

Methodology for assuring interoperability in demand-response services

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Abstract—Building Energy Management Systems (BEMS) have become very popular in the last decade. Many vendors and integrators are providing their own solutions to be deployed in buildings, which sometimes co-exist in the same building. The variety of protocols and communication mechanisms included in these solutions should be considered. Hence, interoperability plays a crucial role in ensuring that these systems can provide a holistic energy management strategy and integrate monitoring and control elements. This work presents a framework to allow the information exchange between sensors, controllers and software services aiming to ensure interoperability in demand response strategies. Under this approach, an interoperable architecture is defined where the core element is the data model to represent information. In this sense, domOS Common Ontology is selected as the kernel and some extensions have been done in order to better include the representation of building assets, Key Performance Indicators (KPIs) and user profiles and preferences. Besides, other extensions have been used to represent other devices and units of measurement.

Keywords— *interoperability, dCO ontology, data model, demand response, interoperable architecture.*

I. INTRODUCTION

The smart building concept is gaining importance across Europe. This aspect is highlighted thanks to the digitalisation processes deployed in the building stock. The consequence is the integration of many sensors, meters, controllers or actuators [1], among others, in the building facilities to allow monitoring and control strategies. Under this umbrella, data-driven algorithms and better-informed decisions are enabled [2]. Smart buildings cannot be only understood without having in mind data, but also smart energy management systems [3]. Within this group, demand response (DR) algorithms look into strategies to manage and balance the supply and demand of electricity in real-time [4]. It involves adjusting the electricity consumption of end-users, such as residential, commercial, and industrial customers, in response to signals from grid operators or utilities. The primary goal of demand response is to enhance grid reliability, avoid blackouts, and efficiently use available energy resources [5].

In a demand response scenario, electricity consumers are incentivized to modify their electricity consumption patterns based on certain conditions, such as peak demand periods or grid instability. Utilities or grid operators send signals or price incentives to encourage consumers to reduce or shift their electricity usage during times of high demand [5]. This can

involve activities like temporarily lowering air conditioning or heating usage, delaying non-essential industrial processes, or using energy storage systems to discharge stored electricity into the grid.

As buildings become increasingly complex and incorporate various technologies for lighting, HVAC (Heating, Ventilation, and Air Conditioning), security, and more, the need for interoperability becomes paramount [2]. This ensures that different components can communicate effectively, share data, and work together efficiently to optimize energy usage and overall performance [6].

Interoperability also plays a pivotal role in achieving energy efficiency and sustainability goals [7]. When building systems can seamlessly share information, they can respond dynamically to changes in occupancy, weather conditions, and other variables. This adaptability allows for more precise control over energy-consuming devices, leading to optimized energy usage and reduced environmental impact. In essence, interoperability in the building energy management sector is a cornerstone for creating smart, energy-efficient buildings [2][7] that can adapt to evolving technologies and environmental considerations.

DR has then emerged as a fundamental component in today's energy sector, especially within the EU energy markets. Significant efforts have been invested in standardizing the data models for DR, such as the case of the authors in [8]. They developed a tool to enable existing DR systems to distribute their components in the cloud while establishing a robust security and privacy framework for data exchange. Additionally, it incorporates a semantic interoperability layer, capable of translating data into a standardized form during exchange. Other authors like [9] aim at redefining key components of formalized semantics include identifying what a “thing” is (its “type”) and defining general information about that “thing” (its characteristics or properties) to ensure its adoption and reducing the soft costs.

The work that is described in this manuscript proposes a methodology to be applied in DR scenarios to assure semantic interoperability. This work has been carried out within the DEDALUS project [10], whose goal is to develop a participatory DR ecosystem aimed to: (a) facilitate and scale up massive participation of residential energy consumers in DR; (b) adapt to a variety of different mono-carrier (electricity, heat) or multi-carrier synergetic scenarios (electricity vs heat and natural gas) at the building/district

scale. In contrast to previous works, this paper explores related ontologies for DR, identifying the gaps to properly extend the most suitable one. Once the strengths and limitations of existing ontologies are discussed, a set of improvements are suggested, covering not only monitoring data, but also static data that enrich the available information to create a context-aware scenario.

