D3.1 EEB Data Models Review Semantic Alignment and Further Enhancement Needs

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EXECUTIVE SUMMARY

This deliverable presents an analysis of the data modelling landscape with the elaboration of specific open standards, semantic models and ontologies relevant to the BEYOND project.

Initially, the scope and objectives of the deliverable are presented alongside with the project aims, objectives and system architecture.

(i) Taking into consideration that there are numerus standards and ontologies covering:
(ii) demand response in buildings;
(iii) machine-to-machine communication and interoperability enhancement at smart building level;
(iv) building data model representation;
(v) business synergies and data exchange between buildings and energy system or network stakeholder a methodology for defining their applicability within the project BEYOND has been developed.

There are ontological standards only focusing on relationships between the modelled entities, communication standards closely focusing on communication layer interoperability, and everything in between.

Compliant with the methodology described in Chapter 1, the identification of BEYOND aims, objectives and needs with the initial requirements for the reference architecture outlined in WP 2, is described in Chapter 2. Additionally, the rationale for the selection of appropriate data models are described.

Congruent with the methodology 42 data models, standards and ontologies related to BEYOND are thoroughly analysed in Chapter 3.

Finally, key findings towards the definition of the BEYOND Common Information Model (CIM) is suggested. For the proper coverage of Energy Efficient Buildings (EEB) data modelling landscape a noteworthy gap identification in the existing standards and ontologies landscape has been performed.

As the uttermost goal of this deliverable further enhancement needs in the data modelling landscape are listed.

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ABBREVIATIONS

AI	Artificial intelligence
AP	Access Point
API	Application Programming Interface
BEMS	Building Energy Management Systems
BIM	Building Information Model
BRP	Balance Responsible Party
CAD	Computer Aided Design
CBDMP	Core Big Data Management Platform
CIM	Common information model
DERs	Distributed Energy Resources
DNAS	Drivers, Needs, Actions and Systems
DSO	Distribution system operator
ED	End Device
EEB	Energy Efficient Buildings
ESCO	Energy Savings Company
EU	European Union
HVAC	Heating, ventilation, and air conditioning
IEC	International Electrotechnical Commission
IoT	Internet of Things
KPI	Key Performance Indicator
M2M	Machine to Machine
OPE	On-Premise Environment
PAN	Personal Area Network
PLC	Programmable Logic Controller
RES	Renewable energy sources
SEP	Secure Experimentation Playground
SGAM	Smart Grids Architecture Model
SPINE	Smart Premise Interoperable Neutral Message Exchange
TSO	Transmission system operator
VEN	Virtual End Node
VTN	Virtual Top Node
WP	Work package

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INTRODUCTION

0.1 Scope and objectives of the deliverable

The aim of deliverable D3.1 "EEB Data Models Review Semantic Alignment and Further Enhancement Needs" is to extensively study the EEB data modelling landscape and select specific open standards imperative propositions development towards the BEYOND CIM.

This deliverable analyses existing data models, formats, and standards relevant to buildings domain, energy efficiency and energy system components communication and evaluates how appropriately they meet the needs of the BEYOND project.

The objective of this deliverable is to scrutinize and select specific data models which are adequate for further elaboration in the BEYOND project. Furthermore, this deliverable aims to elaborate the identified weaknesses and harmonization needs towards achieving a comprehensive coverage of existing data models for the purposes of the BEYOND project alongside with the design and development of the BEYOND CIM.

0.2Project aims, objectives and system architecture.

The European energy sector is undergoing a major fundamental change with the increasing digitalization of energy assets, due to the ongoing roll-out of smart meters and the shift away from traditional monitoring and control approaches that have been applied exclusively over energy assets, since the smart and sustainable energy era is pushing sensing, control and data collection at the edge of energy systems, which need to be further re-defined due to the wide penetration of Distributed Energy Resources (DERs), such as renewable energy sources (RES), smart home devices & appliances/Internet Of Things (IoT) and smart meters among others.

The increasing growth of DERs, is continuously expanding the "end" or the energy system "edge", in terms of controllability, while increasing its operational complexity, since the amount of data (and controllable assets) is growing exponentially and "understanding" of the knowledge encapsulated in these big data streams will be critical for meeting operational requirements for high efficiency and for safeguarding business interests.

The edge of the energy system is currently dominated by the building sector, not only in terms of quantity but also in terms of criticality for the envisaged energy transition, since buildings are the largest energy consumer worldwide (accounting for almost half of the world's consumption). As technology advances and becomes more affordable, buildings are no longer perceived merely as depreciating assets, but are transforming themselves into smart buildings which are associated with the generation of vast amounts of data, spanning Building Energy Management Systems (BEMS), smart metering and sub-metering information (demand), IoT device information (sensing/control), distributed generation (RES), storage and electric vehicle data, altogether characterized by continuously increasing growth rate, multi-diverse spatiotemporal resolutions and huge volume.

BEYOND introduces a novel framework and reference big data architecture and AI Analytics Toolkit that leverages data, primary or secondarily related to the building domain, coming from diverse sources (data APIs, historical data, statistics, sensor / IoT data, weather data, energy market data and various other open data sources, like the EU Building Stock Observatory, building-relevant databases and data hubs at national and international level). The goal of such an architecture and of the services that will be offered on top of it is to improve intelligence on building performance-related optimization functions through advanced AI-analytics-based services destined for the building sector and its energy performance optimization. At the same time BEYOND addresses business and optimization needs of the variety of stakeholders involved in the energy system value chain and are dependent in various ways to data streams generated by the building sector, by increasing their data reach and allowing them to access, process and analyse myriads of diverse building-related and external data assets, towards enhancing their knowledge, intelligence and optimizing their processes, both on the business (financial benefits, informed decision-making, innovative energy service provision) and policy side (evidence-based policy planning), through the utilization of innovative sharing / trading models of data sources and intelligence.

Ultimately, BEYOND brings forward a reference Big Data Management Platform, on top of which an advanced AI analytics toolkit will be offered allowing for the delivery of derivative data and intelligence out of a blend of real-life building data and relevant data coming from external sources (batch and real-time).

In this context, it becomes apparent that for such an infrastructure to be set up and operate in accordance with its functional requirements and with the necessary guarantees for the quality of service it shall provide, there is a need to clearly define its structural components in such a manner that existing standards and data models of the relevant domains are reused, as interoperability, reuse of existing systems, data privacy guarantees, data management performance and the ability to easily connect to BEYOND are key points towards its successful deployment and adoption by the different stakeholders. All those aspects do greatly impact how the different underlying models should be structured for such an architecture to work, while at the same time the existing model do dictate from their side how certain pillars in the architecture should be formulated in order to facilitate both backward compatibilities, but also future proofing of the overall system based on emerging and dominant standards.

As such, the work that is presented in this deliverable, takes into consideration all these aspects, which are expressed as "needs" from the technical perspective of the project (presented under section 2), tries to identify gaps and influence the decisions that should be drawn during the tasks of the detailed architecture definition and of the Common Information Model development.

0.3 Structure of the document

The scope and objectives of the deliverable are presented accompanied by the project aims, objectives and system architecture in the Introduction chapter.

The methodology applied in the scrutinization of data models potentially relevant to BEYOND is presented in Chapter 1 along with the used approach, data collection process and evaluation of the provided templates, scope and method.

Chapter 2 is dedicated to the identification of BEYOND needs and the needs deriving from the reference architecture and introduces the semantic scope of the BEYOND target data model.

The presentation of the scrutinized data models is organized in Chapter 3 while key findings and gap identification accompanied with further enhancement needs are elaborated in Chapter 4.

Main conclusions are indicated in Chapter 0.

1. Methodology

1.1 Approach

The initial step for data models scrutiny and assessment of their applicability in BEYOND was to develop an initial list of standards and ontologies currently in application in building assets, energy system components and energy efficiency domain. In order to perform such data collection, a literature analysis in that domain has been performed and specific data models were selected regardless their level of their applicability in practice.

In a second stage, demo partners were contacted with the intention to enrich the initial list and provide their feedback against the applicability in the building sector. Additionally, observations in relation to specific standards and ontologies applicability concerns were collected. Hence, standards and ontologies used in everyday operation by demo partners were prioritize as essential for further elaboration and application in the framework of BEYOND.

In order to perform an assessment of data models, collected standards and ontologies were classified against their applicability for:

(i) demand response in buildings;
(ii) machine-to-machine communication and interoperability enhancement at smart building level;
(iii) building data model representation and
(iv) business synergies and data exchange between buildings and energy system or network stakeholder.

Moreover, for each specific standard and ontology, stakeholders as potential data models' users were identified (DSO, TSO, BRP, ESCO, energy retailer, aggregator, consumer/prosumer, building/facility manager, or local authority).

In such manner and congruent to the applied categorization a weaknesses and applicability analyses, for each listed data model, was performed. A straightforward ranking based on the data models used in everyday operations by demo partners and highly dispersed standards and ontologies in the building sector, combined with the most suitable data models in relation to the scope of BEYOND was created.

Based on the results of the described scrutinization approach most suitable data models for the purposes of BEYOND were identified and elaborated in Chapter 3. Since numerous standards and ontologies are covering the building domain and business synergies between involved stakeholders, this deliverable introduces a gap identification where different levels of maturity between data models have been identified and selected according to the scope of BEYOND. Furthermore, based on the results delivered by this document, Chapter 4 introduces the related propositions towards the development of the BEYOND CIM which will be further elaborated and described in Deliverable 3.2.

1.2 Data Collection

The data collection process for the selection of BEYOND related data models started in M1 of the project.

Initially, based on the literature analyses a first screening on the state-of-the-art EEB data models review which involved 42 different standards and ontologies was listed. This scrutiny evolved from current achievements from EU funded project such as DELTA (DELTA Project No 773960, 2021; A. Fernández-Izquierdo; A.Cimmino; R. García-Castro; M. Poveda-Villalón; S. Terzi; C. Patsonakis , 2019), FLEXCoop (FLEXCoop Project No 401790, 2019; H. Keko; S. Sučić; K. Tzanidakis; C. Malavazos; P. Hasse; A. Wolf , 2018) and HOLISDER (HOLISDER Project No 768614, 2020), enriched with specific data models applicable or potentially applicable in EEB.

For the purposes of this deliverable, a data collection template for D3.1 was created by KONČAR and circulated among all the consortium partners. Specific attention has been dedicated to the feedbacks from demo partners spanning from DSO (Cuerva), District Heating Network Operator (BEOELEK), Aggregator (Urbener), ESCO (IGM), Energy Retailers/ Suppliers (Mytilineos, Cuerva, BEOELEK), Facility/ Building Managers and Renovation Specialists (FVH, IGM) and City Authoritiy / Urban Planner (FVH).

The initial list was further enhanced and a final list counting 42 data models, of which:

- 24 standards;
- 18 ontologies;

for further scrutiny within the scope of BEYOND.

1.3 Evaluation Scope/Method/Templates

To ensure uniformity of data collection, related to standards and ontologies applicable in the framework of BEYOND, a dedicated template has been created by KONČAR and circulated among partners. The data collection template incorporates the following information:

- *Main reference;*
- *Title;*
- *Type (standard, ontology);*
- *Scope;*

- *Type of data model (Y/N answers)*
  - *Communication standard*
  - *Communication and semantic interpretation*
  - *BIM*
  - *Ontology*
- *Relevance to BEYOND (Y/N answers)*
  - *demand response in buildings;*
  - *machine-to-machine communication and interoperability enhancement at smart building level;*
  - *building data model representation and*
  - *business synergies and data exchange between buildings and energy system or network stakeholder.*
- *Scope of application (stakeholders):*
    - *DSO,*
    - *TSO,*
    - *BRP,*
    - *ESCO,*
    - *energy retailer,*
    - *aggregator,*
    - *consumer/prosumer,*
    - *building/facility manager,*
    - *or local authority*
- *Weakness and Applicability comments.*

The assessment method is in conformity with the input data retrieved from the mentioned template. All the inputs have been analysed according to the data models coverage scope and indicated priority. In consonance with the identification of BEYOND needs, described in Chapter 2, most applicable standards and ontologies have been selected and described in Chapter 3.

According to the assessment method, the scope of BEYOND selected data models is covering demand response in buildings, machine-to-machine communication and interoperability enhancement at smart building level, building data model representation and business synergies and data exchange between buildings and energy system or network stakeholder.

An example of various filled form is shown in Figure 1.

					BEYOND related								Scope of application									GAP identification	
	Main reference	Title	Type	Scope	Communication standard	Communication and semantic interpretation	BIM	Ontology	DR in buildings	Machine-to-machine communication and interoperability enhancement at smart building l	Building Data Model representations	Business synergies and data exchanges between the building and energy system/network stakeholders	DSO	TSO	BRP / Market	Retailer	Aggregators	Customer / Prosumer	ESCO	Building/ Facility manager	Local authority	Weaknesses	Applicability
1	OpenADR, IEC 62746	Smart grid user interface	Standard	Events, measurements, Equipment	Y				Y			Y	A	A	NA	A	A	A	PA	A	NA	Relevant for energy system stakeholders. The specification of the OpenADR supports a wide range of different types of signals including direct load control interactions. The OpenADR standard only provides the DR message exchange and none of the actual underlying application logic.	For the BEYOND project, the most relevant standard among the 62746 group of standards is probably the IEC 62746-10: Open Automated Demand Response (OpenADR 2.0b Profile Specification), which represents the adoption of the OpenADR Alliance standard as the IEC standard. In this document, the IEC 62746-10 and OpenADR are used interchangeably to refer to the same standard. This standard is a flexible data model to facilitate common information exchange between electricity service providers, aggregators, and end users.
2	IEC 62939	Smart grid user interface	Standard	Events, measurements, Equipment	Y				Y			Y	A	A	A	A	A	A	PA	A	NA	This is a conceptual standard: it is relevant for BEYOND deployments only in the design phase. In the practical implementation of an **information** model, this is not that relevant.	Defines and utilizes the Virtual End Node (VEN) and Virtual Top Node (VTN) concepts, which are important in the OpenADR standard. The VEN has operational control of a set of resources and/or processes. It can control the output or demand of these resources and thus affect their production or use of electrical energy intelligently, in response to an understood set of smart grid messages. The VEN may be either a producer or consumer of energy. The VEN is able to communicate (2-way) with a VTN receiving and transmitting smart grid messages that relay grid situations, conditions, or events. A VEN may take the role of a VTN in other interactions.
3	IEC 61968/61970	CIM (Common information model)	Standard	Events, Measurements, Equipment, Products	Y				Y			Y	A	A	NA	A	A	A	PA	A	NA	Probably the biggest problem of IEC CIM (as in IEC 61968/61970) is its overhead and strictness of the ontology imposed on top of the data, as well as only covering the electric power system appropriately. While other energy carriers have been introduced relatively recently, it does remain the most important semantic modeling standard in electric power systems. In short - we must be compatible with IEC CIM (i.e. map to the IEC CIM), however the IEC CIM does not solve everything we need for the BEYOND CIM so we can't just adopt the IEC CIM as our internal model, nor is it designed for that.	More related to TSO and TSO communication. Mainly used in the electrical utility industry. Initially started as the common model for exchange of grid data between the TSOs, and recently gaining traction in the DSO domain too with the introduction of profiles - limited subsets of the model applicable for a certain narrower domain. The closest thing to the semantic definition of all data relevant for electric power system. The core IEC CIM is a language-independent UML model, defining the components of a power system as classes along with the relationships between these classes: inheritance, association and aggregation.
4	IEC 61850	Communication networks and systems in substations	Standard	Events, measurements, Equipment, Semantic interpretation		Y			Y			Y	A	A	NA	A	A	A	PA	A	NA	The IEC 61850 is the de facto standard for communication in electric power engineering and can not be ignored similar to the IEC CIM. It carries data semantics and we probably require mapping of BEYOND-acquired data to and from the IEC 61850 but as with IEC CIM it is not suitable for big data in building sector. We have to interop with IEC61850, though.	The IEC 61850 is practically the first telecontrol standard that includes the data semantics within the protocol. Starting from the electrical substations, its scope has dramatically widened in the recent years. Compared to previous communication standards, the IEC 61850 is the standard that introduces semantic interpretation of the communicated data within the protocol itself. The previous telecontrol standards such as 60870 series are limited to describing the communication only and the payload carried through the communication channel was out of scope.
5	IEC 20922	MQTT (Message Queuing Telemetry Transport)	Standard	Measurements, Equipment	Y					Y			NA	NA	NA	PA	PA	A	PA	A	NA	This is only a messaging standard for message transport. No interpretation of payload is included in MQTT. MQTT can be a message carrier, we need to define message interpretation though.	MQTT is a lightweight standard, implementable at quite low end devices and widely used for queuing and asynchronous applications in many domain due to its relatively small overhead.
6	IEC 62056 COSEM	Systems interface between customer energy management system and the power management system	Standard	Measurements, Equipment	Y							Y	A	A	NA	PA	PA	A	PA	A	NA	This standard only defines metering semantics within a meter. Similar to the IEC 61850, we probably require interoperability, but the limited extent of semantic information is not enough for the requirements of the BEYOND CIM. In effect, we'll have to keep the original DLMS info with the data.	The COSEM model is used in smart metering and represents a companion standard to the DLMS underlying communication protocol. The COSEM server model resembles the IEC 61850 standard: a physical meter is defined as a composition of several logical devices. This logical device concept permit the same meter to be utilized for energy, gas and water. While important for interoperability and well established in practice, the semantics embedded within this standard do not satisfy all the BEYOND requirements.

FIGURE 1 EXAMPLE OF THE DATA COLLECTION TEMPLATE FOR D3.1

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2. Identification of BEYOND Needs

2.1 Analysis of the project aims and objectives

Buildings are generators of a vast amounts of data: from Building Energy Management Systems (BEMS), smart metering and sub-metering information (demand), IoT device information (sensing/control), distributed generation (RES), storage and electric vehicle data, altogether characterized by continuously increasing growth rate, multi-diverse spatiotemporal resolutions and huge volume.

The BEYOND reference architecture needs to incorporate both data from the building domain and from other diverse sources (energy system, energy market, IoT devices, historical data, APIs etc.). Additionally, the idea is that BEYOND will address numerous business and optimization needs for a variety of stakeholders involved in the value chain.

The most promising value of big data derived from buildings environments is sequestrated in sharing such targeted information with energy market stakeholders and actors. Such stakeholders could be directly or indirectly linked with the energy performance in buildings i.e., ESCOs, local authorities, DSOs, energy retailers, aggregators, district heating network operators etc.

BEYOND aims to ensure "end-to-end" coordination between the building sector and energy market actors, not only in business terms but also in exchanging information. Non-discriminatory, transparent, and secure data exchanges and synergies between the building sector and associated energy stakeholders is key to advancing and increasing knowledge generated at the different edges of the integrated energy system and introducing valuable insights in any kind of optimization function considering, otherwise, non-accessible (or non-utilized) critical information generated at the very endpoints of smart buildings remains unlocked.

The BEYOND objective is to deliver a Big Data Management Platform, on top of which an advanced AI analytics toolkit will be offered allowing for the delivery of derivative data and intelligence out of a blend of real-life building data and relevant data coming from external sources (batch and real-time).

The BEYOND Big data platform and its AI Analytics Toolkit will be associated with novel data (intelligence) sharing mechanisms that enable the integration of the value chain stakeholders (building-related stakeholders and energy market actors), thus allowing the latter ones to gain access and the opportunity to acquire building data as well as advanced building data analytics (through BEYOND) and build their own applications and solutions, towards

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(i) providing innovative energy services to the building sector
(ii) improving their business processes and operations (i.e., through de-risked EPC, optimized policy planning, infrastructure sizing).

In turn, out of the sharing approach introduced in BEYOND, buildings will enjoy a wealth of innovative energy services and associated intra-building benefits in the form of

(i) optimized energy performance and reduction of associated energy costs through advanced AI big data analytics-based energy services (exploiting best of the breed Machine Learning and Deep Learning algorithms) and
(ii) new data-driven business models and opportunities for financial gains achieved from data monetization (data sharing negotiations and smart contracts)

or (even more) trading of building flexibility in upstream energy and flexibility markets.

2.2 Needs coming from the initial reference architecture

The BEYOND reference architecture (Figure 3) is conceptually divided in three main tiers, which are illustrated in Figure 2:

- the On-Premise Environment (OPE) that is executed in the value chain stakeholders' premises,
- the Core Big Data Management Platform (CBDMP) that runs in the cloud and communicates with the On-Premise Environments and the Secure Experimentation Playgrounds (SEP) whenever needed through secure channels, and
- the Secure Experimentation Playgrounds that are realized in the form of dedicated virtual machines that are spawned on demand so that each stakeholder is able to execute big data analytics in isolated and secure environments in the BEYOND cloud infrastructure.

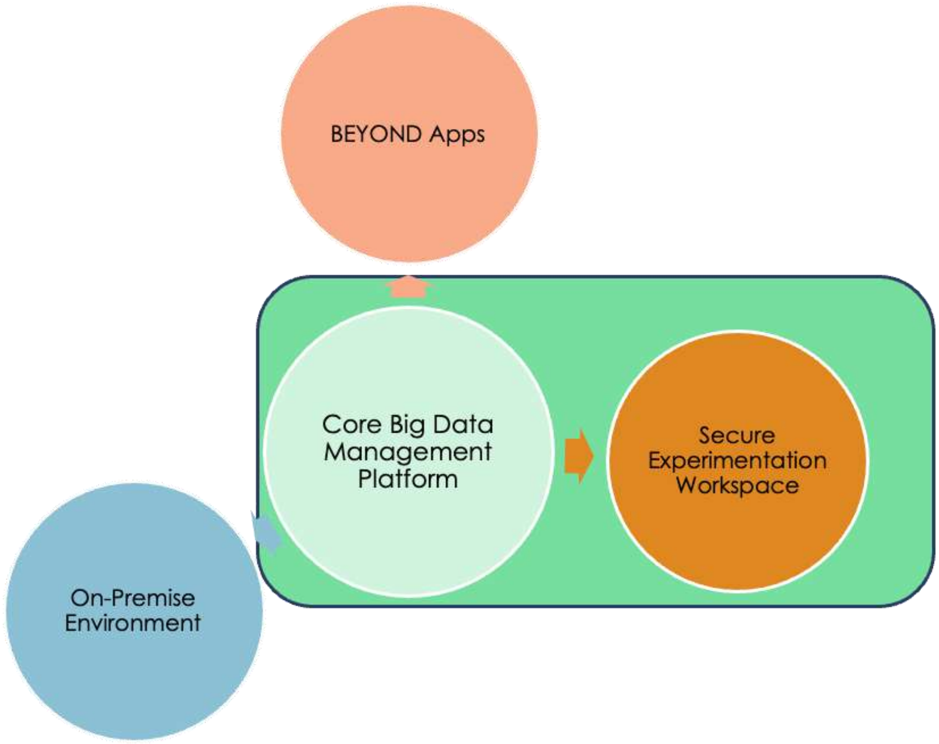

FIGURE 2 CONCEPTUAL "TIERS" OF BEYOND

It is noted that this architectural blueprint and the overall placement of the various components are tentative, as at the moment of writing this deliverable, the overall architecture is being refined, undergoing changes, and will be finalized as part of deliverable D2.5 of the project.

