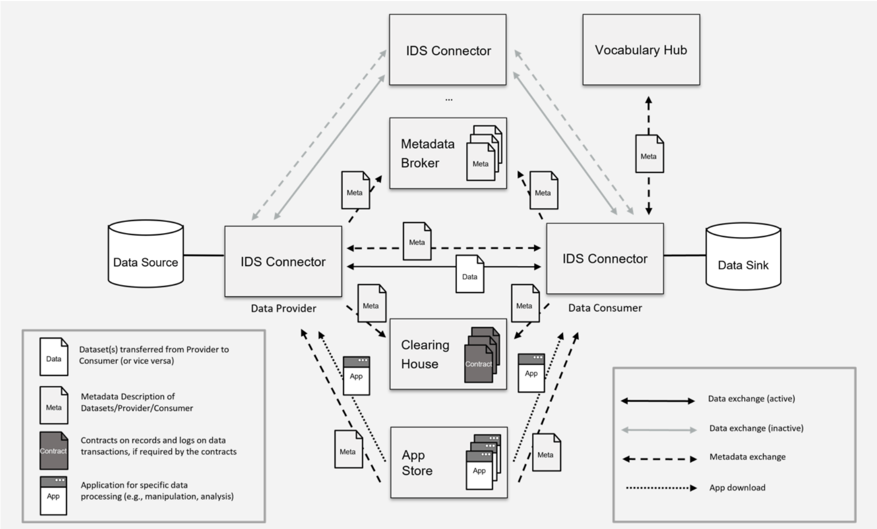



**Figure 2.2. Technical Interaction Between Components [1]**

This structure Figure 1, is complemented by three perspectives: Security, Certification, and Data Governance. Security ensures protection of data through authentication, access control, and encryption mechanisms. Certification provides assurance that participants and components comply with established criteria. Data governance guarantees the enforcement of data usage policies and contracts. This threefold approach is critical for SmartEM, as it enables not only technical but also governance-related trust in energy-focused applications [1].

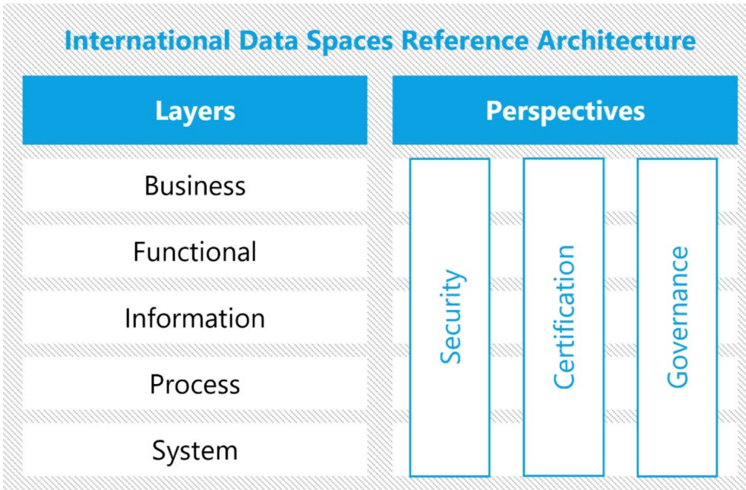



**Figure 2.3. IDS Reference Architecture [1]**

IDS RA is shown in Figure 2. Currently, RAM 4.0 provides the stable framework forming the foundation of IDS, while the vision of RAM 5 introduces decentralized approaches, cross-layer connections, and an updated information model. One of the main goals of RAM 5 is to treat security not as a separate element but as an integral part of the entire architecture. Moreover, unlike previous versions, RAM 5 is expected to evolve from a linear document to one that highlights interconnections between layers and perspectives [1].

For SmartEM, this architecture offers a framework to securely share energy-related data. SmartEM can use IDS components to connect IoT devices and data lakes, publish energy data through a Metadata Broker, and ensure access is granted only to authorized actors via Identity Providers. In this way, SmartEM can leverage model stores not just as a data repository but as an ecosystem component enriched with security, certification, and governance mechanisms [1].

### 2.5.2. Expected and potential extensions to the standard

Unlike RAM 4, RAM 5 will no longer be a linear document but will establish interconnections between layers and perspectives, treating security not as a separate item but as an inherent element of the entire architecture. In addition, RAM 5 introduces decentralized approaches, an updated information model, and a documentation structure that evolves through community contributions [1].

Expected potential extensions relevant to SmartEM include:

- Domain-specific profiles (e.g., sector-specific vocabularies and policies for energy),
- Model Store integration,
- Inclusion of semantic standards (e.g., CIM, Green Button) into the IDS Information Model and Vocabulary Hub,
- Real-time data exchange with low-latency and secure streaming,
- Development of federated data spaces,
- Compliance with GAIA-X and GDPR,
- Lightweight certification mechanisms for SMEs,

Advanced privacy-preserving methods such as homomorphic encryption and federated learning.

### 2.5.3. Communication with the standardisation bodies

For SmartEM, sustainability relies heavily on close communication with IDSA and other standardisation bodies. SmartEM can participate in IDSA's Standards and Norms and Architecture working groups to present its requirements and report implementation challenges (e.g., certification for small devices, performance bottlenecks) back to IDSA.

In addition, collaboration with energy-related standardisation bodies such as IEC, and coordination with European initiatives such as GAIA-X and BDVA, will enhance the visibility and impact of SmartEM. Community contributions can also be achieved through open-source code sharing, webinars, and scientific publications. Encouraging energy stakeholders to join IDSA would strengthen the trust network. Although IDSA was included as a partner in the SmartEM project proposal, Germany did not receive funding; nevertheless, maintaining open communication channels remains essential for contributing to standardisation processes [1].

- Contact points
  - The 'International Data Spaces e.V. (IDS)' was partner in the initial SmartEM FPP proposal – but unfortunately Germany did not get any funding
  - IDS people (e.g. Thorsten Hülsmann, others) will be first points of contact for further discussions with IDS
  - IDS-RAM is co-created by the members of the International Data Spaces Association as part of the activities in the IDSA Working Group Architecture. To become a contributor, please consider joining IDSA and register using the interest form for RAM 5.
- Ways of communication
  - Participation in dedicated working groups – e.g. IDS Working Group Architecture
  - Presentation of specific challenges for model management at …
  - Establishing a new 'IDS Special Interest Group'
  - …
- Standardisation related results
  - Proposals for IDS extensions/adaptions

- Demos and use cases
- …
- Publication on related conferences, e.g. at …

**References**

[1] International-Data-Spaces-Association, "IDS-RAM 4.0 — documentation," GitHub, Jun. 13, 2025. [Online]. Available: https://github.com/International-Data-Spaces-Association/IDS-RAM_4_0/tree/main/documentation . [Accessed: Sep. 29, 2025].