To cover these aspects, the manuscript is structured as follows. Section II provides an interoperability definition within the project. Section III describes the methodology and compares the existing data models to extract strengths and opportunities. With the results of this analysis, Section IV develops the ontology, based on domOS Common Ontology (dCO) [11], with the proposed extensions. Finally, Section V describes the technology enablers to assure the interoperability, while Section VI provides the conclusions and future work.

II. INTEROPERABILITY DEFINITION

Interoperability in the building energy management sector is a crucial concept that addresses the seamless integration and communication between diverse systems and devices within a building's energy infrastructure. One key aspect of interoperability is the adoption of standardized communication protocols and interfaces. These standards enable different devices and systems from various manufacturers to interact with each other cohesively. Common protocols such as BACnet (Building Automation and Control networks) and MQTT (Message Queuing Telemetry Transport) facilitate data exchange and interoperability between disparate building management systems [12]. By adhering to these standards, building owners and operators can select best-of-breed solutions from different vendors without worrying about compatibility issues, fostering a more competitive and innovative marketplace.

Interoperability adopts multiple definitions. Three main levels are defined within this work, which are extracted from [13], where the authors establish the following classification:

- Foundational interoperability, which aims the data exchange between two or more information technologies without the capability to interpret the data. More details will be provided in the architecture, but, this is achieved in two ways: 1) northbound interoperability via data sharing interfaces to be consumed by DR services; 2) southbound to integrate information from the field devices thanks to the IoT (Internet of Things) platform.
- Structural interoperability serves to define the structure or format for data exchange (i.e., the message format standards). Uniform flow and meaning of data are preserved and unaltered. Structural interoperability defines the syntax and ensures interpretation at the data field level.
- Semantic interoperability that is the ability of two or more systems to understand data thanks to common data models. Semantic interoperability takes advantage of both the structuring of the data exchange and the codification of the data including vocabulary so that the receiving data systems can interpret the data in an intended way. This is the major aim of the paper in order to set up common vocabularies in DR services

allowing the data collection and interpretation in a seamless way.

A. State of practice in the interoperability field

As anticipated, interoperability is a crucial aspect in the smart building sector and, in particular, within DR programmes. Some of the existing Building Management Systems (BMS) are proprietary non-interoperable solutions based on automatic operations configured by the users. To solve this issue, researches such as [14] propose interoperable architectures capable of providing plug&play hardware integration, standardised multi-systems interoperability, building/human behaviours prediction, security/privacy protection and smart services provision for increasing building energy-efficiency and grid flexibility. Extrapolated to smart cities (seen as an interactive set of buildings), the authors in [13] presented an interoperable framework with the minimal features to cover the interoperability aspects.

The new paradigm of grid-interactive buildings depends on ensuring interoperability among connected systems and assets. Even though architectures are being investigated, semantic interoperability is a key aspect for a streamlined integration of interdependent applications. In this line, the authors in [9] drove interoperability through a three-pronged approach: 1) industry engagement; 2) a semantic interoperability standard; 3) tools to assist in implementation and a test framework to verify compliance of products. The goal was to accelerate the timeline for adoption of semantic interoperability specifications. Other researches go in the same direction of the semantic interoperability, such as [15], whose focus is placed on the data integration and semantic interoperability issues. The authors dealt with data heterogeneity and its consequent integration and interoperability issues by using of Semantic Technologies and a Canonical Data Model.

Current trends in semantic interoperability leverage the knowledge from existing and publicly available semantic models developed for specific domains, as expressed by the authors in [16]. A review of these existing ontologies was made by the authors in [17], looking for the integration between Building Information Modelling (BIM) and Building Automation Systems (BAS) to provide valuable, accurate and real-time data and control for context-aware Demand-Side Management (DSM).

The previous researches are mainly relying on the existing ontologies. Nevertheless, the smart building and DR contexts are dynamically changing, requiring adaptations to assure interoperability. In this sense, this work bridges the gap of the semantic interoperability by discussing the pros and cons of the existing ontologies to select the most suitable one and extending it to cover the necessary aspects of a global interoperable framework. Under this approach, the main contribution is focused on the proposed extensions of the ontologies to assure DR services and applications.