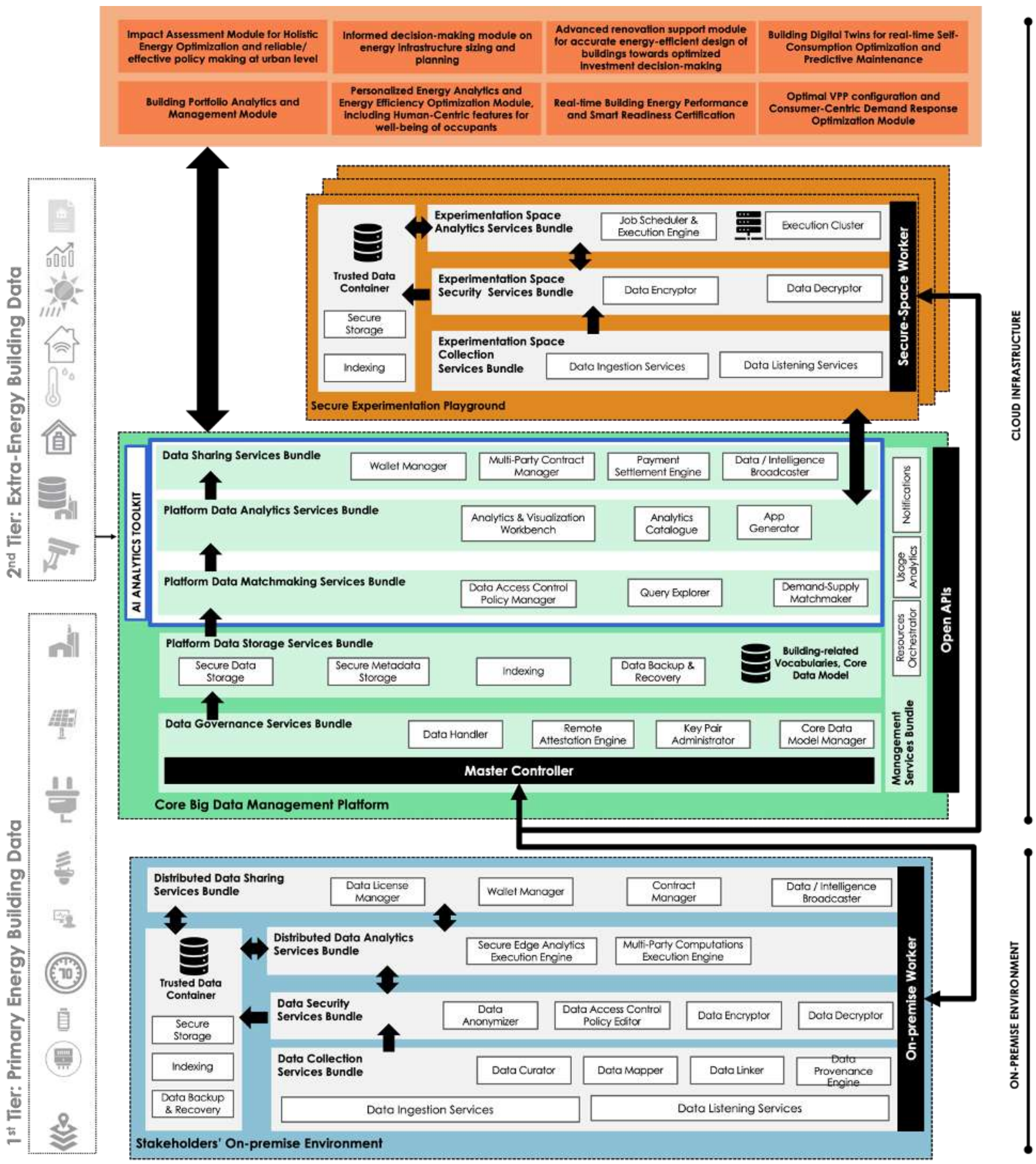

FIGURE 3 CONCEPTUAL VIEW OF THE BEYOND REFERENCE ARCHITECTURE

As seen from the figure above, the BEYOND system is not strictly deploying a centralized infrastructure where all operations take place, but does offer the possibilities to different entities to perform operations locally (on-premise), while certain operations that are happening in the cloud-based platform are also following a virtualization concept towards data and execution isolation, to mimic on-premise environments and actually adhere to high privacy and security requirements that various stakeholders could have. In addition, the centralized platform is also supporting several business services that are executed on top of the platform's offerings, which means that further requirements are posed towards performance, proper data management and access methods.

Based on the above, it is obvious that there is a need for having a clearly defined model, which is able to "host" and "integrate" existing data elements, in order to allow for a smooth operation of the platform. This model, known as CIM (to be produced under T3.2 and delivered as D3.2), will be a synthesis of other models/standards/etc., and will be the one against which all data coming from the different sources should be mapped.

As such, this model, and the architecture at the very end, sets some needs which shall be covered by the different data models to be considered, to the extent this is possible.

These are the following:

- Data Interoperability – There is a high need for the overall system to work with data that is interoperable and that could be used to support different analyses, as the heart of BEYOND is that of a data sharing infrastructure which should go beyond simple data exchange but be able to turn data into insights and make it digestible by the different systems. As such, the different models to be used by the architecture should be in a position to support interoperability and allow for the easy and fast data transformation and/or linking in case this is needed. The architecture of the system will be designed in such a manner that data which is respecting the formats of known, existing interoperable standards would be out-of-the-box supported for ingestion, as limited customized connector shall be build, in an effort to promote the adoption of data interoperability from stakeholders and motivate them to abolish custom solutions and proprietary data formats.
- Data Performance – Under this need we refer to the ability of data to be easily created and consumed in order to serve the requirements set by a big data infrastructure, which supports both on-premises and cloud-based operations, and thus is not only concerned about the performance at the execution location but is also highly depended on the data transfer performance between the different components which may not be placed in the same environments. Towards this direction, it becomes apparent that lightweight models would be in a better position to facilitate these purposes, as they could be very easily managed by the different tools and be highly performant in all operations, due to the reduced header payload they are carrying.
- Data Security. As shown in the architecture, many components imply that data security and privacy are aspects that are highly important for the operation of BEYOND, as these are highly important to data owners who want to have strong guarantees on how their data are protected. Therefore, the architecture calls for the use of models which are able to support security methods and are

in position to guarantee end-to-end security, by utilizing methods that could for example verify the integrity of the data et. Moreover, as encryption might be utilized to secure data, there is a need to choose data structures which can be efficient during crypto-operations in terms of performance, and that would not produce a big resource-utilization footprint during such operations.

- Data Privacy. In the same sense as with security, data privacy is another important aspect for BEYOND. For this reason, the ability of data models and standards to support the operations of privacy relevant operations (such as anonymization, or pseudo-anonymization, data-obfuscation, etc.) without however losing the quality information of the payload is another need that comes come from the architecture.

2.3 Definition of the semantic scope of the BEYOND target data model

Though BEYOND is associated with energy efficiency, its data model must cover a much larger landscape. The BEYOND solution is designed to operate in the building sector and this makes the target area much wider than just the energy sector. As BEYOND is directly associated with overall energy efficient buildings (EEB) landscape, the lateral modelling aspects impacting energy efficient buildings must be covered too.

Energy efficient buildings start generating relevant data even before being built (during the design phase). While utilized, the buildings interact with numerous systems and therefore require coverage of the corresponding data models to fully cover the necessary data semantics. This makes overall semantic requirements of BEYOND data model quite wide.

The EEB landscape spans several application areas: from the Building Energy Management Systems (BEMS), smart metering and sub-metering information (demand), IoT device information (sensing/control), distributed generation (RES), storage and electric vehicle data, environmental information from external sensors etc.

Besides the wide coverage, another challenging characteristic that BEYOND must deal with is the non-uniformly increasing data production rate. Non-uniformity is manifested in diverse spatiotemporal data resolutions: the data production coming from IoT sensors located as data production points in space does not necessarily carry the amount of information corresponding to the temporal increase in the data volume. An example could be several temperature sensors in the same confined space producing the data with comparatively low added information. On the other hand, other relevant data may only be available in an aggregated manner, either spatially, temporally or in both ways. However, this does not directly imply the spatiotemporal aggregation. The BEYOND solution must adequately handle large volumes of raw data, without prematurely discarding and blindly aggregating data. The large projected volume of data imposes additional constraints on the applicability of the model: a data model adding significant overhead unsuitable for a big data platform is similarly not directly usable within BEYOND.

Finally, there is the third key characteristics of the BEYOND data model – its flexibility and extensibility. It is not realistic to expect that at the time of BEYOND data model creation it will be final and suitable for all prospective needs. On the contrary, during the life cycle of BEYOND solution, it is reasonable to expect new actors and new data models will be required, as well as amendments and updates to the existing ones. For this reason, there must be mechanisms to extend and upgrade the data model.

There are, therefore, three principal characteristics required from the BEYOND semantic data model:

1) The semantic model must include all the data semantics relevant to energy efficient buildings, including interoperable mappings to external standards and models established in practice – it must be widely encompassing.
2) It must be suitable for big data sized datasets – it must be performant at big data scale.
3) It must provide mechanisms for extensibility and model life cycle management – it must be extensible.

In the following chapter, existing standards and data models of the domains relevant to the EEBs are evaluated in the view of the above key requirements.

3. Presentation of data models

3.1 Standards

3.1.1 OpenADR (IEC 62746)

Title	Systems interface between customer energy management system and the power management system
Author and License	IEC
URL	[IEC 62746-10-1:2018 | IEC Webstore]()
Scope	Events, measurements, Equipment
BEYOND related	*DR in buildings* þ
	Machine-to-machine communication and interoperability enhancement at smart building level ý
	Building Data Model representations ý
	Business synergies and data exchanges between the building and energy system/network stakeholders þ

Scope of application		
DSO þ	*TSO* þ	*BRP / Market* ý
Retailer þ	*Aggregator* þ	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* ý

This standard defines the system interfaces and communication protocols, essentially covering the demand response value chain between a smart grid flexibility user and smart home or building. The IEC 62746 standard provides application-level service communication that can be used to incentivize responses from the customer-owned and customer-located distributed energy resources.

In IEC 62746, the following core services are specified:

- Register: identification of entities in advance of interactions with other parties
- Event: core demand response event, providing event functions and information models for price-responsive DR
- Report: this service enables feedback to provide either periodic or one-time information on the actual state of a resource

and optionally addressing the short-term changes in availability, providing the facility to communicate opt-in and opt-out schedules from virtual end nodes to virtual top nodes. (H. Keko; S. Sučić; K. Tzanidakis; C. Malavazos; P. Hasse; A. Wolf , 2018) The opt-in and opt-out option is a key difference to classic telecontrol protocols – there, typically only technical unavailability is implemented.

The OpenADR standard specifies the data semantics only to a limited extent – the message payload interpretation does not go beyond the generic types of events as described above. For the purpose of BEYOND the most relevant standard of the IEC 62746 family is IEC 62746-10 (IEC Webstore): Open Automated Demand Response (OpenADR 2.0b Profile Specification), which represents the adoption of the OpenADR Alliance standard as the IEC standard. This standard is a flexible data model to facilitate common information exchange between electricity service providers, aggregators, and end users (i.e. building/facility managers). The concept of an open specification is intended to allow anyone to implement the two-way signalling systems, providing the servers that publish information to the automated clients subscribing to the information.

The OpenADR specifications provide a (minimal, as discussed above) data model and services for DR, pricing, and distributed energy resource (DER) communications and explain how to implement a two-way signalling system to facilitate information exchange between electricity service providers, aggregators and end users. This standard has a definite importance for any kind of demand-response solution.

3.1.2 IEC 62939

Title	Smart grid user interface
Author and License	IEC
URL	[IEC TS 62939-2:2018 | IEC Webstore]()
Scope	Events, measurements, Equipment
BEYOND related	*DR in buildings* þ
	Machine-to-machine communication and interoperability enhancement at smart building level ý
	Building Data Model representations ý
	Business synergies and data exchanges between the building and energy system/network stakeholders þ

Scope of application		
DSO þ	*TSO* þ	*BRP / Market* þ
Retailer þ	*Aggregator* þ	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* ý

IEC 62939 provides an architecture to define interfaces for the information exchange between smart equipment/systems from the demand side and the power grid. It facilitates the interoperability between the IEC common information model (CIM) and customer facility standards for smart grid applications. (IEC Webstore, n.d.)

The SGUI is a logical and abstract cross-domain interface supporting the communications between various entities in the customer domain. In this context, the “user” is not a person, but instead the solution interfacing with various aspects of the smart grid.

The standards specify services for symmetric interoperation between energy suppliers and energy consumers across the SGUI, connecting customer systems to the power system. The services enable the coordination of operative systems that supply or consume energy over time across the SGUI, including:

- an information model and a communication model,
- services for demand response, including dispatch of load resources and price,
- services for measurement and confirmation of response and delivery,
- services to enable collaborative and transactive use of energy across the SGUI
- service definitions consistent with the concept of a Service-Oriented Architecture,
- XML vocabularies for the interoperable and standard exchange of Transactive Energy, and
- XML vocabularies for the interoperable and standard exchange of Demand Response, including the exchange of measurement and confirmation of response and delivery.

Furthermore IEC 62939 standard, makes no assumptions about which entities will enter the energy markets, or as to what those market roles will be called in the future (Figure 4).

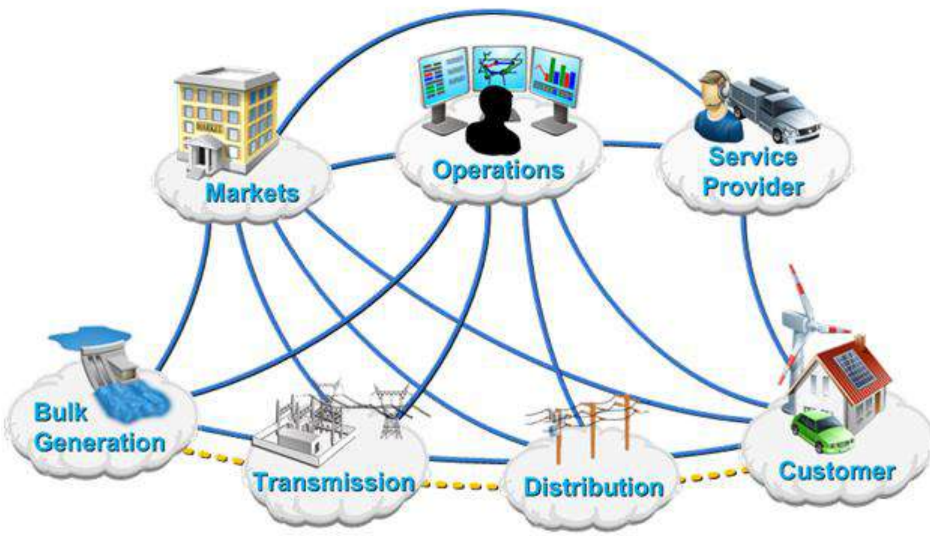

FIGURE 4 THE SCOPE OF IEC 62939 STANDARD: CONCEPTUAL SMART GRID MODEL SHOWING COMMUNICATION REQUIREMENTS RELEVANT FOR THE IEC 62939

This standard is particularly interesting as it defines the Virtual End Node (VEN) and Virtual Top Node (VTN) concepts. The VEN has operational control of a set of resources and/or processes and is able to control the output or demand of these resources to affect their generation or utilization of electrical energy intelligently in response to an understood set of smart grid messages. The VEN may be either a producer or consumer of energy. The VEN is able to communicate (2-way) with a VTN receiving and transmitting smart grid messages that relay grid situations, conditions, or events. A VEN may take the role of a VTN in other interactions. VTNs and VENs may be structured in a tree-like hierarchy; however, any communication between nodes at the same hierarchy levels is not supported. Within the framework of IEC 62939, the VTN is a party which role is the aggregation of information and capabilities of distributed energy resources. The VTN is able to communicate with both the Grid and the VEN devices or systems in its domain. A VTN may take the role of a VEN interacting with another VTN. (IEC Webstore, n.d.) (H. Keko; S. Sučić; K. Tzanidakis; C. Malavazos; P. Hasse; A. Wolf , 2018)

3.1.3 IEC 61968 / 61970

Title	Common information model (CIM)
Author and License	IEC
URL	[IEC 61970-301:2020 | IEC Webstore]
Scope	Events, Measurements, Equipment, Products
BEYOND related	*DR in buildings* ý
	Machine-to-machine communication and interoperability enhancement at smart building level ý
	Building Data Model representations ý
	Business synergies and data exchanges between the building and energy system/network stakeholders þ

Scope of application		
DSO þ	*TSO* þ	*BRP / Market* ý
Retailer þ	*Aggregator* þ	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* ý

The IEC CIM – Common Information Model has stemmed from the standard beyond the energy domain – it started as an open standard defining the interactions of managed elements in an IT environment. Within the context of electric power engineering, the CIM is an ontological standard. The IEC 61968 and IEC 61970 represent the core standards for the IEC CIM.

The principal objective of the IEC 61968 and IEC 61970 series of standards has been to standardize the integration of energy management systems (EMS) developed independently by different vendors, between diverse EMS systems developed independently, or between an EMS system and other systems covering different aspects of power system operations. The IEC CIM coverage nowadays includes many other aspects of electric power system operation. This family of standards is mainly used in the electrical utility industry, and most widely for TSO and DSO communication purposes. The IEC 61970-301 standard is interesting to point out here as it describes the components of a power system at an electrical level and relationships among them.

The IEC 61970 lays down the abstract model representing all the major objects in an electric utility enterprise, through a standardized way of representing power system resources as object classes and attributes. The CIM facilitates the integration of network applications developed independently by different vendors. Essentially, the CIM is de facto standardized semantic model in the electric grids and is therefore highly relevant for any activity within the smart grid scope interacting with established grid entities. (IEC Webstore, n.d.)

3.1.4 IEC 61850

Title	Communication networks and systems for power utility automation
Author and License	IEC
URL	[Homepage | IEC]()
Scope	Events, measurements, Equipment, Semantic interpretation
BEYOND related	*DR in buildings* þ
	Machine-to-machine communication and interoperability enhancement at smart building level ý
	Building Data Model representations ý
	Business synergies and data exchanges between the building and energy system/network stakeholders þ

Scope of application		
DSO þ	*TSO* þ	*BRP / Market* ý
Retailer þ	*Aggregator* þ	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* ý

The IEC 61850 is designed as an interoperable telecontrol protocol, but it is primarily interesting in the BEYOND context as it, contrary to the previous communication protocols that limited their reach to standardizing the communication layer, takes a significant step toward *semantic* interpretation of the message payload. This introduces semantic interpretation within the communication protocol itself. The indicative coverage of IEC 61850 is shown in Figure 5.

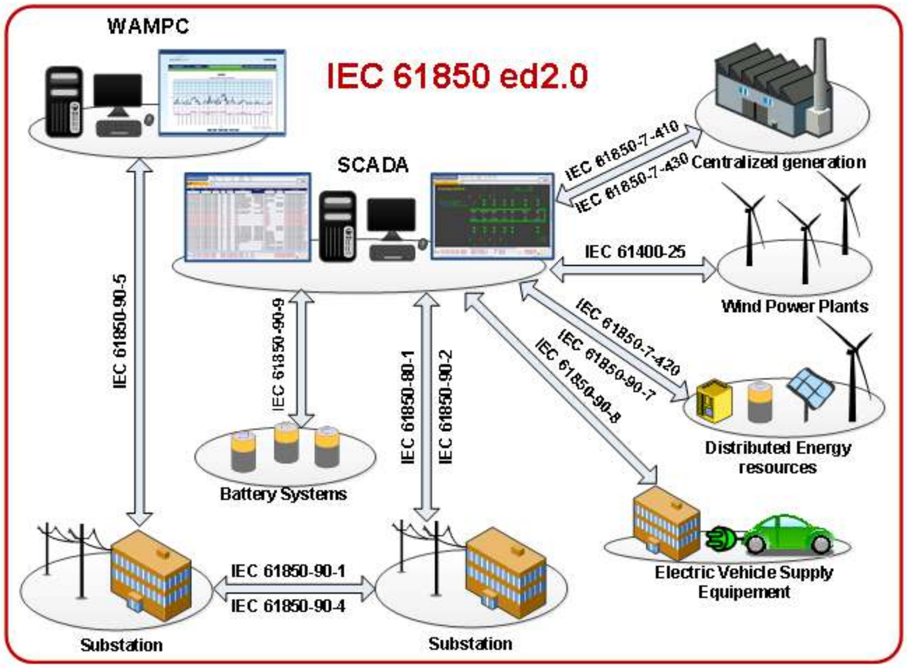

FIGURE 5 INDICATIVE COVERAGE OF THE IEC 61850 EDITION 2.0 SERIES OF STANDARDS

The IEC 61850 data model is a hierarchical, function object-oriented model, described primarily in the IEC 61850-7-2 (IEC Webstore, n.d.), 7-3 (IEC Webstore, n.d.) and 7-4xx (IEC Webstore, n.d.). In this hierarchical model, each physical Intelligent Electronic Device (IED) can perform several functions previously performed by different devices as there is a provision for multiple logical devices to reside within a single physical device (a server). Within each of the logical devices, multiple logical nodes may exist. Each logical node can provide multiple data objects, of which each in turn can have multiple data attributes (Figure 6).