III. METHODOLOGY FOR ACHIEVING INTEROPERABILITY

The definition of a semantic interoperable ontology described in this manuscript has established a methodology based on 4 steps. Fig. 1 illustrates such a methodology, which is designed to choose the most proper ontology to be used as the basis for the DEDALUS one.

The aforementioned process consists of the next steps:

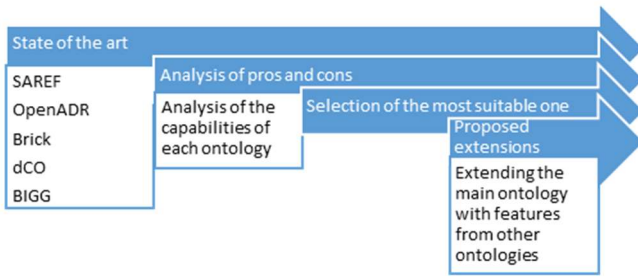


Fig. 1. Methodology for the semantic interoperability definition in DR

- 1) First of all, a SotA is carried out with the goal of identifying the most common ontologies in the smart building sector and, specifically, in the DR context.
- 2) In order to choose the most proper ontology to be used as a starting point, DEDALUS high-level requirements have been taken into consideration. Thus, the capabilities of each one of the ontologies have been analysed (in other words, the pros and cons).
- 3) A matching process has been set up to specify the specific data requirements into the ontology entities. This exercise ends with the selection of the most suitable one according to the coverage ratio. That is to say, the ontology whose entities are able to represent the most of the requirements.
- 4) Finally, the missing requirements that cannot be covered by the selected ontology should include extensions. For that end, from the five aforementioned ontologies, these extensions are taken in order to offer a more comprehensive DEDALUS ontology.

Regarding the result of the matching, a proposal has been done on how to extend the starting ontology with entities/attributes/relationships from other known (and public) ontologies.

A. Existing standards and ontologies

This section delves into a short state-of-the-art analysis (step 1 of the methodology) focusing on various ontologies that could be used in the scope of the DEDALUS project. The list of selected ontologies to be explored has been done based on the know-how of the different contributors in charge of this activity, taking their previous experience on this into account. Moreover, these ontologies are the most commonly used in the smart building sector and, specifically, DR applications.

1) Smart Applications REFerence ontology (SAREF) [18]

SAREF ontology is focused on smart appliances, systems, meters, and spaces, facilitating interoperability among IoT solutions. In order to cover other domains, multiple extensions of this ontology are also available: SAREF4BLDG [19] (building domain), SAREF4ENER [20] (energy domain), SAREF4CITY [21] (smart cities domain)...

SAREF is focused on the device concept, defined as a tangible object designed for a set of specific tasks in households, public buildings and/or offices. In order to accomplish these tasks, the device performs one or more functions, structured by categories (e.g. actuating, sensing and metering). Besides, devices can have properties (e.g., temperature, energy, etc.), and these properties can be related to measurements.

SAREF4ENER is an extension of SAREF which main aim is to provide a standardized way to describe energy-related devices, systems, and services. It is built on top of SAREF, and defines new classes, properties, and rules related to the energy domain. As an example, it provides mechanisms to describe:

- devices as solar panels, electric vehicles, smart meters, et cetera,
- systems like microgrids,
- services such as energy management or demand response.

Using SAREF4ENER, it is possible to develop applications that can easily communicate with different energy devices, systems, and services regardless the protocol they are connected and/or their manufacturer.

From its side, SAREF4BLDG includes building, space, and zone concepts, and uses the containment relationships in order to model links between spaces. It was created based on the Industry Foundation Classes (IFC) standard for building information, although not the whole standard has been transformed since it exceeds the scope of the ontology, which is limited to devices and appliances within the building domain.

SAREF4CITY is an extension of SAREF focused on the Smart Cities domain, and also reuses six other ontologies. Its main aim is to create a common core of general concepts for smart city data oriented to the IoT field.