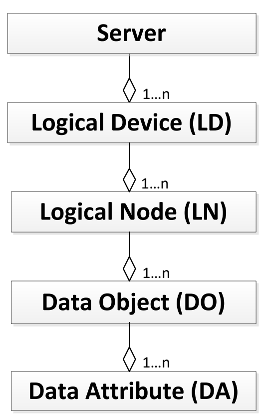

FIGURE 6 OBJECT HIERARCHY IN THE IEC 61850 SEMANTIC MODEL

The IEC 61850 describes each function in the substation equipment by a logical node, and the IEC 61850-7-4 (IEC Webstore, n.d.) standard is, in fact, a semantic definition of the 91 logical nodes, divided into 13 logical groups (e.g. switchgear, power transformer, protection, control, generic, automatic and control, metering and measurement, etc.). This document defines these groups of logical nodes:

- System logical nodes
- Automatic control (neutral current regulator, reactive power control, automatic tap changer)
- Control (alarm handling, interlocking)
- Functional blocks (e.g. counter, curve shape, PID regulator, ramp function)
- Generic references logical nodes
- Interfacing and archiving
- Mechanical and non-electric primary equipment (e.g. pumps, tanks)
- Metering and measurement (including meteorological, ambient and other information)
- Protection functions (differential, distance, harmonic, overcurrent etc.)
- Power quality events
- Protection related functions (e.g. disturbance recorder, breaker failure, autoreclosing, syncrocheck)
- Supervision and monitoring
- Instrument transformers and sensors
- Switchgear
- Power transformers
- Other power system equipment (batteries, capacitor banks etc)

In IEC 61850, each of the logical nodes contains data, some of which is deemed mandatory. This data can be subdivided into common data relevant to the logical node, status information, settings, measured values and finally controls. Even with a relatively limited scope of its semantic information, the IEC 61850 is practically the most utilized common standard in the electrical power engineering when industrial automation is considered – as such, today it is much more than an interoperable transformer substation automation solution. In practice, interacting with the DSO most probably require a certain degree of interoperability with the IEC 61850 and the IEC CIM (IEC 61968/61970) described earlier at higher business integration levels.

3.1.5 IEC 20922

Title	Information technology — Message Queuing Telemetry Transport (MQTT) v3.1.1
Author and License	IEC
URL	ISO - ISO/IEC 20922:2016
Scope	Measurements, Equipment

BEYOND related	*DR in buildings* ý	
	Machine-to-machine communication and interoperability enhancement at smart building level þ	
	Building Data Model representations ý	
	Business synergies and data exchanges between the building and energy system/network stakeholders ý	
Scope of application		
DSO ý	*TSO* ý	*BRP / Market* ý
Retailer ¨	*Aggregator* ¨	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* ý

ISO/IEC 20922:2016 is a Client Server publish/subscribe messaging transport protocol. These characteristics make it ideal for use in many situations, including constrained environments such as for communication in Machine to Machine (M2M) and Internet of Things (IoT) contexts where a small code footprint is required and/or network bandwidth is at a premium. (ISO/IEC, n.d.)

MQTT (Message Queuing Telemetry Transport) is an open OASIS and ISO standard (ISO/IEC 20922) lightweight, publish-subscribe network protocol that transports messages between devices. The protocol usually runs over TCP/IP; however, any network protocol that provides ordered, lossless, bi-directional connections can support MQTT. It is designed for connections with remote locations where a "small code footprint" is required or the network bandwidth is limited.

The protocol runs over TCP/IP, or over other network protocols that provide ordered, lossless, bi-directional connections. As described in (ISO/IEC, n.d.), these features include:

- Use of the publish/subscribe message pattern which provides one-to-many message distribution and decoupling of applications.
- A messaging transport that is agnostic to the content of the payload.
- Three qualities of service for message delivery:
  - "At most once", where messages are delivered according to the best efforts of the operating environment. Message loss can occur. This level could be used, for example, with ambient sensor data where it does not matter if an individual reading is lost as the next one will be published soon after.
  - "At least once", where messages are assured to arrive, but duplicates can occur.
  - "Exactly once", where message is assured to arrive exactly once. This level could be used, for example, with billing systems where duplicate or lost messages could lead to incorrect charges being applied.

This is a very useful and widely used reliable protocol, however its scope of semantic coverage is deliberately very limited. In other words, MQTT is not enough as message transport – an information schema is required to be imposed on the message payloads for MQTT to function in an interoperable fashion.

3.1.6 IEC 62056 COSEM

Title	Systems interface between customer energy management system and the power management system
Author and License	IEC
URL	[IEC TR 62746-2:2015 | IEC Webstore]()
Scope	Measurements, Equipment
BEYOND related	*DR in buildings* ý
	Machine-to-machine communication and interoperability enhancement at smart building level ý
	Building Data Model representations ý
	Business synergies and data exchanges between the building and energy system/network stakeholders þ

Scope of application		
DSO þ	*TSO* þ	*BRP / Market* ý
Retailer ¨	*Aggregator* ¨	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* ý

The IEC 62056 COSEM specifies the functionalities of smart meters by setting the rules for data exchange for electric power measuring equipment. The standard uses object modelling techniques to model the meter functionalities whereas making any assumptions of which functions need to be supported, how those functions are implemented, and data will be transported. The COSEM model is used in smart metering and represents a companion standard to the DLMS underlying communication protocol. The COSEM server model resembles the IEC 61850 standard: a physical meter is defined as a composition of several logical devices. This logical device concept permits the same meter to be utilized for energy, gas and water. In terms of semantic interpretation, it is limited to the context of smart meters. Its wide usage in practice, similar to the IEC 61850, means a certain degree of interoperability with COSEM is needed, but its limited extent of semantic information is not enough for the requirements of the BEYOND CIM.

3.1.7 CEN EN 16836 (ZigBee SEP2)

Title	EN 16836 (ZigBee SEP2)
Author and License	European Committee for Standardization (CEN)
URL	[CEN - EN 16836-2]()
Scope	Measurements, Equipment, Products
BEYOND related	*DR in buildings* ý
	Machine-to-machine communication and interoperability enhancement at smart building level þ
	Building Data Model representations ý
	Business synergies and data exchanges between the building and energy system/network stakeholders ý

Scope of application		
DSO ý	*TSO* ý	*BRP / Market* ý
Retailer ¨	*Aggregator* ¨	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* ý

The CEN EN 16836 (ZigBee SEP2) (CEN - EN 16836-2, 2016) intents to define devices and interfaces for smart energy applications in residential buildings or slightly commercial environments. ZigBee can be used for sub-metering purposes or for communication between devices in a home/building environment.

In detail, this standard describes several types of metering, real time recordings, historical information, status indications. Apart from the types of devices, the ESI (Energy Services Interface), the In-Premises Display and PCT (Programmable Communicating Thermostat) are also incorporated in the standard. Crucial functions in energy management systems, such as demand response, load control, pricing, messaging, and billing are also available.

The ZigBee network layer supports both star and tree networks, and generic mesh networking. Every network must have one coordinator device, tasked with its creation, the control of its parameters and basic maintenance. Within star networks, the coordinator must be the central node. Both trees and meshes allow the use of ZigBee routers to extend communication at the network level. The following figure depicts an indicative topology for a ZigBee network (Figure 7).

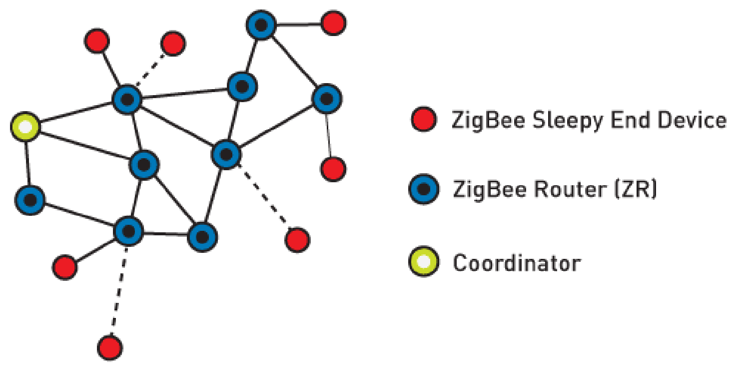

FIGURE 7 ZIGBEE NETWORK TOPOLOGY

ZigBee builds on the physical layer and media access control defined in the IEEE standard 802.15.4 for low-rate WPANs. The specification includes four additional key components: network layer, application layer, ZigBee device objects (ZDOs) and manufacturer-defined application objects which allow for customization and favour total integration. ZDOs are responsible for a number of tasks, including keeping track of device roles, managing requests to join a network, as well as device discovery and security.

3.1.8 CENELEC EN 50631-1 (SPINE)

Title	EN 50631-1 (SPINE)
Author and License	CENELEC
URL	[CENELEC - EN 50631-1]
Scope	Measurements, Equipment, Products
BEYOND related	*DR in buildings* ý
	Machine-to-machine communication and interoperability enhancement at smart building level þ
	Building Data Model representations ý
	Business synergies and data exchanges between the building and energy system/network stakeholders ý

Scope of application		
DSO ý	*TSO* ý	*BRP / Market* ý
Retailer ¨	*Aggregator* ¨	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* ý

The EN-50631 (CENELEC, n.d.) standard focuses on interoperability on information exchange among various appliances in the home. It describes the necessary control and monitoring and defines a set of functions of household and similar electrical appliances. The functions in this standard cover, next to energy-management, main remote-control and monitoring. (Study on ensuring interoperability for enabling Demand Side Flexibility use cases., 2018)

SPINE defines a neutral layer to connect different technologies to build a smart home or a smart grid system. Additionally, defines procedures on application level and is independent from the transport protocol. Any technology that supports the bi-directional exchange of arbitrary data can be used directly, i.e. SmartHome IP (SHIP), also created by the EEBUS Initiative, or Thread, which is very much used by the Energy@home association. For other communication technologies, a mapping is needed. SPINE covers use cases dealing with control and monitoring of smart appliances, i.e. white goods, HVAC, EV, focusing on their interconnection in a smart energy and building environment. (DELTA Project No 773960, 2021)

3.1.9 CENELEC EN 50090 (KNX)

Title	EN 50090 (KNX)
Author and License	CENELEC
URL	[KNX - MyKNX]
Scope	Measurements, Equipment, Products
BEYOND related	*DR in buildings* ý
	Machine-to-machine communication and interoperability enhancement at smart building level þ
	Building Data Model representations ý
	Business synergies and data exchanges between the building and energy system/network stakeholders ý

Scope of application		
DSO ý	*TSO* ý	*BRP / Market* ý
Retailer ¨	*Aggregator* ¨	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* ý

The KNX standards is approved as European Standard through CENELEC EN 50090 and CEN EN 13321-1. KNX is designed for the control of applications in industrial, commercial and residential buildings, ranging from lighting and shutter control to various security systems, heating, ventilation, air conditioning, monitoring, alarming, water control, energy management, metering as well as household appliances, audio and lots more. It can be applied in new as well as in existing homes and buildings.

Recent efforts at KNX aim at investigating the benefits of associating a KNX IoT ontology to the model underlying the ETS tool and leverage semantic technologies, as enabler to add semantic information for advanced functional queries without preknowledge on the devices implementing the actual functions. The KNX IoT ontology is available at https://knxiot.org (access to the KNX ontology requires credentials that can be obtained contacting the KNX association). (Study on ensuring interoperability for enabling Demand Side Flexibility use cases., 2018)

3.1.10 CENELEC EN 50491-11 Smart Metering

Title	CENELEC EN 50491-11 Smart Metering
Author and License	CENELEC
URL	CEI EN 50491-11
Scope	Measurements, Equipment, Products
BEYOND related	*DR in buildings* ý
	Machine-to-machine communication and interoperability enhancement at smart building level þ
	Building Data Model representations ý
	Business synergies and data exchanges between the building and energy system/network stakeholders ý

Scope of application		
DSO ý	*TSO* ý	*BRP / Market* ý
Retailer	*Aggregator*	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* ý

CENELEC EN 50491-11 Smart Metering standard specifies a data model to abstract the metering world towards a simple external consumer display. The data model, as described by means of functional blocks contained in EN 50491-11, lays down the format of metering data accessible by a simple external consumer display. The EN 50491-11 standard does not specify the communication protocol used between the meters and the meter communication functions but considers the EN 62056 COSEM series for the definition of the data model. (Study on ensuring interoperability for enabling Demand Side Flexibility use cases., 2018)

3.1.11 EN 13757 M-Bus

Title	EN 13757 M-Bus
Author and License	CEN
URL	M-Bus (m-bus.com)

Scope	Measurements	
BEYOND related	*DR in buildings* ý	
	Machine-to-machine communication and interoperability enhancement at smart building level þ	
	Building Data Model representations ý	
	Business synergies and data exchanges between the building and energy system/network stakeholders þ	
Scope of application		
DSO ¨	*TSO* ¨	*BRP / Market* ý
Retailer þ	*Aggregator* ¨	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* ý

Metering Bus (M - Bus) is a standard which is used to read remotely gas, or electricity meters (EN 13757-2 physical and link layer, EN 13757-3 application layer). It is also capable of reading remotely the other types of consumption meters such as gas or water within a home. M-Bus is applicable where physical wiring is sometimes inexecutable as in large buildings, for the purposes of reading energy meters and billing information exchange with energy utilities.

3.1.12 Bluetooth Low Energy (BLE)

Title	Bluetooth Low Energy (BLE)	
Author and License	Bluetooth SIG	
URL	Bluetooth® Technology	
Scope	Measurements, Equipment, Products	
BEYOND related	*DR in buildings* ý	
	Machine-to-machine communication and interoperability enhancement at smart building level þ	
	Building Data Model representations ý	
	Business synergies and data exchanges between the building and energy system/network stakeholders ý	
Scope of application		
DSO ý	*TSO* ý	*BRP / Market* ý
Retailer ¨	*Aggregator* ¨	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* ý

BLE is ideal for applications requiring episodic or periodic transfer of small amounts of data. Therefore, BLE is especially well suited for sensors, actuators and other small devices that require extremely low power consumption. As stated in (Mats Andersson, 2014) BLE incorporates the following features:

- works well with high numbers of communication nodes with limited latency requirements;
- It has very low power consumption;
- It is as robust as the classic Bluetooth;
- It provides short wake-up and connection times;
- It provides good smartphone and tablet support.

Many features of classic Bluetooth are inherited in BLE, including Adaptive Frequency Hopping (AFH). These inherited features make BLE easy to setup, robust and reliable in tough environments. To support simpler and cheaper radio chipsets, BLE uses 402 MHz wide channels while classic Bluetooth uses 791MHz channels.

BLE is a wireless networking technology designed as an ultra-low power PAN. In contrast of ZigBee, BLE implements a star topology. The requirement for mesh networking is a key enabler for the IoT paradigm and Bluetooth SIG has already solved this “BLE issue” with the Bluetooth mesh networking officially launched in July 2017 (ericsson.com, n.d.).

3.1.13 Z-Wave

Title	Z-Wave	
Author and License	Z-Wave Alliance	
URL	Z-Wave Specifications	
Scope	Measurements, Equipment, Products	
BEYOND related	*DR in buildings* ý	
	Machine-to-machine communication and interoperability enhancement at smart building level þ	
	Building Data Model representations ý	
	Business synergies and data exchanges between the building and energy system/network stakeholders ý	
Scope of application		
DSO ý	*TSO* ý	*BRP / Market* ý
Retailer	*Aggregator*	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* ý

The Z-Wave protocol is a wireless RF-based communications technology designed specifically for control, monitoring and status reading applications in residential and light commercial environments. The protocol supports full mesh networks, enabling numerous Z-Wave devices to communicate with each other simultaneously and allows for secure and low power consuming communication between approved Z-Wave devices.

Even though the protocol is specified by the Z-Wave Alliance the specifications are not publicly available, but a qualitative description is provided in (Study on ensuring interoperability for enabling Demand Side Flexibility use cases., 2018). It is a low-powered RF communications technology that supports full mesh networks without the need for a coordinator node. It operates in the sub-1GHz band, is designed specifically for control and status apps, and supports data rates of up to 100kbps. The application layer specification defines what and why two Z-Wave nodes communicate with each other and contains the relevant semantics.

Z-Wave devices on the market can be categorized into one of the following function groups:

- Electrical switches are designed either as plug in modules for wall outlets or as replacement for traditional wall switches (digital actors). It is also possible to have these actors already built into certain electrical appliances such as electrical stoves or heaters.
- Electrical dimmers, either as plug-in modules for wall outlets or as replacement for traditional wall switches (analogue actors).
- Motor control, usually to open or close a door, a window, a window sun blind or a venetian blind (analogue or digital actors).
- Electrical Display or other kind of signal emission such as siren, LED panel, etc. (digital actors).
- Sensors of different kind to measure parameters like temperature, humidity, gas concentration (e.g. carbon dioxide or carbon monoxide), analogue or digital sensors.
- Thermostat controls: either as a one knob control or using a temperature display (analogue sensors).
- Thermostats controls such as TRVs (Thermostat Radiator Valves) or floor heating controls (analogue or digital actors).
- Remote Controls either as universal remote control with IR support or as dedicated Z-Wave.

- USB sticks and IP gateways to allow PC software to access Z-Wave networks. Using IP communication these interfaces also allow remote access over the internet.

All communication within the Z-Wave network is organized in Command Classes, which are a group or commands and responses related to a certain function of a device.

3.1.14 Energy@home

Title	Energy@home
Author and License	Energy@home association
URL	Energy@home specification
Scope	Equipment, Products, Measurements
BEYOND related	*DR in buildings* ý
	Machine-to-machine communication and interoperability enhancement at smart building level þ
	Building Data Model representations þ
	Business synergies and data exchanges between the building and energy system/network stakeholders ý

Scope of application		
DSO þ	*TSO* ¨	*BRP / Market* ¨
Retailer þ	*Aggregator* þ	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* ý

The Energy@home protocol extends the ZigBee Home Automation and Smart Energy profiles, thus in order to satisfy all the requirements of Energy@home use cases, introduces new devices and clusters.

The Energy@home data model specifies a representation model for home area networks, including smart appliances, power profiles, renewable energy generation, smart meters and smart user interfaces. It is based on the CIM approach and is broadly aligned with the OpenADR schema. It formalizes a method of describing devices energy consumption profiles in terms of energy phases, modes, power profiles and extended profiles. (Hippolyte, Jean-Laurent & Howell, Shaun & A. Sleiman, Hassan & Vinyals, Meritxell & Yuce, Baris & Vanhée, Loïs & Mourshed, Monjur, 2016)

3.1.15 Modbus

Title	Modbus
Author and License	Modbus Organization
URL	Modbus Specifications and Implementation Guides
Scope	Measurements, Equipment, Products
BEYOND related	*DR in buildings* ý
	Machine-to-machine communication and interoperability enhancement at smart building level þ
	Building Data Model representations ý
	Business synergies and data exchanges between the building and energy system/network stakeholders ý

Scope of application		
DSO ý	*TSO* ý	*BRP / Market* ý
Retailer ¨	*Aggregator* ¨	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* ý

Modbus is a data communications protocol originally developed for programmable logic controllers (PLCs). Modbus has become a de facto standard communication protocol and is now a commonly available means of connecting industrial electronic devices. Provides client/server communication between devices connected on different types of buses or networks and uses character serial communication lines, Ethernet, or the Internet protocol suite as a transport layer.

Modbus supports communication to and from multiple devices connected to the same cable or Ethernet network. For example, there can be a device that measures temperature and another device to measure humidity connected to the same cable, both communicating measurements to the same computer.

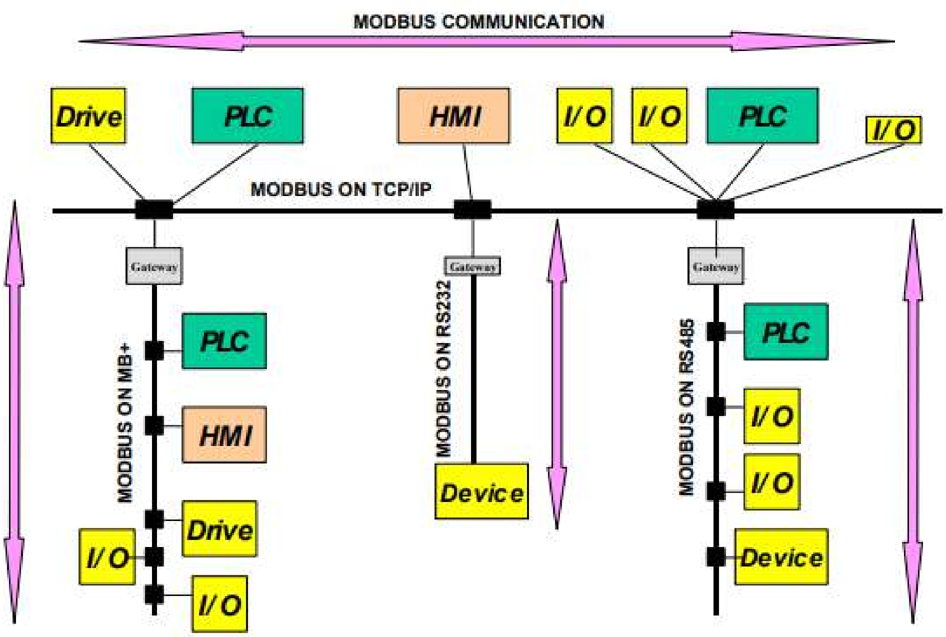

FIGURE 8 EXAMPLE OF MODBUS ARCHITECTURE (HMI - HUMAN MACHINE INTERFACE; I/O INPUT/OUTPUT)

3.1.16 SimplRF

Title	Simpl (Simplified Modbus Protocol Layer) RF	
Author and License	Decode	
URL	[DWS100 - Decode]()	
Scope	Measurements, Equipment	
BEYOND related	*DR in buildings* ý	
	Machine-to-machine communication and interoperability enhancement at smart building level þ	
	Building Data Model representations ý	
	Business synergies and data exchanges between the building and energy system/network stakeholders ý	
Scope of application		
DSO ý	*TSO* ý	*BRP / Market* ý
Retailer ¨	*Aggregator* ¨	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* ý

The SimplRF is a wireless sensor network (WSN) made by Decode. It is used for wireless monitoring of physical or environmental conditions. Network consists of one or more wireless End Devices (ED) and one Access Point Device (AP) through which Host computer access the wireless network. SimpIRF wireless sensor network use star configuration, ISM band (868 MHz, 916 MHz and 433 MHz) and open source SimpliciTI protocol from Texas Instruments. Communication is two-way, both ED and AP can send and receive messages. The communication is encrypted with XTEA standard. The SimpIRF find its application in offices, data centers, storage facilities and more.

The ED is battery-powered sensor device and works in Sleep/Poll mode. In order to save the battery, ED device remains in sleep mode most of the time. Nevertheless, the ED periodically wakes up for a short period of time to perform communication and measurement tasks. The disadvantage or this mode is the increased latency of communication with battery powered devices.

The Host computer and AP use Host AP Interface Protocol (HAPI) to communicate. The connection between them can be established either by a direct connection between RS-232 and USB interfaces or while for IP network connection Ethernet and WiFi are options. The AP and Host device are both powered constantly. ED`s are available with different kind of sensing elements.

3.1.17 NAESB Energy Usage Information Model

Title	NAESB Energy Usage Information Model
Author and License	NAESB
URL	NAESB
Scope	Measurements, Equipment, Products
BEYOND related	*DR in buildings* ý
	Machine-to-machine communication and interoperability enhancement at smart building level ý
	Building Data Model representations þ
	Business synergies and data exchanges between the building and energy system/network stakeholders ý

Scope of application		
DSO ý	*TSO* ý	*BRP / Market* ý
Retailer ¨	*Aggregator* ¨	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* ý

The starting point for the energy usage information model is the *UsagePoint*. *UsagePoints* identifies key references for the information set optionally including identification of the customer, the location, and the physical asset. *UsagePoint* is associated in turn with zero or more *MeterReadings*. A *MeterReading* composes information about a particular measurement such as kWh or kW. A *MeterReading* has a *ReadingType* which describes the nature of the measurement including its units of measure, and zero or more IntervalReadings or Readings and associated quality information. *UsagePoint* may also be associated with summary information on load and usage, and optionally, power quality. For applications requiring third party access to this information, additional classes are identified to facilitate associating customer and customer agreement information with the measurements available at a *UsagePoint*. (NASEB, n.d.)

The energy usage information model includes many optional components. The complete set of information expressible using the energy usage information model satisfies a wide range of applicability requirements identified by the industry. Users of this Business Practice Standard may optionally take advantage of these extended definitions based on need without requiring them. Applications built on the energy usage information model may elect which optional components to present. However, clients of this information can be expected to recognize all components provided in the application.

The NAESB standard identifies the set of core model elements that shall be supported by specifications claiming conformance to this Business Practice Standard. Figure 9 illustrates the core of the energy usage information model. (Rahman, Md Moshiur & Kuzlu, Murat & Pipattanasomporn, Manisa & Rahman, Saifur, 2014; NASEB, n.d.)

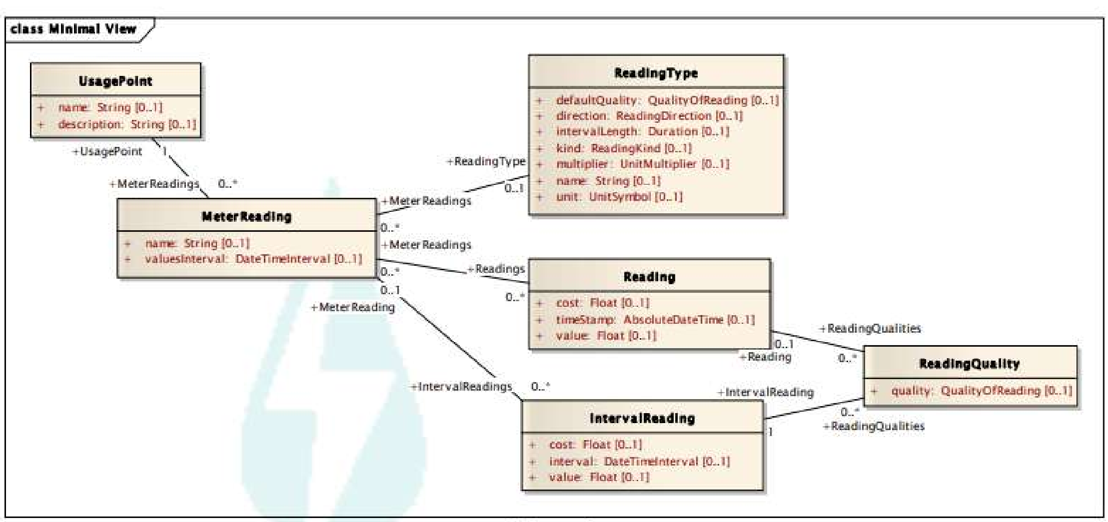

FIGURE 9 CORE OF THE ENERGY USAGE INFORMATION MODEL (NASEB, N.D.)

3.1.18 Energy Flexibility Interface (EFI)

<table>
<tr><td>Title</td><td colspan="2">Energy Flexibility Interface (EFI)</td></tr>
<tr><td>Author and License</td><td colspan="2">FAN (Flexible Power Alliance Network)</td></tr>
<tr><td>URL</td><td colspan="2">EFI - Energy Flexibility Interface</td></tr>
<tr><td>Scope</td><td colspan="2">Measurements, Equipment, Products</td></tr>
<tr><td rowspan="4">BEYOND related</td><td colspan="2">DR in buildings þ</td></tr>
<tr><td colspan="2">Machine-to-machine communication and interoperability enhancement at smart building level þ</td></tr>
<tr><td colspan="2">Building Data Model representations ý</td></tr>
<tr><td colspan="2">Business synergies and data exchanges between the building and energy system/network stakeholders ý</td></tr>
<tr><td colspan="3">Scope of application</td></tr>
<tr><td>DSO þ</td><td>TSO ¨</td><td>BRP / Market ý</td></tr>
<tr><td>Retailer ¨</td><td>Aggregator ¨</td><td>Customer/Prosumer þ</td></tr>
<tr><td>ESCO ¨</td><td>Building/Facility manager þ</td><td>Local authority ý</td></tr>
</table>

The EFI is a communication interface between smart devices (such as washing machines, air conditioning units, solar panels and car chargers) and Demand Side Management solutions aimed to become a common language for energy flexibility. It is strongly supported by the Flexible Power Alliance Network and is supported by the large DSOs in the Netherlands.

Whenever manufacturers develop devices that support EFI, these devices can communicate with all Smart Grid technologies (Powermatcher, OpenADR, Triana). Conversely, by supporting EFI, developers of Smart Grid technologies can rely on their solution being able to communicate with all smart devices that support EFI. EFI is an open-source standard that enables smart devices to communicate with smart grids and vice versa. It will make it possible for us to make as much flexible energy available as possible. And this in turn helps the transition to a sustainable and affordable energy supply. (EFI, n.d.)

It is important to point out that EFI only focused on abstract modelling of the available energy flexibility.

3.1.19 USEF (Universal Smart Energy Framework)

Title	USEF (Universal Smart Energy Framework)
Author and License	ABB, Alliander, DNV GL, Essent, IBM, ICT Automation and Stedin
URL	USEF Energy
Scope	Measurements
BEYOND related	*DR in buildings* ý
	Machine-to-machine communication and interoperability enhancement at smart building level ý
	Building Data Model representations ý
	Business synergies and data exchanges between the building and energy system/network stakeholders þ

Scope of application		
DSO þ	*TSO* ý	*BRP / Market* þ
Retailer ¨	*Aggregator* þ	*Customer/Prosumer* ý
ESCO ¨	*Building/Facility manager* ¨	*Local authority* ý

USEF describes a market framework for flexibility trading, it specifies stakeholders' roles and describes how they interact. In order to optimize the value of flexibility across all roles in the system, USEF introduces a new market-based coordination mechanism (MCM) along with new processes. The MCM provides equal access to a smart energy system to all interested stakeholders. The USEF framework provides a universal model in which the aggregator presents a crucial role. An in-depth description of the aggregator business is provided in (USEF, n.d.).

USEF is developed, maintained, and audited by the USEF Foundation, a non-profit partnership of seven organizations, active in all areas of the smart energy industry: ABB, Alliander, DNV GL, Essent, IBM, ICT Automation and Stedin. USEF Foundation published the following major documents (USEF, n.d.):

- The framework explained: outlines the vision and approach to the flexibility market design, with a description of the structure, market roles, tools and rules;
- The framework specifications: delivers detailed technical guidelines for implementation of an optimised market-based energy system;
- The privacy and security guideline: USEF definition for balancing consumer confidence with security of supply, while complying with new European General Data Protection Regulation;

- The framework implemented: USEF's reference implementation offers sample coding to make building a USEF compliant IT system easier. It is available on GitHub under the Apache 2.0 license.

The USEF model can be used for the interaction between aggregators, balance responsible parties (e.g. retailers) and DSO which means it is not applicable for buildings directly.

3.1.20 Industry Foundation Classes (IFC) - ISO 16739-1:2018

Title	ISO 16739-1:2018 Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries
Author and License	ISO
URL	ISO 16739-1:2018
Scope	Building information model (BIM)
BEYOND related	*DR in buildings* ý
	Machine-to-machine communication and interoperability enhancement at smart building level ý
	Building Data Model representations þ
	Business synergies and data exchanges between the building and energy system/network stakeholders þ

Scope of application		
DSO ý	*TSO* ý	*BRP / Market* ý
Retailer ¨	*Aggregator* ¨	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* ý

The Industry Foundation Classes, IFC, are an open international standard for Building Information Model (BIM) data that are exchanged and shared among software applications used by the various participants in the construction or facility management industry sector.

IFC is a standardized, digital description of the built asset industry. The standard includes definitions that cover data required for buildings over their life cycle. This release, and upcoming releases, extend the scope to include data definitions for infrastructure assets over their life cycle as well.

The Industry Foundation Classes specify a data schema and an exchange file format structure. The data schema is defined in:

- EXPRESS data specification language, defined in ISO 10303-11,

- XML Schema definition language (XSD), defined in XML Schema W3C Recommendation,

whereas the EXPRESS schema definition is the source, and the XML schema definition is generated from the EXPRESS schema according to the mapping rules defined in ISO 10303-28. The exchange file formats for exchanging and sharing data according to the conceptual schema are:

- Clear text encoding of the exchange structure, defined in ISO 10303-21,
- Extensible Markup Language (XML), defined in XML W3C Recommendation.

Alternative exchange file formats may be used if they conform to the data schemas.

ISO 16739-1:2017 of IFC consists of the data schemas, represented as an EXPRESS schema and an XML schema, and reference data, represented as definitions of property and quantity names, and formal and informative descriptions.

A subset of the data schema and referenced data is referred to as a Model View Definition (MVD). A particular MVD is defined to support one or many recognized workflows in the construction and facility management industry sector. Each workflow identifies data exchange requirements for software applications. Conforming software applications need to identity the model view definition they conform to. (ISO, n.d.)

The IFC transports enough information for the simulation software to read and analyze the spaces (building elements) in the reference model. The IFC model is however a reference copy of the original design and does not allow major modifications (i.e., an engineer wants to do some modifications in the HVAC system) in the model itself but could be done by the IFC model architect. In the IFC based workflow each discipline remains author and owner of their model content. (buildingSMART , n.d.)

3.1.21 COBie

Title	Construction Operations Building Information Exchange (COBie)
Author and License	buildingSMART
URL	buildingSMART COBie
Scope	Building information model (BIM)
BEYOND related	*DR in buildings* ý
	Machine-to-machine communication and interoperability enhancement at smart building level ý
	Building Data Model representations þ

	Business synergies and data exchanges between the building and energy system/network stakeholders þ	
Scope of application		
DSO ý	*TSO* ý	*BRP / Market* ý
Retailer ¨	*Aggregator* ¨	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* ý

Construction Operations Building Information Exchange (COBie) is a non-proprietary data format for the publication of a subset of building information models (BIM) focused on delivering asset data as distinct from geometric information. COBie was developed by a number of US public agencies to improve the handover process to building owner-operators. It is, typically, a Microsoft Excel spreadsheet, but other spreadsheet applications may be used. (NBS, n.d.)

The idea behind COBie is that the key information is all pulled into one format and shared between the construction team at defined stages in a project. The most common way in which construction companies will interact with COBie is through the COBie spreadsheet, but the data can be presented in a variety of different ways according to the needs of the owner and the specific operations maintenance and asset data transfer.

A COBie file is by no means a full BIM, but it does contain structured content from all members of the construction team and from many information models. The COBie data model is part of the buildingSMART data model, which is more commonly known as the IFC (Industry Foundation Class). COBie is also part of the openBIM movement which aims to foster support for the collaborative design, construction, and operation of buildings. It is also part of the building information modelling (BIM) Level 2 initiative (The Cad Room, n.d.).

At the core of COBie are three basic principles:

- Classification system. This is a key foundation for COBie although the system used is up to the owner. Using a classification system helps users to navigate the information more easily and also brings with it the possibility of aggregation across projects.
- Data model. As we have mentioned above, COBie is aligned with the buildingSMART open IFC model meaning it shares good practice across the sector. It also means that integrating design tools and construction processes will become easier.
- Delivery format. Users of COBie have the option to see the information in a variety of different delivery formats including standard IFC ones. They also have the option to use a spreadsheet-based data collection and delivery format as

well. This allows participation in an openBIM workflow even if you don't have access to a BIM model view or have any knowledge of the IFC data model.

COBie in itself is a very simple concept which is why many BIM companies were quick to adopt it, although its adoption in the construction industry as a whole has been much slower. (The Cad Room, n.d.)

3.1.22 obXML

Title	obXML
Author and License	Tianzhen Hong et al.
URL	[XML Schema – obXML]
Scope	Building information model (BIM)
BEYOND related	*DR in buildings* ý
	Machine-to-machine communication and interoperability enhancement at smart building level ý
	Building Data Model representations þ
	Business synergies and data exchanges between the building and energy system/network stakeholders þ

Scope of application		
DSO ý	*TSO* ý	*BRP / Market* ý
Retailer ¨	*Aggregator* ¨	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* ý

Considering that energy-related occupant behavior in buildings is difficult to define and quantify, obXML introduces (Tianzhen Hong, Simona D'Oca, Sarah C. Taylor-Lange, William J.N. Turner, Yixing Chen, Stefano P. Corgnati,, 2015) the DNAS (Drivers, Needs, Actions and Systems) framework, to standardize the description of energy related occupant behavior in buildings. The topology of the DNAS framework was implemented into an XML schema titled 'occupant behavior XML' or obXML schema. The topology of the DNAS framework implemented in the obXML schema has a main root element OccupantBehavior, linking three main elements representing Buildings, Occupants and Behaviors, and two optional elements Seasons and Time of Day (behavior.lbl.gov, n.d.).

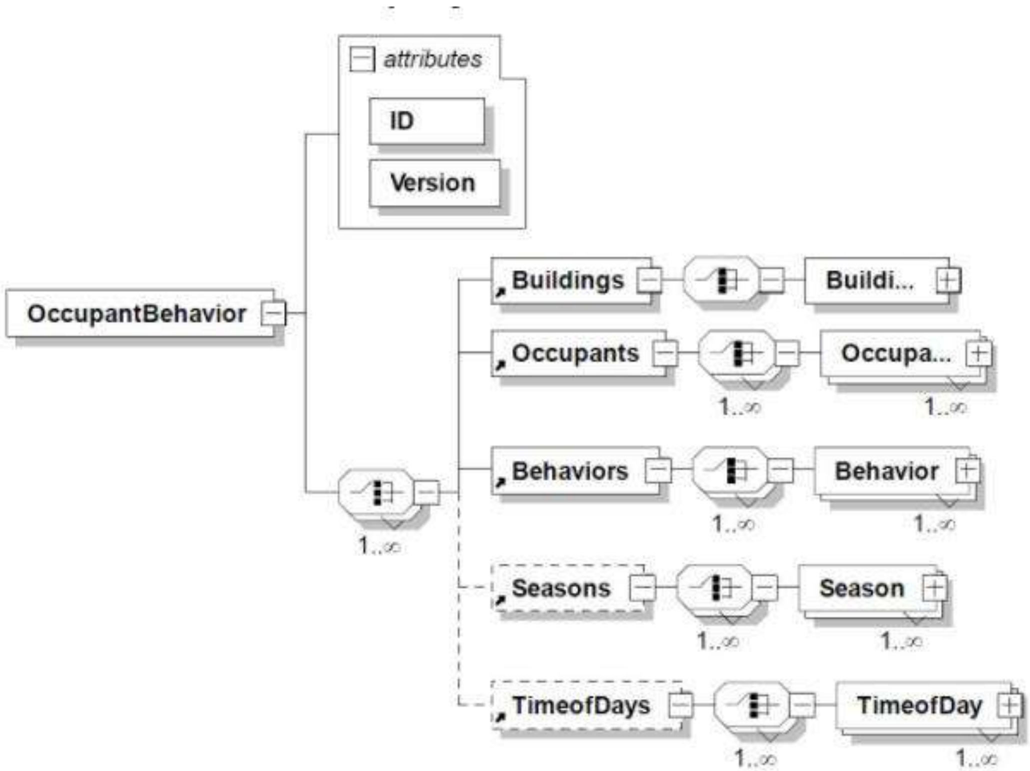

FIGURE 10 OBXML SCHEMA (BEHAVIOR.LBL.GOV, N.D.)

The Buildings element, as described in (behavior.lbl.gov, n.d.), pertains specifically to the inputs related to occupant behaviours in the building. It has a unique ID attribute and requires *Type* and *Spaces* children elements. The Type element contains 39 enumeration building types, consistent with those commonly used in BIM schemas (such as gbXML). The Building element has optional children's elements of Address and Description to be input as a string. The Spaces element allows for the choice of one to infinity spaces to be defined. Each Space element includes a unique attribute ID, and the required child elements of Type (MeetingRoom, Corridor, Outdoor, Office, ResidentialOwn, ResidentailRent, OfficeShared, OfficePrivate, Other) and GroupPriority (Majority). In addition, a description, maximum or minimum number of occupants within the space and meeting information is optional input. If the space is communal, the *Meeting* element contains child elements describing the Duration, StartTime, EndTime, and the Probability of the meeting occurring. The Building parent element hosts the Systems child element, describing the physical equipment or components with which an occupant may interact. The child elements of the *Systems* element include the Window, Shade, Light, Thermostat, Equipment, and HVAC control, each with a unique ID attribute, an optional Description element, and an enumeration selection for the *Type* of control: window - operable or fixed; shade - operable or fixed; light - on/off, dimmable, two step, three steps; thermostat - adjustable, none, fixed; HVAC system - central, zonal controllable, zonal fixed. More descriptive material is provided in (Tianzhen Hong, Simona D'Oca, Sarah C. Taylor-Lange, William J.N. Turner, Yixing Chen, Stefano P. Corgnati,, 2015). The obXML schema is used for the practical implementation of the DNAS framework into building simulation tools.

3.1.23 Green Building XML schema (gbXML)

Title	Green Building XML schema (gbXML)
Author and License	gbXML
URL	[gbXML Green Building XML Schema]()
Scope	Building information model (BIM)
BEYOND related	*DR in buildings* ý
	Machine-to-machine communication and interoperability enhancement at smart building level ý
	Building Data Model representations þ
	Business synergies and data exchanges between the building and energy system/network stakeholders þ

Scope of application		
DSO ý	*TSO* ý	*BRP / Market* ý
Retailer ¨	*Aggregator* ¨	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* ý

The Green Building XML schema (gbXML) has been developed as a language of buildings to facilitate the transfer of building information stored in CAD-based building information models, enabling interoperability between disparate building design and engineering analysis software tools.

Nowadays, gbXML has the industry support and wide adoption by leading Building Information Modeling (BIM) vendors. With the development of export and import capabilities, gbXML has become a de facto industry standard schema. Its use dramatically streamlines the transfer of building information to and from architectural and engineering models, eliminating the need for time consuming plan take-offs. This removes a significant cost barrier to designing sustainable and energy efficient buildings. It enables building design teams to truly collaborate and realize the potential benefits of Building Information Modeling. (gbXML, n.d.)

3.1.24 INSPIRE ISO/TC 211

Title	INSPIRE ISO/TC 211 Geographic information/Geomatics
Author and License	ISO
URL	[EC JRC - The European INSPIRE Directive (iso.org)]()
Scope	Geographic information/Geomatics
BEYOND related	*DR in buildings* ý
	Machine-to-machine communication and interoperability enhancement at smart building level ý
	Building Data Model representations ý
	Business synergies and data exchanges between the building and energy system/network stakeholders þ

Scope of application		
DSO ¨	*TSO* ¨	*BRP / Market* ý
Retailer ¨	*Aggregator* ¨	*Customer/Prosumer* ¨
ESCO ¨	*Building/Facility manager* þ	*Local authority* þ

The INSPIRE Directive aims to create a European Union spatial data infrastructure for the purposes of EU environmental policies and policies or activities which may have an impact on the environment. The idea is to enable the sharing of environmental spatial information among public sector organizations, facilitate public access to spatial information across Europe and assist in policymaking across boundaries. INSPIRE is based on the infrastructures for spatial information established and operated by the Member States of the European Union

ISO Technical Committee (TC) 211, Geographic information/Geomatics, is developing a suite of standards for geographic information that forms a basics upon geomatics (modelling of the earth) can be performed. The TC 211 standards are extensively used for the creation of non-legally binding INSPIRE Technical guideline documents. As defined in (ISO, n.d.) ISO standards are used as 'building blocks' for the:

- encoding of data and metadata,
- and network services for discovery, viewing and downloading of data.

ISO/TC 211 does not keep track of statistics on implementation and compliance with the standards. However, any device or product that makes use of location coordinates derived from a GNSS device is likely to follow ISO 6709:2008, Geographic information -Standard representation of geographic point location by coordinates. Many, if not most, geospatial products are based on ISO 19107, Geographic information -- Spatial schema, a conceptual schema describing the spatial characteristics of geographic features and operations on them.