2) OpenADR ontology [22]

The Open Automated Demand Response (OpenADR) ontology was developed in order to model the OpenADR protocol. OpenADR is an open and standardized interface that assists DR providers in the communication of DR signals within customer facilities in the scope of automated demand response program events. In this scope, DR providers (which communicate DR signals to customer facilities in order to generate automated demand response program events) are called Virtual Top Nodes (VTN), while customers are known as Virtual End Nodes (VEN). VEN can receive and respond to events, and they can also generate reports and control demand-side resources.

It is important to notice that the OpenADR ontology was developed within a European Project, and, as this project has finalized, the maintenance of the ontology has been discontinued

3) Brick ontology [23]

Brick is an open-source initiative that aims to standardize semantic descriptions of the physical, logical and virtual assets in buildings, and the relationships between them. Brick defines:

- An extensible dictionary of terms and concepts in and around buildings.
- A set of relationships for linking and composing objects together.
- A flexible data model that allows for the integration of Brick with existing tools and databases.

Brick includes entities to represent equipment, locations, points, and the relationships between all of these concepts. In this sense, equipment concept describes physical devices that provide services to the building, while points represent data sources or control inputs (e.g., sensors, setpoints, commands, alarms, etc.). Properties of equipment (such as design capacities and voltage ratings) are also considered within Brick, as well as location (which can be both physical or logical spaces grouped based on similar features).

Relationships can also be modelled using Brick, and they describe how classes (equipment, points, locations, etc.) are related to each other. These relationships can be used to describe physical composition (e.g., how equipment is composed of others), logical composition (e.g., how zones are composed of rooms) or topology (e.g., how equipment is related to rooms).

It is important to notice that Point instances in a Brick model can include “foreign key” properties to link them to the data source where the data can be found (e.g., historical storage, location in a BAS network, etc.). Concerning this issue, Brick metadata can be obtained using queries against a Brick model, and this metadata can contain useful information to fetch or subscribe to the building telemetry.

4) dCO Ontology [11]

This ontology (developed in the scope of the domOS project [24]) focuses on providing a common structure to describe devices and services in smart home environments and energy management systems.

dCO ontology integrates the Thing Description ontology, Smart Applications REFERENCE ontology (SAREF) core ontology, SAREF4ENER, and Building Topology Ontology (BOT [25]). Using it, a common directory of information can be created for IoT service providers in order to let them search for building metadata. It is important to notice that other additional ontologies have been also included in dCO in order to make it more complete, and this is the case of the Ontology of units of measure (OM [26]), which provides a standard way to represent and describe units of measurement and their relationships. OM is designed to be used in conjunction with other ontologies (e.g., SAREF4ENER, Things Description (TD), BOT...), is based on the Web Ontology Language (OWL), and Resource Description Framework (RDF) standards and also aligned with the International System of Units (SI) and ISO standards for units of measure.

From its side, BOT was designed to describe the physical structure and layout of buildings, its components, and also the location of properties of these building components. Its main aim is to provide a standardized way to represent building information across different applications and domains. It is based on OWL and RDF standards, which makes it easy to be integrated with other ontologies, such as SAREF4ENER and TD. This ontology provides seamless integration into Building Information Modelling (BIM) authoring tools like Revit and Industry Foundation Classes (IFC) (BOT facilitates export and import). It provides a rich functional building topology, focusing on asset management and description of the building itself, but lacks concepts to characterize systems, equipment, devices and their telemetric data. In order to represent this kind of concepts, BOT requires alignment with other ontologies such as Brick or SAREF, and this is what has been done within domOS (as stated before, domOS ontology

integrates the TD ontology, SAREF core ontology, SAREF4ENER and BOT).

dCO has been designed following a modular approach in order to enhance the maintainability of the ontology. dCO modules are listed and briefly explained below:

- dCO core module: this module reuses the SAREF core ontology, and allows the integration of the other modules to ensure semantic interoperability. This module is integrated with the thing description module and the device module using a subsumption relationship. The core module is integrated with the building description module and the units of measurement module respectively using the property `dco:isLocatedAt` and `dco:isMeasuredIn`.
- Building structure module. It contains the representation of building-related metadata and building topology. In this module, some concepts from BOT have been reused.
- Thing description module. This module reuses and extends the Thing Description ontology, and integrates this ontology with the dCO core module using a subsumption relationship to `dco:Device`.
- Device module. It represents the set of devices in an IoT ecosystem. Devices are structured in categories (subclasses), that reflect different types of devices (e.g., `dco:Meter`).
- Power, electricity, and heating flow module. This module represents the flow of power, electricity and heating between devices and spaces in a Building. The ontological design of the energy/heating/electricity flux has four main abstraction classes: `dco:Hub`, `dco:Storage`, `dco:Consumer`, and `dco:Producer`. Each of these classes has three specialization subclasses related to power, electricity, and heating.
- Energy flexibility module. It reuses and extends SAREF4ENER.
- Units of measurements module. This module represents all the units of measurements of IoT devices and reuses the Units of Measurement Ontology [31].

5) BIGG Ontology [27]

This ontology (developed in the scope of the BIGG project [28]) is designed to represent various aspects of smart grids systems, including energy generation, distribution, and optimization.

The Building Information aGGregation, harmonization, and analytics platform (BIGG) project was launched to demonstrate the utilization of big data technologies and data analytic techniques on buildings' life cycle across six different pilot testbeds. The BIGG ontology fully conceptualizes knowledge for BIGG use cases in the building domain, aligning with existing ontologies and data standards. The core of the BIGG ontology considers three blocks: building elements, organisation building and building devices, but it also provides some extensions such as the following:

- Extension for Retrofit projects.
- Extension devoted to Tariff and Emissions.
- Key Performance Indicators (KPI) extension.

- Extension focused on Industry Foundation Classes.
- Energy Performance Certificates extension.

B. Architecture for data interoperability

To achieve a full interoperability, it is not only important to highlight the semantic interoperability, but also the technical and structural interoperability. For that end, an architecture is proposed that combines the three levels defined before. This encompasses data acquisition (i.e., southbound technical interoperability) through the IoT and local businesses platforms, the communication formats (i.e., structural interoperability) and ontology (i.e., semantic interoperability).

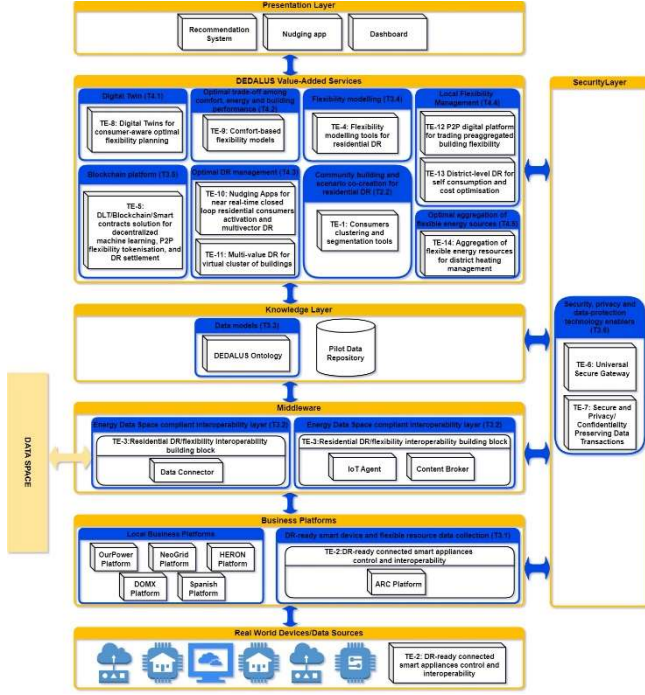


Fig. 2. DEDALUS architecture for demand response interoperability

Fig. 2 illustrates the aspect of the architecture that is composed by six layers plus the transversal security layers. Following a bottom-up approach, the levels are:

- Real world devices for the physical sensor and actuators environment.
- Business platforms as data acquisitions systems for the buildings, including an IoT platform in charge of connection those cases that do not provide an interface for data collection.
- Middleware in form of IoT agents and a context broker that also covers interoperability with external data providers, such as data spaces.
- Knowledge layer with two main components: the DEDALUS ontology to ensure the semantic interoperability and the repository for data persistent storage.
- DEDALUS value-added services to deploy all the demand response services that are part of the project, which make use of the ontology to consume data for applying artificial intelligence [29][30].