Similarly, most object-relational databases have implemented ISO 19125-2:2004, Geographic information - Simple feature access - Part 2: SQL option, which has now been integrated into the ISO/IEC 13249 series of standards on database languages for SQL multimedia. (ISO, 2019)

3.2 Ontologies

3.2.1 SAREF

Title	Smart Appliances REFerence ontology (SAREF)
Author and License	ETSI
URL	SAREF: the Smart Applications REFerence ontology (etsi.org)
Scope	Location, Stakeholders, Products, Equipment, Measurements, Events
BEYOND related	*DR in buildings* ý
	Machine-to-machine communication and interoperability enhancement at smart building level þ
	Building Data Model representations þ
	Business synergies and data exchanges between the building and energy system/network stakeholders ý

Scope of application		
DSO ý	*TSO* ý	*BRP / Market* ý
Retailer	*Aggregator*	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* ý

The SAREF reference ontology explicitly specifies the recurring core concepts in the smart appliances' domain, their relationships and mappings to other concepts used by different assets, standards or models. Within the scope of smart appliances, the SAREF ontology has reached the highest level of maturity.

SAREF is based on the fundamental principles of:

- reuse and alignment of (existing) concepts and relationships that are defined in existing assets,
- modularity to allow separation and recombination of different parts of the ontology depending on specific needs,
- extensibility to allow further growth of the ontology, and
- maintainability to facilitate the process of identifying and correcting defects, accommodate new requirements, and cope with changes in (parts of) SAREF.

The Smart Appliances REFerence ontology (SAREF) is conceived as a shared model of consensus that facilitates the matching of existing assets in the smart appliances' domain. The SAREF requires one set of mappings to each asset, instead of a dedicated set of mappings for each pair of assets. Different assets share some recurring, core concepts, but they often use different terminologies and adopt different data models to represent these concepts. Using SAREF, different assets can keep using their own terminology and data models, but still can relate to each other through their common semantics.

These are the main SAREF concepts (in alphabetical order):

- Building Object (Door, Window)
- Building Space
- Command (e.g. *OnCommand, OffCommand, PauseCommand, GetCommand, NotifyCommand, SetLEvelCommand*)
- Commodity (e.g. *Electricity, Gas, Water*)
- Device (e.g. *Switch, Meter, Sensor, Washing Machine*)
- Device Category
- Duration Description
- Function (*Actuating Function, EventFunction, Metering Function, Sensing Function*)
- Function Category
- Profile
- Property (*Energy, Humidity, Light, Motion, Occupancy, Power, Pressure, Price, Smoke, Temperature, Time*)
- Service
- State
- Task (e.g. *Cleaning, Safety, Entertainment*)
- Temporal Entity
- UnitOfMeasure (e.g. *Currency, EnergyUnit, Power Unit, Temperature Unit*).

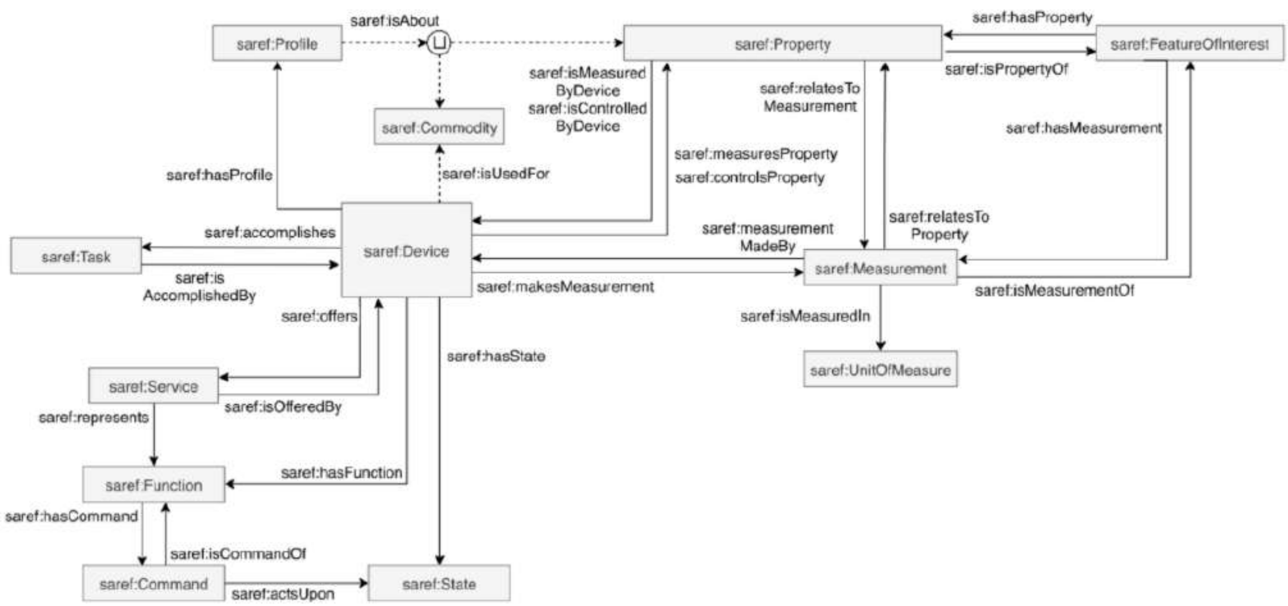

Figure 11 Overview of the SAREF ontology (ETSI, n.d.)

3.2.1.1 SAREF4BLDG

Title	SAREF extension for building
Author and License	ISO, IFC
URL	[SAREF extension for building (etsi.org)](#)
Scope	Location, Stakeholders, Products, Equipment, Measurements, Events
BEYOND related	*DR in buildings* ý
	Machine-to-machine communication and interoperability enhancement at smart building level þ
	Building Data Model representations þ
	Business synergies and data exchanges between the building and energy system/network stakeholders ý

Scope of application		
DSO ¨	*TSO* ¨	*BRP / Market* ¨
Retailer ¨	*Aggregator* ¨	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* ¨

SAREF4BLDG is an extension of SAREF ontology designed by buildingSMART International and published as the ISO 16739 standard. The buildingSMART tries to break down the information siloes, and its technical core is based on ISO-certified Industry Foundation Classes (ISO 16739-1:2018).

The idea behind SAREF4BLDG is to enable the interoperability between these actors: architects, engineers, consultants, contractors, product component manufacturers, etc. and applications managing building information involved in the different phases of the building life cycle. The life cycle phases considered include planning, design, construction, commissioning, operation, retrofitting and refurbishment, and demolition. By using SAREF4BLDG, smart appliances from manufacturers that support the IFC data model will easily communicate with each other. (ETSI, n.d.)

As described in (ETSI, n.d.), Figure 12 presents an overview of the classes (only the top levels of the hierarchy) and the properties included in the SAREF4BLDG extension. As it can be observed the classes *s4bldg:Building*, *s4bldg:BuildingSpace* and *s4bldg:PhysicalObject* have been declared as subclasses of the class *geo:SpatialThing* in order to reuse the conceptualization for locations already proposed by the geo ontology. The modelling of building objects and building spaces has been adapted from the SAREF ontology; in this sense, the new classes deprecate the *saref:BuildingObject* and *saref:BuildingSpace* classes. In addition, a new class has been created, the *s4bldg:Building* class, to represent buildings.

The concepts *s4bldg:Building* and *s4bldg:BuildingSpace* are related to each other by means of the properties *s4bldg:hasSpace* and *s4bldg:isSpaceOf;* such properties are defined as inverse properties among them. These properties might also be used to declare that a *s4bldg:BuildingSpace* has other spaces belonging to the class *s4bldg:BuildingSpace*.

The relationship between building spaces and devices and building objects has also been transferred and generalized from the SAREF ontology. In this regard, a *s4bldg:BuildingSpace* can contain (represented by the property *s4bldg:contains*) individuals belonging to the class *s4bldg:PhysicalObject*. This generalization has been implemented in order to support building spaces to contain both building objects and devices. Accordingly, the classes *s4bldg:BuildingObject* and *saref:Device* are declared as subclasses of *s4bldg:PhysicalObject*.

Finally, the class representing building devices, namely *s4bldg:BuildingDevice*, is defined as a subclass of both *saref:Device* and *s4bldg:BuildingObject*. This class is a candidate for replacing the *saref:BuildingRelated* class.

SAREF4BLDG extends the base coverage of SAREF by adopting the Industry Foundation Classes into SAREF. In conclusion, while the IFC classes are used to ensure semantic interoperability in business transactions, the SAREF4BLDG is directed towards IoT and devices, in line with the general SAREF scope.

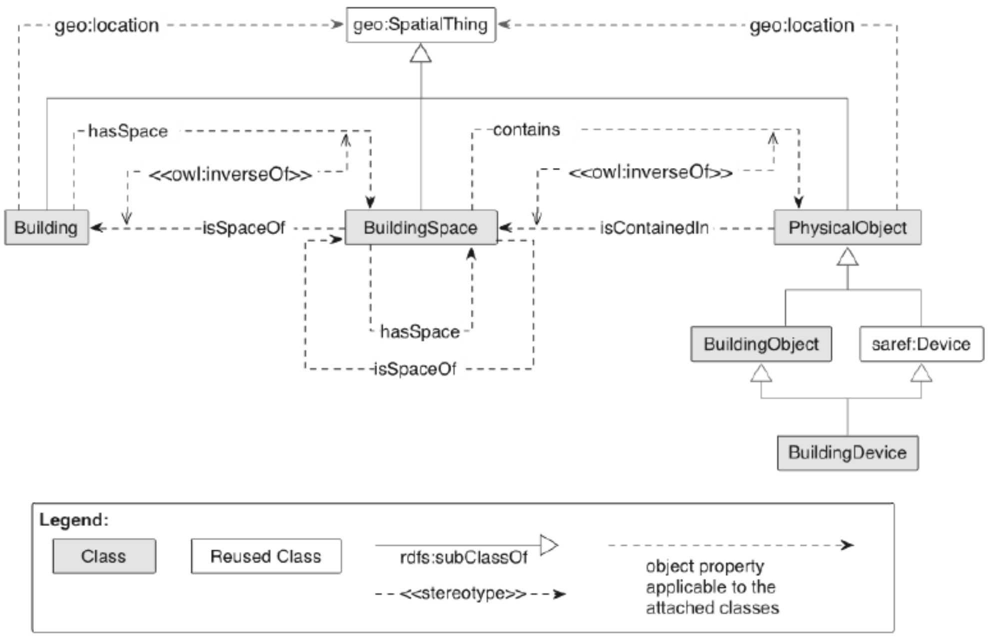

FIGURE 12 GENERAL OVERVIEW OF THE TOP LEVELS OF THE SAREF4BLDG EXTENSION (ETSI, N.D.)

3.2.1.2 SAREF4ENER

Title	SAREF4ENER: an extension of SAREF for the energy domain
Author and License	ETSI - Energy@Home and EEBus associations
URL	[SAREF4ENER: an extension of SAREF for the energy domain]()
Scope	Location, Stakeholders, Products, Equipment, Measurements, Events
BEYOND related	*DR in buildings* þ
	Machine-to-machine communication and interoperability enhancement at smart building level þ
	Building Data Model representations þ
	Business synergies and data exchanges between the building and energy system/network stakeholders ý

Scope of application		
DSO ¨	*TSO* ¨	*BRP / Market* ¨
Retailer ¨	*Aggregator* ¨	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* ¨

The SAREF4ENER ontology is an extension of SAREF, created in collaboration with Energy@Home and EEBus.

Figure 13 presents an overview of the SAREF4ENER ontology. Rectangles containing an orange circle are used to denote classes created in SAREF4ENER, while rectangles containing a faded orange circle denote classes reused from other ontologies, such as SAREF. For all entities described in (ETSI, n.d.), it is indicated whether they are defined in the SAREF4ENER extension or elsewhere by the prefix included before their identifier, , i.e. if the element is defined in SAREF4ENER the prefix is s4ener:, while if the element is reused from another ontology it is indicated in the Namespace Declarations section.

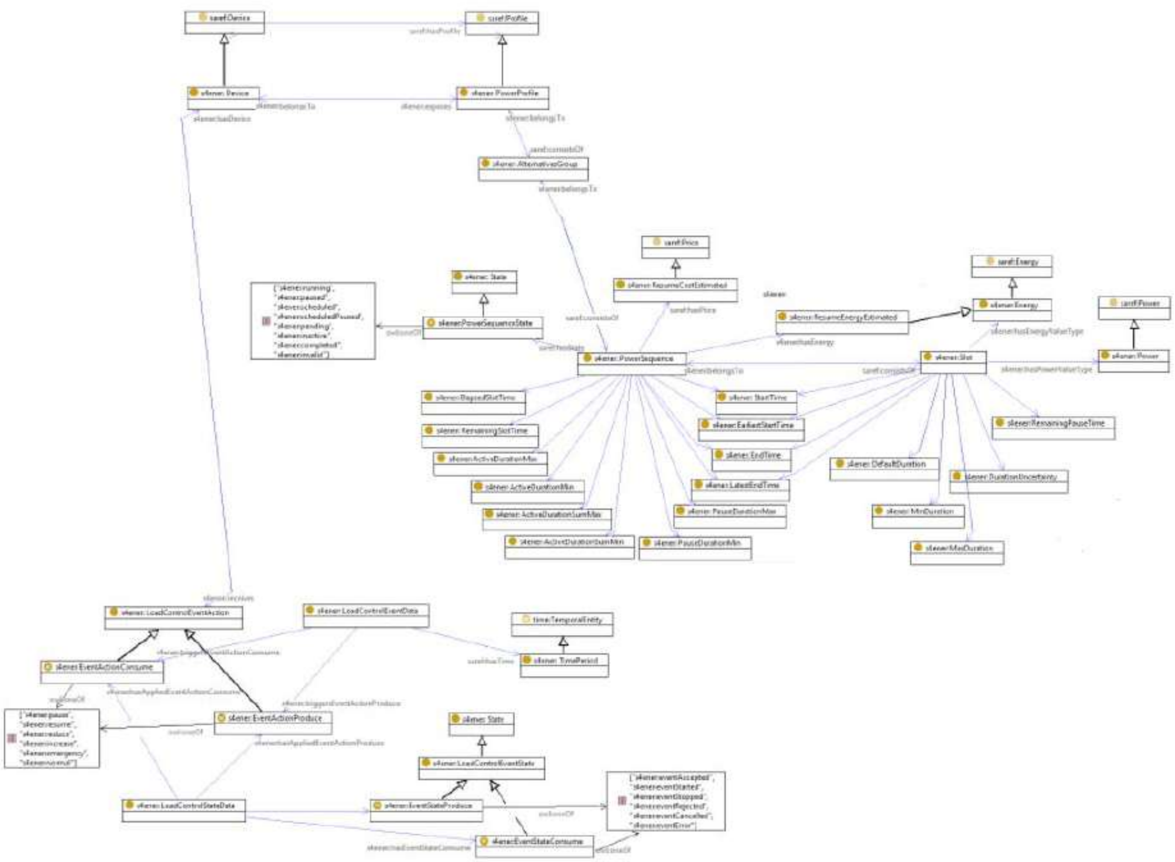

FIGURE 13 SAREF4ENER OVERVIEW (ETSI, N.D.)

Additionally, SAREF4ENER is applicable for energy management purposes in buildings. The classes within SAREF4ENER are used to schedule devices in certain modes and preferred times using power profiles to optimize energy efficiency and accommodate the customer's preferences thus accommodate DR programs. These classes are *s4ener:PowerProfile*, *s4ener:Alternative*, *s4ener:PowerSequence* and *s4ener:Slot*, which are shown in Figure 14.

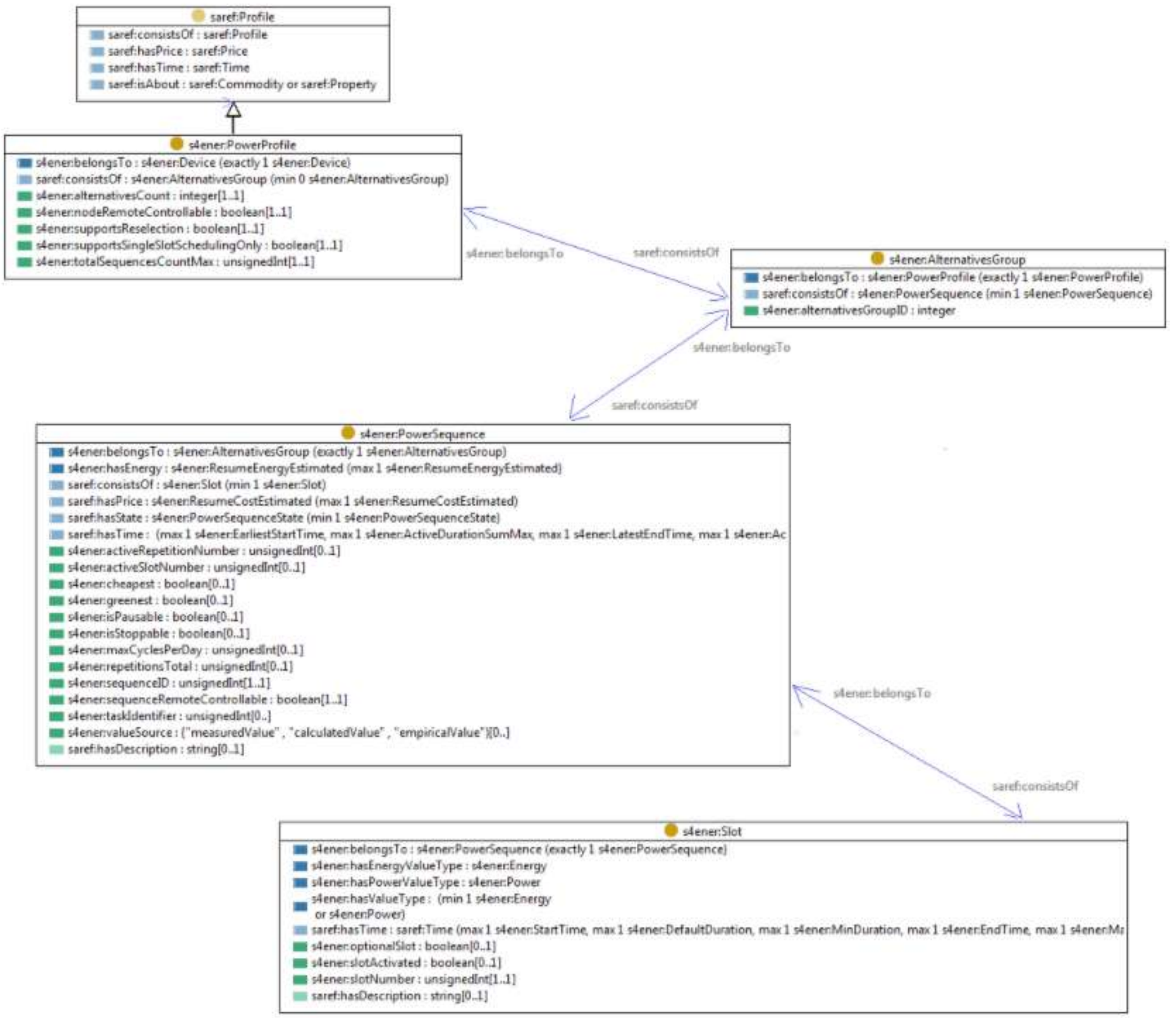

FIGURE 14 SAREF4ENER FOR POWER PROFILES

3.2.1.3 SAREF4CITY

Title	SAREF extension for Smart City
Author and License	Open Geospatial Consortium and. Spanish Federation of Municipalities and Provinces et al.
URL	[SAREF extension for Smart City (etsi.org)]()
Scope	Location, Stakeholders, Products, Equipment, Measurements, Events
BEYOND related	*DR in buildings* ý
	Machine-to-machine communication and interoperability enhancement at smart building level ý
	Building Data Model representations þ

	Business synergies and data exchanges between the building and energy system/network stakeholders ý	
Scope of application		
DSO ¨	*TSO* ¨	*BRP / Market* ¨
Retailer	*Aggregator*	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* þ

The SAREF4CITY ontology is an extension of SAREF for the Smart Cities domain (ETSI, n.d.). The SAREF4CITY ontology is a compilation of investigated resources from standardization bodies primarily operating in Smart Cities domain such as Open Geospatial Consortium (OGSC), industry trade associations and several European-level funded research projects and initiatives. It is a reference ontology for IoT in the context of smart cities.

The following sets of requirements have been identified and categorized:

- Topology,
- Administrative Area,
- City Object,
- Event,
- Measurement,
- Key Performance Indicator.

An overview of the SAREF4CITY ontology is presented in Figure 15 . As in the case of SAREF4ENER prefixes and used to identify whether the element has been created in SAREF4CITY of elsewhere, while arrows are used to represent properties between classes.

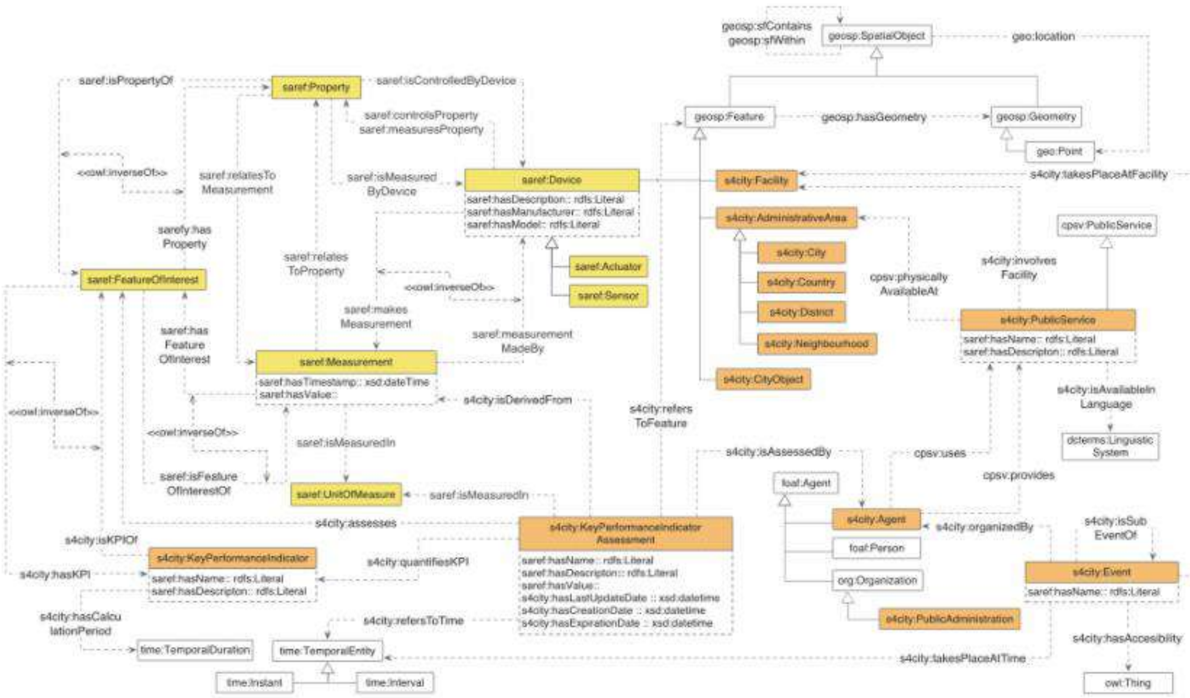

FIGURE 15 SAREF4CITY OVERVIEW (ETSI, N.D.)