- Presentation layer with the human-machine interaction in form of apps and graphical user interfaces.
- Security layer responsible for safeguarding the system against unauthorized access, data breaches, and other security threats.

IV. DEDALUS ONTOLOGY

As one of the most important good practices for ontology development is based on reusing, five ontologies were finally explored to determine the most suitable one (step 2 of the methodology) to serve as the foundation for the DEDALUS ontology. As each of the ontologies addressed within section III.A has been designed to accomplish a set of purposes linked, somehow, with the DEDALUS project, all of them provide a certain level of alignment (step 3 of the methodology); but, considering all the information given, dCO seems to be the most proper one to be used in DEDALUS. As aforementioned, dCO has been recently developed (early 2023) in the scope of the domOS project, which is also related to flexibility and demand response (as well as DEDALUS project). Besides, dCO incorporates, and extends, SAREF (SAREF4ENER). From the buildings side, dCO uses BOT, so it seems that BRICK is not needed by this moment. Besides, and as BOT is built using the Semantic Web, it can be used in tandem with Brick.

Concerning BOT, and that it (unlike BRICK) does not incorporate modelling support of systems such as HVAC, Lighting and others. The ontology dCO takes advantage of SAREF4ENER in order to cover this part.

With regard to the ontology developed within the BIGG project, several interesting entities and properties have been identified, such as AnalyticsResults for baseline and benchmarking purposes, so, if finally needed, this ontology would be also considered. However, it was not selected in this case because its scope is broader than the one envisaged by the DEDALUS project. For example, BIGG also includes information on Renovation Projects and Energy Performance Certificates (EPCs), which are not considered within DEDALUS. Additionally, the BIGG project concluded by the end of 2023, whereas the domOS project is still ongoing. Therefore, if any further information is needed regarding the dCO Ontology, contacting a project partner would be easier for domOS than for the BIGG project.

Once all the process was carried out, it was confirmed that the dCO ontology was the most suitable one, but a few extensions are needed to comply with all the requirements.

TABLE I. COMPARATIVE OF THE ANALYSED ONTOLOGIES

Ontology	Features	
	Pros	Cons
SAREF	Focused on smart appliances, systems, meters and spaces.	Some concepts needed within DEDALUS are not available (e.g. flexibility)
OpenADR	Focused on modelling OpenADR protocol, so it contains multiple concepts related to flexibility and demand response.	Due to its focus (demand response), other (more generic) concepts are missing.
Brick	Focused on buildings.	As it is focused on buildings, other concepts are missing.

Ontology	Features	
	Pros	Cons
BIGG	Designed to represent multiple aspects of smart grid systems, including energy generation, distribution, consumption, and optimization. Other ontologies have been taken as a base (e.g. SAREF, BOT, IFC...). The project where it was developed was finalized by the end of 2023.	Due to its broad scope and its bit size, sometimes it is difficult to follow, as well as its scope is more focused on Energy Performance Certificates (although some entities are helpful for the extensions).
dCO	Focused on providing a common structure to describe devices and services in smart home environments and energy management systems. It takes known ontologies as a base (e.g. SAREF, BOT...). Its scope is similar to the DEDALUS' one. The project where it was developed is still ongoing.	Some parts are a bit "confusing", but we will re-define them in the next version of the DEDALUS architecture. Some concepts are missing, but we will extend dCO in order to solve this issue.