SAREF4CITY is an OWL-based ontology that bases on basic SAREF ontology and reusing six other ontologies. It consists of 31 base classes, 13 additional to 18 coming from original SAREF, 36 object properties (20 new, 16 reused) and 7 data type properties (3 new, 4 reused from SAREF). The primary focus of this ontology is to go beyond the base SAREF smart appliance focused ontology and extend into the smart city data, primarily directed towards the IoT field.

SAREF4CITY includes several interesting concepts, such as handling of the geospatial data, and handling of time intervals which is relevant for measurement validity. The geospatial modelling has been reused from GeoSPARQL, a standard for representation and querying of geospatial linked data, designed by Open Geospatial Consortium.

SAREF4CITY includes models of abstract terms such as event classes, designed to represent temporal and scheduled events, and key performance indicators (KPIs). A KPI in SAREF4CITY is split: the KPI itself defines the KPI in general terms, while the KPI assessment class defines the actual value of the KPI for a given location and time span. While generally an interesting idea, this extended coverage inevitably introduces additional complexity into the model.

3.2.2 OntoENERGY

Title	OntoENERGY	
Author and License	Tobias Linnenberg; Andreas W. Mueller; Lars Christiansen; Christian Seitz and Alexander Fay	
URL	OntoENERGY	
Scope	Measurements	
BEYOND related	*DR in buildings*ý	
	Machine-to-machine communication and interoperability enhancement at smart building level ý	
	Building Data Model representations þ	
	Business synergies and data exchanges between the building and energy system/network stakeholders ý	
Scope of application		
DSO ¨	*TSO* ý	*BRP / Market* ý
Retailer þ	*Aggregator* þ	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* ¨

OntoENERGY is an attempt to create an ontology that supports energy-efficiency tasks. It aims to define the fundamental physical quantities and their interrelations in the energy domain. OntoENERGY also distinguishes three main interpretations of energy: physical, industrial and automation. These are used to sub-classify the associated forms of energy. As described in (Linnenberg, Tobias & Müller, Andreas & Christiansen, Lars & Seitz, Christian & Fay, Alexander, 2013), the objective of this ontology is to support energy-efficiency analysis, the quantity of energy dissipation regarded in this context and the most important results of energy efficiency evaluation.

3.2.3 SESAME-S

Title	SESAME-S Smart Ontology for Buildings
Author and License	Research Centre for Telecommunication
URL	SESAME-S
Scope	Location, Products, Measurements, Equipment
BEYOND related	*DR in buildings* ý
	Machine-to-machine communication and interoperability enhancement at smart building level ý
	Building Data Model representations þ

	Business synergies and data exchanges between the building and energy system/network stakeholders þ	
Scope of application		
DSO ¨	*TSO* ¨	*BRP / Market* þ
Retailer ¨	*Aggregator* ¨	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* ý

SESAME-S is an ontology that includes concepts related to devices, tariffs, energy usage profiles and activities. The ontology has been developed within the SESAME-S project and describes an energy-aware home and the relationships between the objects and actors within the control scenario. SESAME uses an ontology-based modelling approach to describe an energy-aware home and the relationships between the objects and actors within its control scenario. The main components of the SESAME ontology expressed in OWL are Automation Ontology, Meter Data Ontology and Pricing Ontology (Tomic, Slobodanka Dana Kathrin & Fensel, Anna & Pellegrini, Tassilo., 2010).

3.2.4 SEMANCO

Title	SEMANCO	
Author and License	Politecnico di Torino	
URL	SEMANCO Project - Ontology	
Scope	Equipment, Products, Measurements, Location	
BEYOND related	*DR in buildings* ý	
	Machine-to-machine communication and interoperability enhancement at smart building level ý	
	Building Data Model representations þ	
	Business synergies and data exchanges between the building and energy system/network stakeholders þ	
Scope of application		
DSO ý	*TSO* ý	*BRP / Market* ý
Retailer þ	*Aggregator* þ	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* þ

The SEMANCO Energy Model is a formal ontology, which is specified using Web Ontology Language 2 (OWL 2), comprise concepts captured from diverse sources including standards, use cases and activity descriptions and data sources related to the domains of urban planning and energy management. It encompasses the terms and attributes that describe regions, cities, neighbourhoods and buildings; energy consumption and CO_2 emission indicators, as well as climate and socio- economic factors that influence energy consumption. The ontology enables semantic tools to access the data stemming from different domains and applications.

The SEMANCO Energy Model is based on existing energy information standards. SEMANCO Ontology describes the domain of urban planning based on the OWL-based translation of the Suggested Upper Merged Ontology (SUMO). In particular, energy model terminology is specified in ISO/IEC CD 13273 (Energy efficiency and renewable energy sources), ISO/DTR 16344 (Common terms, definitions and symbols for the overall energy performance rating and certification of buildings), ISO/CD 16346 (Assessment of overall energy performance of buildings), ISO/DIS 12655 (Presentation of real energy use of buildings), ISO/CD 16343 (Methods for expressing energy performance and for energy certification of buildings), and ISO 50001:2011 (Energy management systems – requirements with guidance for use). (SEMANCO, n.d.)

3.2.5 EEBUS

Title	EEBUS
Author and License	EEBUS initiative
URL	Technology - EEBus Initiative e.V.
Scope	Equipment, Products, Measurements, Location
BEYOND related	*DR in buildings* þ
	Machine-to-machine communication and interoperability enhancement at smart building level þ
	Building Data Model representations þ
	Business synergies and data exchanges between the building and energy system/network stakeholders þ

Scope of application		
DSO ¨	*TSO* ¨	*BRP / Market* ¨
Retailer þ	*Aggregator* þ	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* ý

The EEBus Initiative is a non-profit association with leading manufacturers from the sectors of networked building technology, electromobility and energy (EEBUS, n.d.). This initiative has a high-reaching goal to become a language for energy, governing the exchange of information to coordinate and shift the energy between the intelligent power grid and practically all the devices connected to it. The idea is to have a common language that every device and every platform could freely use, regardless of the manufacturer and technology.

The EEBUS architecture is based on a Smart Grids Architecture Model (SGAM) model as described in Figure 16. EEBUS specifies the language of energy using the SHIP, SPINE and Use Case specifications.

SHIP describes the standardized transport of data over IP and provides mechanisms for setting up a secure network. A SHIP device can communicate with any SHIP device within the same network. On the other hand, SPINE is a toolbox of modular elements with the main objective to enable the realization of any present or future use cases. The toolbox contains a collection of data classes that can be exchanged on various technological platforms, communication, and transmission channels. SPINE can be mapped in various technologies such as KNX, Modbus, oneM2M and others. Furthermore, EEBUS is Energy@home are cooperating with the goal to embed SPINE into SAREF.

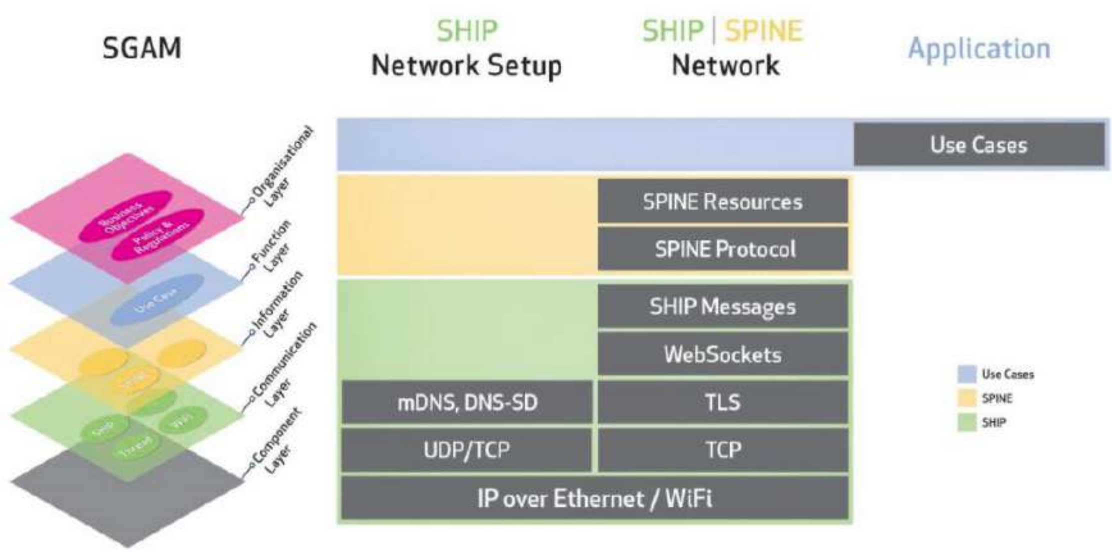

FIGURE 16 SGAM ARCHITECTURE MODEL FOR EEBUS (EEBUS, N.D.)

3.2.6 Digital Twins Definition Language (DTDL) ontology for Energy Grid

Title	Digital Twins Definition Language (DTDL) ontology for Energy Grid
Author and License	Microsoft, Azure IoT
URL	[DTDL based ontology for Energy Grid]()
Scope	Equipment, Products, Measurements, Location
BEYOND related	*DR in buildings* þ
	Machine-to-machine communication and interoperability enhancement at smart building level þ
	Building Data Model representations þ
	Business synergies and data exchanges between the building and energy system/network stakeholders þ

Scope of application		
DSO þ	*TSO* ¨	*BRP / Market* ¨
Retailer ¨	*Aggregator* ¨	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* ¨

The associated open modelling language, Digital Twins Definition Language (DTDL), is a blank canvas which can model any entity. It is therefore important to provide common domain-specific ontologies to bootstrap solution development and enable developers to quickly model and create sophisticated digital representations of connected environments like buildings, factories, farms, energy networks, railways, stadiums, and cities, then bring these entities to life within a live execution environment that integrates IoT and other data sources. (Microsoft, 2021)

The Azure IoT engineering team has released the energy grid ontology adapted from Common Information Model (CIM), a global standard for energy grid assets management, power system operations modelling and physical energy commodity market. The CIM-based DTDL ontology provides contextual understanding of data by identifying the properties of various grid entities and the relationships among them. Power & Utilities customers and partners can leverage as well as extend this open-source repository for their solutions and contribute their learnings to the repository for others to benefit from. (Digital Twins Definition Language (DTDL) ontology for Energy Grid, 2021)

The CIM organizes entities into distinct packages including core, wire, and generation packages, and prosumer-related entities from metering, customer, and Distributed Energy Resource (DER) packages.

Core Package contains the PowerSystemResource, ConductingEquipmen, and common collections of those entities shared by all applications. Most of the other packages have associations and generalizations that depend on the core package. Wire Package is an extension to the Core that provides model information on the electrical characteristics of transmission and distribution networks. This package is used by network applications, such as state estimation, load flow, and optimal power flow. Generation Package has information for unit commitment and economic dispatch of hydro and thermal generating units, load forecasting, automatic generation control, and unit modelling for training simulation. Finally, the prosumer – includes various entities related to consumer and DER in the prosumer folder. For examples, EquivalentLoad, UsagePoints, and MeterReading. (Digital Twins Definition Language (DTDL) ontology for Energy Grid, 2021)

3.2.7 RealEstateCore ontology

<table>
<tr><td>Title</td><td colspan="2">RealEstateCore ontology</td></tr>
<tr><td>Author and License</td><td colspan="2">Microsoft, RealEstateCore Consortium</td></tr>
<tr><td>URL</td><td colspan="2">RealEstateCore Ontology</td></tr>
<tr><td>Scope</td><td colspan="2">Equipment, Products, Measurements, Location</td></tr>
<tr><td rowspan="4">BEYOND related</td><td colspan="2">DR in buildings þ</td></tr>
<tr><td colspan="2">Machine-to-machine communication and interoperability enhancement at smart building level þ</td></tr>
<tr><td colspan="2">Building Data Model representations þ</td></tr>
<tr><td colspan="2">Business synergies and data exchanges between the building and energy system/network stakeholders þ</td></tr>
<tr><td colspan="3">Scope of application</td></tr>
<tr><td>DSO ¨</td><td>TSO ¨</td><td>BRP / Market ¨</td></tr>
<tr><td>Retailer</td><td>Aggregator</td><td>Customer/Prosumer þ</td></tr>
<tr><td>ESCO ¨</td><td>Building/Facility manager þ</td><td>Local authority ¨</td></tr>
</table>

In February 2021, a partnership formed of Microsoft, RealEstateCore (a Swedish consortium of real estate owners, software houses, and research institutions) and Willow have launched a Digital Twins Definition Language-based RealEstateCore ontology for smart buildings.

Azure Digital Twins (ADT), and its underlying Digital Twins Definition Language (DTDL), are at the heart of Smart Building solutions built on Azure. DTDL is an open modeling language based on JSON-LD and RDF, by which developers can define the schema of the entities they expect to use in their graphs or topologies.

Since DTDL is a blank canvas which can model any entity, the idea is to reduce developers' time to results by providing a common domain-specific ontology to bootstrap solution development, as well as seamless integration between DTDL-based solutions from disparate vendors (Microsoft, 2021).

RealEstateCore is a common language used to model and control buildings, simplifying the development of new services and it has seen practical deployments across sizeable real estate portfolios over the past several years, and has gone through several revisions based on real-world feedback and learning. The aim of RealEstateCore is not to be a new standard, but rather provides a common denominator and bridge with other building industry standards such as Brick Schema, Project Haystack, W3C Building Topology Ontology (W3C BOT), and more.

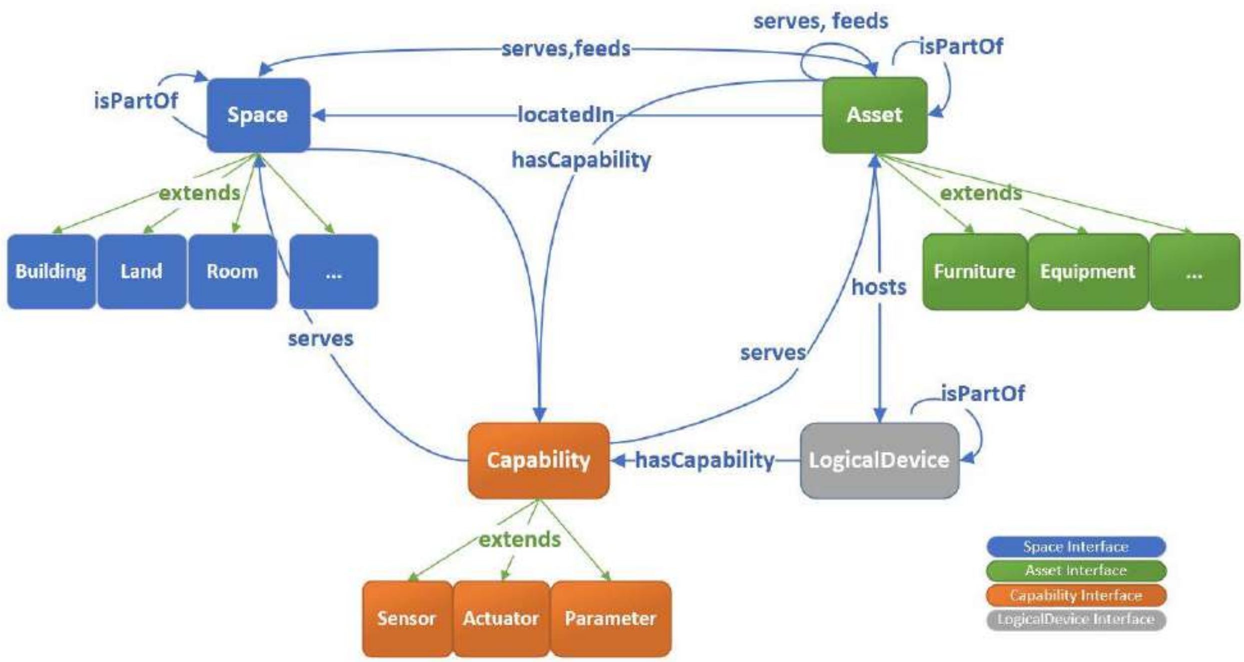

FIGURE 17 REALESTATECORE STRUCTURE (MICROSOFT, 2021)

As defined in (Microsoft, RealEstateCore Consortium, Idun Real Estate Solutions and Willow, 2020), RealEstateCore ontology consists of a main set of interfaces such as:

- Asset – An object which is placed inside of a building, but is not an integral part of that building's structure, for example architectural, furniture, equipment, systems, etc.

- LogicalDevice – A physical or logical object defined as an electronic equipment or software that communicates and interacts with a digital twin platform.
- Capability - A capability indicates the capacity of an entity, be it a Space, an Asset, or a LogicalDevice, to produce or ingest data.
- Space - A contiguous part of the physical world that has a 3D spatial extent and that contains or can contain sub-spaces.

RealEstateCore also contains additional base interfaces:

- Agent - Any basic types of stakeholder that can have roles or perform activities, e.g., people, companies, departments.
- Building Component - A part that constitutes a piece of a building's structural makeup, for example Facade, Wall, Slab, etc.
- Collection - An administrative grouping of entities that are addressed and treated as a unit for some purpose.
- Document - A formal piece of written, printed, or electronic matter that provides information or evidence or that serves as an official record, for example LeaseContract, Building Specification, Warranty, Drawing, etc.
- Event - A spatiotemporally indexed entity with participants, something which occurs somewhere, and that has or takes some time, for example a Lease or Rent.
- Role - A role that is held by some agent, for example a person could hold a Sales Representative role, or an organization could hold a Maintenance Responsibility role

RealEstateCore contains a number of relationship types, here we list the main ones:

- isPartOf, hasPart - A simplified set of topological relations to connect sub- and super-entities within the top-level RealEstateCore interface tree. "isPartOf" and "hasPart" are now defined to operate on entities of the same type, for example Spaces have only Spaces as parts, Assets have only Assets as parts, etc.
- hasCapability - Indicates that a Space, Asset or LogicalDevice has the ability to produces or ingest data represented by sensors, actuators or parameters.
- includedIn - Indicates that an entity is included in some Collection, for example a Building is included in a RealEstate, or a Room is included in an Apartment. Inverse of includes, for example a Campus includes some Space, an Apartment includes some Room
- locatedIn - Indicates that a given Asset is physically located in a Space. There is no inverse of this one.
- hosts - Indicates that a given Asset hosts a logical device; for example, a Raspberry Pi hosts a Home Assistant installation, or an IoT-connect smart camera unit hosts an IoT Edge runtime. Inverse of: hostedBy, which indicates

the physical hardware asset that a given logical device is hosted and executed on.

- serves - The coverage or impact area of a given Asset or Sensor/Actuator. For example: an air-treatment unit might serve several Rooms or a full Building. Note that Assets can also service one another, for example an air-treatment Asset might serve an air diffuser Asset. Inverse of: servedBy
- feeds - Indicates that a given equipment is feeding "something" to another equipment or space, like electricity, water or air. Inverse of: isFedBy
- hasBuildingComponent - Parthood traversal property linking Buildings to the Building Components that they are made up of, for example a Building hasBuildingComponent a Facade or Wall which are of type BuildingComponent,. Inverse of: componentOfBuilding.
- owns - Indicates that an agent is the legal owner of a given entity, for example a Company owns some Real Estate. Inverse of: ownedBy.

A key principle of this ontology is to ensure that any models we develop can be easily deployed by industry partners in real world projects.

3.2.8 Brick Ontology

Title	Brick Ontology
Author and License	Brick Consortium
URL	[Brick Ontology Documentation (brickschema.org)](https://brickschema.org)
Scope	Equipment, Products, Measurements
BEYOND related	*DR in buildings* ý
	Machine-to-machine communication and interoperability enhancement at smart building level ý
	Building Data Model representations þ
	Business synergies and data exchanges between the building and energy system/network stakeholders ý

Scope of application		
DSO ý	*TSO* ý	*BRP / Market* ý
Retailer þ	*Aggregator* þ	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* ¨

Brick is an open-source effort to standardize semantic descriptions of the physical, logical and virtual assets in buildings and the relationships between them. Brick consists of an extensible dictionary of terms and concepts in and around buildings, a set of relationships for linking and composing concepts together, and a flexible data model permitting integration of Brick with existing tools and databases. Through the use of powerful Semantic Web technology, Brick can describe the broad set of idiosyncratic and custom features, assets and subsystems found across the building stock in a consistent matter.

The Brick ontology is also defined using the Resource Description Framework (RDF) data model (similar to IEC CIM) that represents a labelled, directed graph where the nodes are the entities, while the edges represent their relationships. The Brick ontology is a hierarchical class model. The postulate is that in the process of identifying an appropriate class for an entity, a user can browse the hierarchy from the most general classes (equipment, location, sensor, setpoint, substance) to the specific class whose definition best describes the entity.

3.2.9 Project Haystack

Title	Project Haystack
Author and License	Project Haystack non-profit
URL	[Project Haystack (project-haystack.org)](https://project-haystack.org)
Scope	Equipment, Products, Measurements, Locations
BEYOND related	*DR in buildings* ý
	Machine-to-machine communication and interoperability enhancement at smart building level ý
	Building Data Model representations þ
	Business synergies and data exchanges between the building and energy system/network stakeholders ý

Scope of application		
DSO ý	*TSO* ý	*BRP / Market* ý
Retailer þ	*Aggregator* þ	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* ¨

Project Haystack is an open industry initiative, focused on providing a common metadata methodology for building automation, smart city, and other applications. It is supported by a non-profit organization established in the United States (Project Haystack, 2021).

The principal goal of the Project Haystack is that it tries to streamline working with the data in the age of the Internet of Things, coming from diverse sources, and reduce the semantic data models to the extent these are easy enough to use, but still enabling to unlock value from the vast quantity of data being generated by the smart devices. The coverage of Project Haystack includes building equipment systems, automation and control devices, and general sensors and sensing devices. Project Haystack is open source, and all the related works are accessible under a permissive open source license.

In technical terms, the Project Haystack approaches the data description task by employing a data tagging approach. The tags are designed as semantic carriers – akin to markup language describing the data. This is a deceptively simple approach but the Haystack efforts in fact consists of:

- a standard specification on defining and describing device descriptive data,
- a standard tag set – a vocabulary or a taxonomy,
- a set of software tools: reference implementations on diverse platforms, API specifications, converter plug-ins to make other systems Haystack-aware and finally tools to streamline the process of tagging and
- the modelling working groups effort to develop and extend tagging models.

The promise of Project Haystack remains making all data "self-describing", by applying the data modelling methodology using the tagging approach. Any data item can be marked with a set of tags. The Haystack tags can be value tags (representing key-value pairs) and marker tags (representing singular annotations).

3.2.10 HTO

<table>
<tr><td>Title</td><td colspan="2">Haystack Tagging Ontology</td></tr>
<tr><td>Author and License</td><td colspan="2">Victor Charpenay</td></tr>
<tr><td>URL</td><td colspan="2">http://www.vcharpenay.link/hto/doc.htm</td></tr>
<tr><td>Scope</td><td colspan="2">Measurements, Equipement, Products, Events</td></tr>
<tr><td rowspan="4">BEYOND related</td><td colspan="2">DR in buildings ý</td></tr>
<tr><td colspan="2">Machine-to-machine communication and interoperability enhancement at smart building level þ</td></tr>
<tr><td colspan="2">Building Data Model representations þ</td></tr>
<tr><td colspan="2">Business synergies and data exchanges between the building and energy system/network stakeholders ý</td></tr>
<tr><td colspan="3">Scope of application</td></tr>
<tr><td>DSO ¨</td><td>TSO ¨</td><td>BRP / Market ¨</td></tr>
<tr><td>Retailer ¨</td><td>Aggregator ¨</td><td>Customer/Prosumer þ</td></tr>
<tr><td>ESCO ¨</td><td>Building/Facility manager þ</td><td>Local authority ý</td></tr>
</table>

The Haystack Tagging Ontology is an OWL ontology for Project Haystack, a domain vocabulary for Building Automation Systems. Haystack is designed around the concept of tagging entities with name/value pairs to describe facts about those entities. The formal definitions of these tags and their value types are captured in a machine-readable format which is used to generate the tags. But how tags are combined lacks formal machine-readable definitions. For example, the description and constraints of how to model site/equip/point entities is largely described by documentation without a corresponding formal schema and machine-readable format. Historically this has been by design since formalization of "compound types" introduces significant complexity. But with broader adaptation of Haystack, there seems to be a pent-up demand to formalize types/schema. (Project Haystack, n.d.)

3.2.11 CityGML and CityGML-based ontologies

Title	CityGML
Author and License	Open Geospatial Consortium
URL	https://www.ogc.org/standards/citygml
Scope	Equipment, Products, Measurements, Location
BEYOND related	*DR in buildings* ý
	Machine-to-machine communication and interoperability enhancement at smart building level ý
	Building Data Model representations þ
	Business synergies and data exchanges between the building and energy system/network stakeholders þ

Scope of application		
DSO ¨	*TSO* ¨	*BRP / Market* ¨
Retailer ¨	*Aggregator* ¨	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* þ

CityGML is an open data model and XML-based format for the storage and exchange of virtual 3D city models. It is an application schema for the Geography Markup Language, the extendible international standard for spatial data exchange issued by the Open Geospatial Consortium (OGC) and the ISO TC211. The CityGML is a data model however there are various conversions and extensions of the CityGML data model into ontological-based models (D. Vinasco-Alvarez, J. S. Samuel, S. Servigne, and G. Gesquière, 2020). The CityGML models capture the physical structure and human concepts of natural and built environments that do or could exist. The ontology that supports the semantic structure is inherently derived from human concepts of the natural and built environments. While by itself it does have ontological properties, there are several approaches that take the step of conversion towards OWL-based ontologies.

The aim of the development of CityGML is to reach a common definition of the basic entities, attributes, and relations of a 3D city model. This is especially important with respect to the cost-effective sustainable maintetnance of 3D city models, allowing the reuse of the same data in different application fields.

CityGML models both complex and georeferenced 3D vector data along with the semantics associated with the data. In contrast to other 3D vector formats, CityGML is based on a rich, general purpose information model in addition to geometry and appearance information. For specific domain areas, CityGML also provides an extension mechanism to enrich the data with identifiable features under preservation of semantic interoperability.

CityGML not only represents the graphical appearance of city models but specifically addresses the representation of the semantic and thematic properties, taxonomies and aggregations. CityGML includes a geometry model and a thematic model. The geometry model allows for the consistent and homogeneous definition of geometrical and topological properties of spatial objects within 3D city models. (OGC, 2021)

3.2.12 BOnSAI

Title	BOnSAI	
Author and License	International Hellenic University	
URL	BOnSAI: A smart building ontology for ambient intelligence	
Scope	Measurements, Equipment, Location	
BEYOND related	*DR in buildings* ý	
	Machine-to-machine communication and interoperability enhancement at smart building level þ	
	Building Data Model representations þ	
	Business synergies and data exchanges between the building and energy system/network stakeholders ý	
Scope of application		
DSO ý	*TSO* ý	*BRP / Market* ý
Retailer ý	*Aggregator* ý	*Customer/Prosumer* þ
ESCO ý	*Building/Facility manager* þ	*Local authority* ý

The BOnSAI ontology (a Smart Building Ontology for Ambient Intelligence) was designed with the aim of enabling the vision of Ambient Intelligence in large-scale service-oriented pervasive systems. BOnSAI classes can be categorized in context-related, service-related, hardware-related, and functionality-related. (Stavropoulos, Thanos & Vrakas, Dimitris & Vlachava, Danai & Bassiliades, Nick, 2012). The BOnSAI ontology models different aspects of a service-oriented smart building system: (1) concepts modelling for services, operations, inputs, outputs, logic, parameters, and environmental conditions; (2) QoS such as resources and QoS parameters; (3) hardware such as smart devices, sensors and actuators, appliances, and servers; (4) users and (5) context such as user profiles, moods, location and rooms.

3.2.13 Mirabel

<table>
<tr><td>Title</td><td colspan="2">Mirabel</td></tr>
<tr><td>Author and License</td><td colspan="2">TNO</td></tr>
<tr><td>URL</td><td colspan="2">An ontology for modeling flexibility in smart grid energy management | TNO Publications</td></tr>
<tr><td>Scope</td><td colspan="2">Measurements, Equipement, Products, Events</td></tr>
<tr><td rowspan="4">BEYOND related</td><td colspan="2">DR in buildings þ</td></tr>
<tr><td colspan="2">Machine-to-machine communication and interoperability enhancement at smart building level ý</td></tr>
<tr><td colspan="2">Building Data Model representations þ</td></tr>
<tr><td colspan="2">Business synergies and data exchanges between the building and energy system/network stakeholders ý</td></tr>
<tr><td colspan="3">Scope of application</td></tr>
<tr><td>DSO ý</td><td>TSO ý</td><td>BRP / Market ý</td></tr>
<tr><td>Retailer þ</td><td>Aggregator þ</td><td>Customer/Prosumer þ</td></tr>
<tr><td>ESCO ¨</td><td>Building/Facility manager þ</td><td>Local authority ý</td></tr>
</table>

The Mirabel ontology characterizes how the actors can express their energy flexibility for a specific device. The flexibility is described by the users via the amount, time, and price. The flexibility offer combines the user preferences with the corresponding device energy profile while each device is described by its own load profile over a time period.

This ontology is represented in OWL and defines the objects involved in flexibility and their relationships hence, this ontology gives a semantically better view on the flexibility concept and its meaning in relation to the building on the one hand and the smart grid on the other hand.

3.2.14 OEMA Ontology Network

Title	OEMA Ontology Network
Author and License	Javier Cuenca, Felix Larrinaga and Edward Curry
URL	OEMA Ontologies
Scope	Equipment, Products, Measurements, Location, Stakeholders
BEYOND related	*DR in buildings* þ
	Machine-to-machine communication and interoperability enhancement at smart building level þ
	Building Data Model representations þ
	Business synergies and data exchanges between the building and energy system/network stakeholders ý

Scope of application		
DSO ¨	*TSO* ý	*BRP / Market* ý
Retailer þ	*Aggregator* þ	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* þ

The OEMA ontology network covers different energy domains such as energy performance, infrastructures, weather data. Such domains are represented in different existing energy ontologies at greatest level of detail. The OEMA ontology network also provides a common representation of concepts that belong to different energy domains. The OEMA ontology network is made up of eight interconnected domain ontologies. Each ontology represents one or various energy domains.

The following ontologies are part of the OEMA Ontology Network, and elaborated in detail in (OEMA, n.d.):

- **OEMA Infrastructure ontology**: contains the following data about Infrastructures/buildings: infrastructure/building types (i.e., household, microgrid, power station, etc.), technical data (i.e. material, surface, orientation, etc.), spaces data (i.e. floors, rooms, etc.), geometrical data (i.e. floor area, etc.), external and internal equipment (light, control, hydronic loop, furniture, etc.) and internal and external environmental conditions (occupation, internal temperature, etc.)
- **OEMA Energy and Equipment ontology**: represents the following energy equipment: building automation system resources (sensors, actuators/controllers and Heating, ventilating and air conditioning (HVAC)

systems), industrial equipment (i.e., construction and manufacturing equipment), energy generators (i.e. Electric Vehicles (EVs), Home Power Plants, etc.), Loads (white and brown goods), power storage/energy carriers (gas energy carriers, electrical batteries, etc.) and wearable devices. The ontology also represents the following data: devices Demand Response events, flex-offers, devices power curve and power profile, device operation category (i.e. on-off device, finite state machine, etc.), energy sources (renewable and non-renewable), devices consumption category and device state.

- **OEMA Geographical ontology**: includes geographical information from DBpedia ontology. The rest of branches have been pruned. The geographical ontology represents populated places (i.e. country, city, district, etc.), natural places (i.e. mountain, sea, etc.), other places (i.e. protected area, etc.) and places geographical attributes (i.e. altitude, depth, area, etc.).
- **OEMA External Factors ontology**: captures external factors that can influence in energy usage: climate type (i.e. alpine, continental, etc.), climatic index (i.e. rain index), environmental conditions (i.e. lighting, noise, air pollutants, etc.), pollutant indicators (i.e. pollutant level, pollutant limit value, etc.), household socio-economic factors (i.e. household income, housing price, etc.), people socio-economic factors (i.e. salary, education level, etc.), population socio-economic factors (i.e. density, main origin, mean income, etc.), weather phenomenon (i.e. temperature, precipitation, etc.), weather reports and weather state (i.e. rainy, sunny, etc.).
- **OEMA Smart Grid Stakeholders' ontology**: represents Smart Grid stakeholder roles in the energy market (i.e., energy consumers, energy suppliers, Distribution System Operators (DSOs), etc.) and energy flexibility operations (market processes, flex-offers exchange, etc.).
- **OEMA Energy Saving ontology**: represents general and personalized energy saving recommendations. These recommendations are also classified by device types (i.e. HVAC systems, lighting equipment, etc.).
- **OEMA Units of Measure ontology:** represents different units of measure that share the OEMA ontologies.

3.2.15 W3C SSN ontology

Title	W3C SSN
Author and License	OGC and W3C
URL	Semantic Sensor Network Ontology (w3.org)
Scope	Equipment, Products, Measurements,
	DR in buildings **ý**

BEYOND related	*Machine-to-machine communication and interoperability enhancement at smart building level* þ	
	Building Data Model representations þ	
	Business synergies and data exchanges between the building and energy system/network stakeholders ý	
Scope of application		
DSO ý	*TSO* ý	*BRP / Market* ý
Retailer þ	*Aggregator* þ	*Customer/Prosumer* þ
ESCO ¨	*Building/Facility manager* þ	*Local authority* þ

The Semantic Sensor Network (SSN) ontology is an ontology for describing sensors and their observations, the involved procedures, the studied features of interest, the samples used to do so, and the observed properties, as well as actuators. SSN follows a horizontal and vertical modularization architecture by including a lightweight but self-contained core ontology called SOSA (Sensor, Observation, Sample, and Actuator) for its elementary classes and properties.

4. Key findings and gap identification

4.1 Key Findings - Propositions towards the BEYOND CIM

From the analysis of the existing data models related to the scope of building and energy data, thus taking into consideration the needs for BEYOND, it can be deducted that none of the existing semantic standards covers the semantic scope entirely.

Generally, given the semantic coverage, the examined data models can be grouped in the following categories:

- General semantic data models (e.g. IEC 61968/61970), only relevant for a certain scope of application however;
- Data models allowing demand response (DR) in buildings;
- Data models for machine-to-machine communication and interoperability enhancement at smart building level (e.g. SAREF);
- Building data model representation (e.g. SAREF4BLDG);
- Data models allowing business synergies and data exchange between the building and the energy system/network stakeholders (e.g. USEF, all BIM related standards);

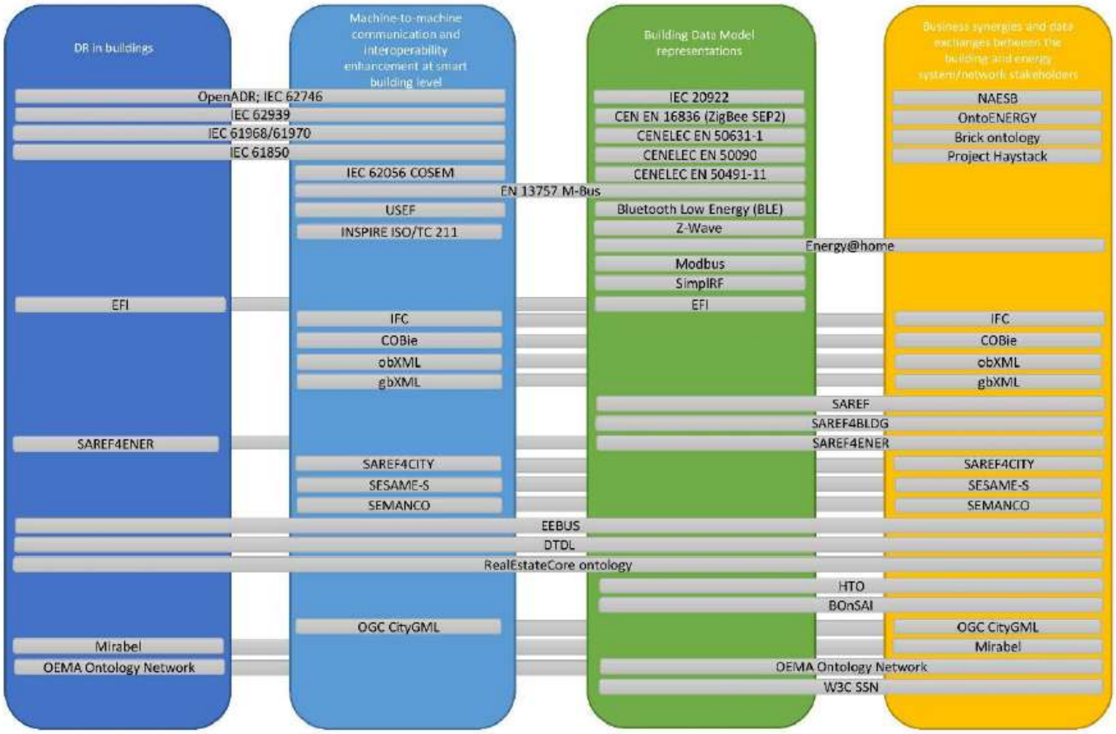

FIGURE 18 SEMANTIC COVERAGE CATEGORIES FOR SELECTED DATA MODELS

Table 1 Scope of application per entities / stakeholders (A – Applicable, PA – Possibly Applicable, NA – Not Applicable)

Standard Coverage	*DSO*	*TSO*	*BRP / Market*	*Retailer*	*Aggregators*	*Customer/ Prosumer*	*ESCO*	*Building/ Facility manager*	*Local authority*
OpenADR; IEC 62746	A	A	NA	A	A	A	PA	A	NA
IEC 62939	A	A	A	A	A	A	PA	A	NA
IEC 61968/61970	A	A	NA	A	A	A	PA	A	NA
IEC 61850	A	A	NA	A	A	A	PA	A	NA
IEC 20922	NA	NA	NA	PA	PA	A	PA	A	NA
IEC 62056 COSEM	A	A	NA	PA	PA	A	PA	A	NA
CEN EN 16836 (ZigBee SEP2)	NA	NA	NA	PA	PA	A	PA	A	NA
CENELEC EN 50631-1	NA	NA	NA	PA	PA	A	PA	A	NA
CENELEC EN 50090	NA	NA	NA	PA	PA	A	PA	A	NA
CENELEC EN 50491-11	NA	NA	NA	PA	PA	A	PA	A	NA
EN 13757 M-Bus	PA	PA	NA	A	PA	A	PA	A	NA
Bluetooth Low Energy (BLE)	NA	NA	NA	PA	PA	A	PA	A	NA
Z-Wave	NA	NA	NA	PA	PA	A	PA	A	NA
Energy@Home	A	PA	PA	A	A	A	PA	A	NA
Modbus	NA	NA	NA	PA	PA	A	PA	A	NA
SimplRF	NA	NA	NA	PA	PA	A	PA	A	NA
NAESB Energy Usage Information Model	NA	NA	NA	PA	PA	A	PA	A	NA
Energy Flexibility Interface (EFI)	A	PA	NA	PA	PA	A	PA	A	NA
USEF	A	NA	A	PA	A	NA	PA	PA	NA
ISO 16739-1:2018 Industry Foundation Classes (IFC)	NA	NA	NA	PA	PA	A	PA	A	NA
COBie	NA	NA	NA	PA	PA	A	PA	A	NA
obXML	NA	NA	NA	PA	PA	A	PA	A	NA
gbXML	NA	NA	NA	PA	PA	A	PA	A	NA

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement n° 957020.

Standard Coverage	*DSO*	*TSO*	*BRP / Market*	*Retailer*	*Aggregators*	*Customer/ Prosumer*	*ESCO*	*Building/ Facility manager*	*Local authority*
INSPIRE ISO/TC 211	PA	PA	NA	PA	PA	A	PA	A	A
SAREF	NA	NA	NA	PA	PA	A	PA	A	NA
SAREF4BLDG	PA	PA	PA	PA	PA	A	PA	A	PA
SAREF4ENER	PA	PA	PA	PA	PA	A	PA	A	PA
SAREF4CITY	PA	PA	PA	PA	PA	A	PA	A	A
OntoENERGY	PA	NA	NA	A	A	A	PA	A	PA
SESAME-S	PA	PA	A	A	A	A	PA	A	NA
SEMANCO	NA	NA	NA	A	A	A	PA	A	A
EEBUS	PA	PA	PA	A	A	A	PA	A	NA
DTDL	A	PA	PA	A	A	A	PA	A	PA
RealEstateCore ontology	PA	PA	PA	A	A	A	PA	A	PA
Brick ontology	NA	NA	NA	A	A	A	PA	A	PA
Project Haystack	NA	NA	NA	A	A	A	PA	A	PA
HTO	PA	PA	PA	PA	PA	A	PA	A	NA
OGC CityGML	PA	PA	PA	PA	PA	A	PA	A	A
BOnSAI	NA	NA	NA	NA	NA	NA	PA	A	NA
Mirabel	NA	NA	NA	A	A	A	PA	A	NA
OEMA Ontology Network	PA	NA	NA	A	A	A	PA	A	A
W3C SSN	NA	NA	NA	A	A	A	PA	A	A

The classification of the examined standards and ontologies in the above-mentioned groups has been already presented for each data models in chapters 3.1 and 3.2. The primary challenges of information modelling in BEYOND are discussed in chapter 2.3. The key findings from the analysis of data models in chapters 3.1 and 3.2 are:

- There is no general (overall) semantic model equivalent to IEC CIM in the electric grids, or, in a different sense to the Brick Ontology or other ontologies built on top of tagging models, that would directly cover the whole value chain BEYOND must address. In other words, there is no model that could be adopted for BEYOND directly.
- Several analysed models are related to demand response, however, only one of the things BEYOND addresses is the demand response: it in itself has a quite large coverage of required data: starting at the hardware level, it covers local equipment command models, then it must address the occupancy modelling, comfort forecasting, and on higher levels it has to address market interactions (e.g. as abstracted by USEF) – and there is also no single standard or ontology that duly covers the whole demand response value chain;
- Machine to machine interoperability modelling has, in recent years, been quite notably improved; oneM2M based communication and SAREF has received strong support from various projects and in the last 2-3 years there have been notable advances, however a winning standard is not crystallized yet;
- Building data model representation is a challenge in itself: BIM-related models aim to resolve interoperability between different activities in the building sector (construction, asset management, maintenance, upgrades etc), while there are ontological models that focus on operating the building as a system (e.g. SAREF4BLDG); in this context the principal challenge is the diverse level of development in different fields, for instance many cities in Europe use the IFC extensively so a degree of interoperability with these standards is necessary
- There are also standards such as CityGML and INSPIRE ISO/TC 211 that cover the geometric representation and indoor and outdoor spatial modelling; the CityGML is a good example here as its coverage is quite extensive: indoor spaces, city furniture, roads, environmental data – however its targeted scope is actually mainly useful for urban planning and BEYOND data modelling must be applicable in other fields as well;
- For BEYOND to promise of creating additional value based on building data, data models allowing business synergies and data exchange between the building and the energy system/network stakeholders are also quite important: in this context, interoperability with the established IEC CIM standard common in grid operations, the IEC standards for participation in the markets and other standards governing the interaction between market players such as USEF is also desirable.

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement n° 957020.

The above points illustrate the wide range of challenges the BEYOND data model must address, and as indicated previously, several technical challenges are related to the applicability of the standard in the context of big data.

Many of the listed standards and ontologies utilize strict ontological relations which means that the user needs to comply with the selection of abstractions in the standards. Any additions in the ontology require an amendment of ontological definition and strict placement of new class within the modelling ontology. This may be a limiting factor for the evolving data ecosystem that we want to build with BEYOND.

In recent years, at first glance simplistic tagging-based models such as Project Haystack have taken a pragmatic approach for handling the semantic information. In such models, a standardized descriptive vocabulary and a transport mechanism is defined, while not imposing a full strict ontological hierarchical model. This way, the semantic information is encoded in the form of properties or tags.

There have even been evolutions and "upgrades" of tagging models that function as full OWL-based ontologies built upon a tagging model. This way, a trade-off path is selected – a flexible, tagging vocabulary is utilized and as the system evolves, stricter ontological relations between tags are built later – an example is the HTO (Haystack Tagging Ontology).

However, the selection of a tagging-based model is not straightforward: the lack of clear class hierarchy, misnaming or using wrong tags is easily possible. This directly impacts consistency and longevity of the tagging-based data model. The extensibility of the tagging model is especially challenging – it is deceptively simple, but it does not include rules for composition or generalization of existing tags. To an extent, it can be mitigated by a careful selection of tags and pruning of duplicate tags that might cause confusion: a strong suggestion is to maintain a consistent and comparatively small selection of descriptive tags. Preferably, a minimum set of tags spanning the "vector space" of data modelling would be used as this eliminates ambiguity.

4.2Gap Identification

In consideration of the fact that there are 42 data models considered in this deliverable, a very pragmatic gap identification needs to determine which of them could be used for the purpose of BEYOND project.

The existing data models relevant for BEYOND range from "on the wire" communication standard to abstract semantic ontologies. On another axis, it should consider different energy carriers. Moreover, different existing standards could be mutually compatible and have conversions and mappings between themselves. Different stakeholders might be involved. Finally, as BEYOND considers big data scale, there are also the BEYOND-native requirements for the data model to be suitable for large scale data volumes.

In other words, the gap identification is not a single-dimensional problem.

Table 2 presents an indicative gap identification of standards and ontologies listed identified in the previous chapters, where it is clearly defined if the data model is a strict communication model, if it includes a semantic interpretation, if it represents an ontology or a BIM data model. For each model, the general usability of the proposed standard is briefly covered. The synthesis follows in Chapter 4.3.

TABLE 2 GAP IDENTIFICATION OF STANDARDS AND ONTOLOGIES ANALYSED FOR BEYOND

Main reference	Category	Weaknesses	Applicability
OpenADR; IEC 62746	Communication standard	Relevant for energy system stakeholders. The specification of the OpenADR supports a wide range of different types of signals including direct load control interactions. The OpenADR standard only provides the DR message exchange and none of the actual underlying application logic.	For the BEYOND project, the most relevant standard among the 62746 group of standards is probably the IEC 62746-10 : Open Automated Demand Response (OpenADR 2.0b Profile Specification), which represents the adoption of the OpenADR Alliance standard as the IEC standard. In this document, the IEC 62746-10 and OpenADR are used interchangeably to refer to the same standard. This standard is a flexible data model to facilitate common information exchange between electricity service providers, aggregators, and end users.
IEC 62939	Communication standard	This is a conceptual standard: it is relevant for BEYOND deployments only in the design phase. In the practical implementation of an information model, this is not that relevant.	Defines and utilizes the Virtual End Node (VEN) and Virtual Top Node (VTN) concepts, which are important in the OpenADR standard. The VEN has operational control of a set of resources and/or processes. It can control the output or demand of these resources and thus affect their production or use of electrical energy intelligently, in response to an understood set of smart grid messages. The VEN may be either a producer or consumer of energy. The VEN is able to communicate (2-way) with a VTN receiving and transmitting smart grid messages that relay grid situations, conditions, or events. A VEN may take the role of a VTN in other interactions.

IEC 61968/61970	Communication standard	Probably the biggest problem of IEC CIM (as in IEC 61968/61970) is its overhead and strictness of the ontology imposed on top of the data, as well as only covering the electric power system appropriately. While other energy carriers have been introduced relatively recently, it does remain the most important semantic modelling standard in electric power systems. In short - we must be compatible with IEC CIM (i.e., map to the IEC CIM), however the IEC CIM does not solve everything we need for the BEYOND CIM so we can't just adopt the IEC CIM as our internal model, nor is it designed for that.	More related to TSO and TSO communication. Mainly used in the electrical utility industry. Initially started as the common model for exchange of grid data between the TSOs, and recently gaining traction in the DSO domain too with the introduction of profiles - limited subsets of the model applicable for a certain narrower domain. The closest thing to the semantic definition of all data relevant for electric power system. The core IEC CIM is a language-independent UML model, defining the components of a power system as classes along with the relationships between these classes: inheritance, association, and aggregation.
IEC 61850	Communication and semantic interpretation	The IEC 61850 is the de facto standard for communication in electric power engineering and cannot be ignored similar to the IEC CIM. It carries data semantics, and we probably require mapping of BEYOND-acquired data to and from the IEC 61850 but as with IEC CIM it is not suitable for big data in building sector. We have to interop with IEC61850, though.	The IEC 61850 is practically the first telecontrol standard that includes the data semantics within the protocol. Starting from the electrical substations, its scope has dramatically widened in the recent years. Compared to previous communication standards, the IEC 61850 is the standard that introduces semantic interpretation of the communicated data within the protocol itself. The previous telecontrol standards such as 60870 series are limited to describing the communication only and the payload carried through the communication channel was out of scope.
IEC 20922	Communication standard	This is only a messaging standard for message transport. No interpretation of payload is included in MQTT. MQTT can be a message carrier, we need to define message interpretation though.	MQTT is a lightweight standard, implementable at quite low-end devices and widely used for queueing and asynchronous applications in many domains due to its relatively small overhead.
IEC 62056 COSEM	Communication standard	This standard only defines metering semantics within a meter. Similar to the IEC 61850, we probably require interoperability, but the limited extent of semantic information is not enough for the requirements of the BEYOND CIM. In effect, we'll have to keep the original DLMS info with the data.	The COSEM model is used in smart metering and represents a companion standard to the DLMS underlying communication protocol. The COSEM server model resembles the IEC 61850 standard: a physical meter is defined as a composition of several logical devices. This logical device concept permits the same meter to be utilized for energy, gas and water. While important for interoperability and well established in practice, the semantics embedded within this standard do not satisfy all the BEYOND requirements.
CEN EN 16836 (ZigBee SEP2)	Communication standard	This is a communication protocol with little semantics interpretation	Commonly used to link appliances, lighting, and other equipment in buildings.
CENELEC EN 50631-1	Communication standard	See above	See above
CENELEC EN 50090	Communication standard	See above	See above
CENELEC EN 50491-11	Communication standard	See above.	Data model to present the metering to a customer display.
EN 13757 M-Bus	Communication standard	See Zigbee and others	See Zigbee and others
Bluetooth Low Energy (BLE)	Communication standard	See above	See above

Z-Wave	Communication standard	See above	See above
Energy@Home	Communication and semantic interpretation	This is an attempt on standardizing the semantics of in-house device consumption profiles.	It is based on the CIM approach and is broadly aligned with the OpenADR schema. It formalizes a method of describing devices energy consumption profiles in terms of energy phases, modes, power profiles and extended profiles.
Modbus	Communication standard	This is a very widely used communication standard. We probably, similar to many other communication standards, require a degree of interoperability with it (e.g., to keep track which register and device a certain dataset has been read out), however Modbus has no interpretation of data semantics.	Modbus is a very widely used communication standard due to its pragmatic approach and simplicity. There are 2 variants, Modbus over serial (or Modbus RTU) and Modbus over TCP/IP. Modbus has no general interrogation capability, nor does it carry any semantics - in order to ensure interoperability even at communication level you need to know the mappings of registers and data types.
SimplRF	Communication standard	SimplRF is a useful addition to suite of protocols known to BEYOND, however we need to interpret the data semantics beyond what it provides	SimplRF is a derivative of the Texas Instrumetnts SimpliciTI protocol. It is a wireless sensor network protocol designed by Decode and used for wireless local monitoring of physical and environmental conditions.
NAESB Energy Usage Information Model	Communication and semantic interpretation	Requires further enhancements in semantics since it is not an ontology.	The NESB is an energy usage model with semantic interpretation of data on energy usage, metering reading and other customer related information.
Energy Flexibility Interface (EFI)	Communication and semantic interpretation	This standard is aimed towards standardizing energy flexibility in an interoperable fashion. It can serve as an inspiration for building the wider encompassing BEYOND model - however its area of application is relatively limited. It recognizes 4 classes of devices: inflexible devices, devices allowing scheduling of use (i.e., dishwashers), energy storages and flexible output devices such as controllable vehicle chargers.	The EFI is designed to become a "common language for energy flexibility". As such, this is the scope it covers. It does include semantic interpretation of data to an extent.
USEF	Communication and semantic interpretation	Not fully applicable for the building's environment, it is applicable once the buildings are considered as providers of flexibility.	USEF is the most important standard governing the market mechanisms between the consumers of flexibility as USEF delivers the market model for the trading and commoditization of energy flexibility, and the architecture, tools and rules to make it work effectively. The USEF framework standardizes the roles in a system for flexibility trading, without dictating how and where the trading should take place.
ISO 16739-1:2018 Industry Foundation Classes (IFC)	BIM	More applicable in the design and maintenance of the building systems (i.e., HVAC) than in the actual building usage phase.	IFC standard includes definitions that cover data required for buildings over their life cycle. This release, and upcoming releases, extend the scope to include data definitions for infrastructure assets over their life cycle as well.
COBie	BIM	Not applicable during building usage.	More applicable in the design and construction phase. COBie file is by no means a full BIM, but it does contain structured content from all members of the construction team and from many information models.

obXML	BIM	Applicable for building simulation tools and less for real world.	The obXML schema includes the semantic interpretation of various occupant related data, could be useful for building data modelling in the scope of BEYOND.
gbXML	BIM	Applicable for building simulation tools and less for real world.	It is an attempt to standardize the description of energy related occupant behavior in buildings. Each building space is identifying and presents information about occupancy which is applicable for dana modelling in BEYOND.
INSPIRE ISO/TC 211	Geographic information	No particular weaknesses are noticed in its applicability scope for BEYOND.	Represents a standard for geographic information and is used for encoding data and metadata as well as network services for discovery, viewing and downloading dana.
SAREF	Ontology	This is an ontological standard - and one quite strongly supported by the EC. It is designed to be an abstraction on top of the communication protocols and tries to explicitly specify the core concepts in smart appliances domain, their relationships, and mappings to other external models. Highly relevant but not directly applicable to BEYOND.	SAREF = Smart Appliance REFerence ontology is an ontological model designed towards interoperability of smart devices. It is designed by the Dutch TNO and supported by European Commission. It is NOT a communication protocol, generally it is designed to work on top of OneM2M communication layer - instead, it only focuses on the data semantics. This is highly relevant for BEYOND CIM.
SAREF4BLDG	Ontology	See above - SAREF4BLDG is a SAREF extension specific for buildings. Relevant to BEYOND but also not directly applicable as it is an ontological standard.	This is an extension of base SAREF ontology proposed by buildingSMART International and also adopted as ISO 16739 standard. It is based on the IFC Industry Foundation Classes that standardize a data model. It aims to enable interoperability between architects, engineers, consultants, contractors, component manufacturers etc. in all phases of building life cycle.
SAREF4ENER	Ontology	See above - SAREF4EN is a SAREF extension specific for buildings. Relevant to BEYOND but also not directly applicable as it is an ontological standard.	
SAREF4CITY	Ontology	See general SAREF. SAREF4CITY is an effort to expand the general SAREF into the Smart Cities domain. The context is primarily in the governance of smart cities, visible from well-defined KPI mechanisms.	Includes models of abstract terms such as event classes, designed to represent temporal and scheduled events, and key performance indicators (KPIs). A KPI in SAREF4CITY is split: the KPI itself defines the KPI in general terms, while the KPI assessment class defines the actual value of the KPI for a given location and time span. Given the importance the EC pays to SAREF-related ontologies overall, we have to take this into account.
OntoENERGY	Ontology	Covers solely measurements.	Supporting energy efficiency issues. It aims to define the fundamental physical quantities and their interrelations in the energy domain.
SESAME-S	Ontology	Developed for buildings of educational purposes could require extension for more complex buildings systems.	This ontology includes concepts related to devices, tariffs, energy usage profiles and activities.
SEMANCO	Ontology	More applicable for urban planning.	The SEMANCO is an ontology that contains the terms and attributes that describe regions, cities, neighborhoods, and buildings. It could be relevant for BEYOND since it includes energy consumption and CO2 emission indicators, as well as climate

			and socioeconomic factors that influence energy consumption.
EEBUS	Ontology	Requires further enhancements for complex buildings systems.	The goal of the EEBUS initiative is to provide a data model for the exchange of information to coordinate and shift the energy between the intelligent power grid and practically all the devices connected to it. The idea is to have a common language that every device and every platform could freely use – regardless of the manufacturer and technology.
DTDL ontology for Energy Grid	Ontology	Possibly requires further alignment in buildings but is compatible with RealEstateCore ontology.	The energy grid ontology adapted from the IEC Common Information Model (CIM). DTDL ontology provides contextual understanding of data by identifying the properties of various grid entities and the relationships among them. The CIM organizes entities into distinct packages, it encompasses core, wire, and generation packages, and prosumer-related entities from metering, customer, and Distributed Energy Resource (DER) packages.
RealEstateCore ontology	Ontology	Possibly requires further alignments for BEYOND.	It uses DTDL and it represents an open-source ontology definition which learns from, builds on, and uses industry standards, and meets the needs of solution builders in the built world. For its scope and background, it is applicable for the BEYOND project since it solves many ontological queries relevant to buildings.
Brick ontology	Ontology	It does not have a predefined class hierarchy or at least not explicitly and there could be semantic conflicts in the interpretation of tags	Is an open-source effort to standardize semantic descriptions of the physical, logical and virtual assets in buildings and the relationships between them with the "self-describing" approach.
Project Haystack	Ontology	The interpretation of tags might be an issue, however no particular weaknesses are notices for applying such data model in BEYOND.	Project Haystack is an open-source data model that uses the tagging approach. As the Brick ontology uses the "self-describing" approach. It has been adopted by several major market players, especially in building automation.
HTO	Ontology	The formal definitions of these tags and their value types are captured in a machine-readable format which is used to generate the tags. But how tags are combined lacks formal machine-readable definitions	The Haystack Tagging Ontology is an OWL ontology for Project Haystack.
OGC CityGML	Ontology	No particular weaknesses are noticed in its applicability scope for BEYOND.	Applicable for city 3D models. The CityGML defines the classes and relations for the most relevant topographic objects in cities and regional models. Their geometrical, topological, semantical and appearance properties are modelled.
BOnSAI	Ontology	No particular weaknesses are noticed in its applicability scope but does not fully satisfy the semantic coverage needed for BEYOND.	Data model for Ambient Intelligence.
Mirabel	Ontology	No particular weaknesses are noticed in its applicability scope but does not fully satisfy the semantic coverage needed for BEYOND.	The Mirabel ontology defines how actors can express their energy flexibility for a specific device with respect to amount, time and price in user preferences.

OEMA Ontology Network	Ontology	Possibly requires further alignments for BEYOND.	The OEMA ontology network covers different energy domains such as energy performance, infrastructures, weather data to a great level of details.
W3C SSN	Ontology	No particular weaknesses are noticed in its applicability scope but does not fully satisfy the semantic coverage needed for BEYOND.	The Semantic Sensor Network (SSN) ontology is an ontology for describing sensors and their observations, the involved procedures, the studied features of interest, the samples used to do so, and the observed properties, as well as actuators.

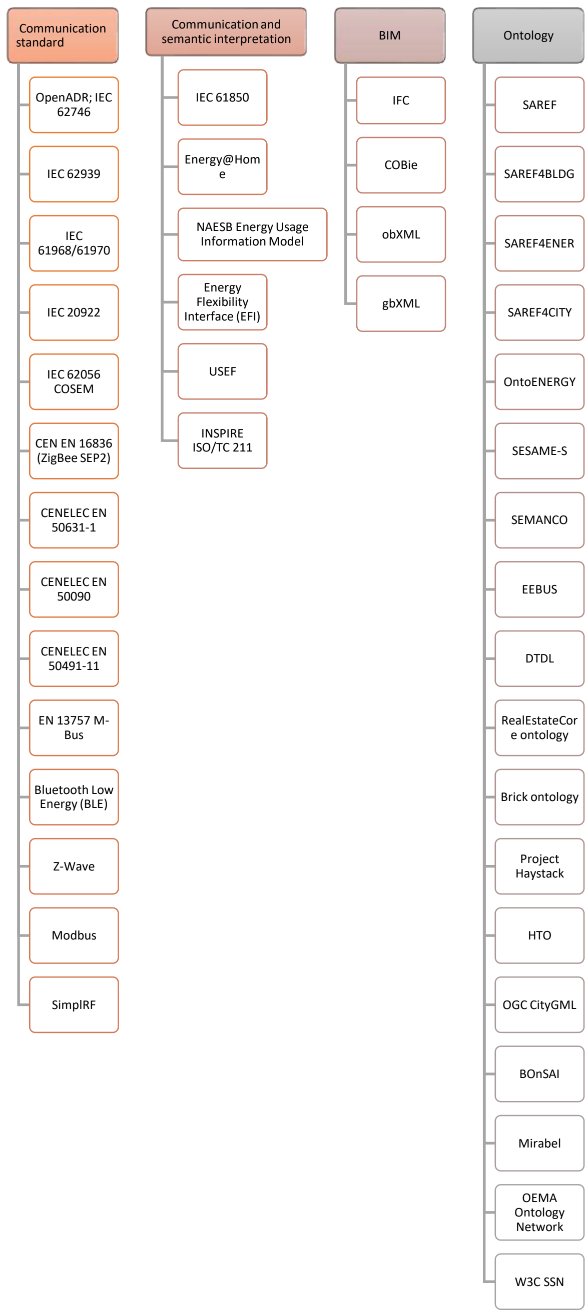

Figure 19 Classification of Principal Data models analyzed for BEYOND

4.3 Considerations for the BEYOND CIM

As pointed out in the previous chapters, especially in the Chapter 4.1 above, an abundance of standards and ongoing data modelling efforts are covering the scope of BEYOND in a minor or larger extent. Coupled with the table of standards and ontologies in the chapter 4.2, the following points indicate the general **functional requirements** of the BEYOND CIM:

1. The principal task of BEYOND CIM is to properly handle the semantics of the existing data and to ensure interoperability with existing legacy systems at all levels and all areas BEYOND covers. We need to keep the exactly enough level of semantics to enable BEYOND interoperability, but without making it intractable and inefficient. This point per se, together with the required ease of extensibility, practically eliminates a majority of very strict ontological models. The model should not be an impediment to the functioning of big data platform, while keeping all the relevant data semantics together with the data. The requirement to keep the data semantics along with the data itself is needed as the BEYOND solution should not function as an intractable data lake.
2. Interoperability must work both at technical and at semantic level: as both are needed for BEYOND to succeed. Consistent and non-ambiguous data interpretation across BEYOND scope is an absolute must. An ambiguous data model would not handle semantics properly and is one of notable risks for a solution interacting with large number of different systems and platforms, each with its own internal data model.
3. Given the mature technologies in building sector we need to connect to diverse data sources ranging from BMS systems to the EU open data repository, and BEYOND has to be integrable into existing enterprise, smart city, markets and other data value chains. This may require the inclusion of additional modelling properties whose principal purpose is interoperability only (i.e. mapping to the external data sources or sinks).
4. The model should allow extensibility as it is not reasonable to think of an ontological model today that would work for all future applications of BEYOND – however, the extension mechanisms and handling of model upgrades should be provided. We foresee the BEYOND solution will evolve with time.
5. A great challenge to the viability of the model is the ambiguity of modelling – periodic pruning of ambiguous concepts in the model should be envisioned too. There should, preferably, at all times be only one semantic interpretation

of a data asset (see point 2 above), but it is however inevitable that with the incremental evolution of the model some ambiguity will appear. Thus, a good model upgrade mechanism coupled with a periodic pruning strategy that would take care of eventual ambiguities is required.

With all the above points in mind, it is obvious the BEYOND model should bring together diverse data standards together instead of adopting a single existing one. There are numerous stakeholders and corresponding complementary information that existing standards do not consider adequately.

Furthermore, the BEYOND CIM should use the existing standards and ontologies and provide mappings to existing representations apparent from the data collection tasks. This means the BEYOND internal common information model will keep some of the additional semantic information that may not be utilized in the BEYOND platform directly but will be used for interoperability at the edges of the platform, and to avoid loss of information and creation of ambiguity.

In other words, we may keep the exact identifier from IEC 61968 or SAREF so the data asset can be mapped back to its origin. These identifiers add the interoperability value to BEYOND and make the BEYOND solution integrable into the existing enterprise and smart city systems.

5. Conclusions

This deliverable delivers the principal requirements for the BEYOND data model. It departs from the identification of the BEYOND project data modelling needs and the identification of three principal characteristics the data model must have:

1) Widely encompassing coverage of all the relevant data areas for energy efficient buildings
2) Applicability and performance at big data scale and
3) Extensibility and upgrade management.

The deliverable proceeds with a thorough analysis of existing data models, formats, and standards relevant to buildings domain, energy efficiency and energy system components communication. The analysis provides an evaluation of how the existing standards meet the needs of the BEYOND project. The related data models widely differ in terms of coverage, applicability for various stakeholder needs and maturity (from communication standards to ontologies).

From the analysis above and an initial gap identification in coverage of existing models, the main conclusion is that not a single data model covers all the requirements of the BEYOND CIM. The BEYOND data model should bring together diverse data standards together instead of adopting a single existing one.

These findings are accompanied by the principal functional requirements for the BEYOND CIM:

1. BEYOND must interact with existing mature systems and is not designed to replace them – so it must be interoperable with the legacy systems at all levels and all areas of coverage, keeping or adding the semantic information of external data without making the system intractable at big data scale.
2. The CIM must be consistent and non-ambiguous.
3. Additional modelling properties seemingly irrelevant to internal CIM may be required, so that proper mapping to the external data sources or sinks is kept.
4. The CIM should be extensible so extension mechanisms and model upgrades should be possible.
5. With incremental model growth, ambiguities are inevitable so a mechanism for periodic pruning should be envisioned too.

This deliverable will serve as the principal input to the creation of BEYOND CIM in Task 3.2 and will be reflected during the development of the D3.2 – BEYOND Common Information Model.

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