A. Proposed extension to achieve full interoperability

dCO is not itself able to cover the full list of requirements. Therefore, a set of extensions are proposed, mainly concerning the following concepts:

- **Key Performance Indicator:** Services require the calculation of Key Performance Indicators in order to determine the performance of the actions. However, dCO does not comply with this specification; therefore, extension from BIGG is used in order to represent the entities for these aspects.
- **Device:** dCO includes many of the devices to be used in the DEDALUS project. Nevertheless, two specific devices as the weather station and the inverter are obtained from the requirements. Then, the weather station is obtained from BIGG, while a new entity for the inverter is created as a new specification.
- **Building:** Two entities need to be provided as the case of the zone to represent thermal zones from IFC (but also from BIGG), as well as the region to locate the weather station (composed by city and country from Saref4city ontology).
- **Units of measurement:** Related to the weather station, at the moment, there is no ontology covering the radiation measurement.
- **User:** Finally, users are key players of the demand response programs. dCO includes a "Person" entity, but it is not covering the behaviour and personal preferences. That is why, the "Person" entity from dCO is being extended with the "User" entity from InterConnect ontology [32], which is not included in the SotA analysis, but it provides this very valuable entity to be included. In this sense, a user could be, for example, a person living in a building. A user can have different profiles depending on the situation (e.g. a profile for working, a profile for relaxing...).

TABLE II. PROPOSED EXTENSIONS FOR THE DEDALUS INTEROPERABILITY ONTOLOGY

Entity	Sub-entity	Ontology	Description
Key Performance Indicator	Single K P I Assessment	BIGG	Entity for a single KPI calculation (not just the measurement).
	Aggregated K P I Assessment		Entity for an aggregated KPI by using an analytical model in time series format.
Device	WeatherStation	BIGG	Entity that represents the concept of the WeatherStation, even composed by sensors.
	Inverter	n.a.	Entity for representing the inverter that is in any solar installation.
Building	Zone	IFC / BIGG	Entity coming from IfcZone to depict the thermal zones in the building.
	City	Saref4city	Entities combined to the representation of the region (i.e., location) to be used in the climate services (external weather station).
	Country		
Units of measurement	Radiation	n.a.	Entity for the solar radiation measurement.
User	UserProfile	Inter Connect	Entities that represent the concept of Person in order to obtain the behaviour, preferences and activities for any specific user.
	UserPreference		
	UserActivity		

V. DEDALUS INTEROPERABILITY ENABLERS

As mentioned in section III.B, achieving complete interoperability involves not only semantic compatibility, but also technical and structural alignment. In this sense, this section contains a summary of the main technologies envisaged to be used within DEDALUS in order to this technical and structural alignment.

From the perspective of interoperability, a set of technology enablers are established, which rely on FIWARE. The FIWARE Foundation [33] is an open-source initiative that aims to build an open sustainable ecosystem based on public, royalty-free, and implementation driven software platform standards that will facilitate the creation of smart applications in multiple sectors where data and services are seamlessly connected. FIWARE technology is a curated framework of open-source software platform components, called Generic Enablers (GE), that can be assembled together with other third-party components to build platforms supporting the development of Smart Solutions faster, easier, and cheaper across multiple sectors.

FIWARE provides a common platform and a set of Application Programming Interfaces (APIs) that ensure interoperability between different systems and components. The main and only mandatory component of any "Powered by FIWARE" platform or solution is a FIWARE Context Broker (component of the architecture, within the knowledge layer) Generic Enabler, which allows to model, manage, and gather context information at large scale, enabling context-aware applications. The Context Broker makes it possible to store and access context-information using simple context models, offers Representational State Transfer (REST) Application Programming Interface (API) for updating or consuming

context information, and supports subscriptions and notifications.

The FIWARE Next Generation Service Interface (NGSI) [34] is an open standard for context data management. FIWARE components use NGSI as a mechanism to ensure interoperability in Smart Systems. FIWARE NGSI API specifications have evolved over time, initially matching the NGSI-v2 specifications (JavaScript Object Notation (JSON)), now to support Linked Data (LD), aligning with the ETSI NGSI-LD standard [35] (JSON + JSON-LD). NGSI-v2 is ideal for creating individual applications offering interoperable interfaces for web services or IoT devices, in isolated smart systems [36]. NGSI-LD and Linked Data are necessary when creating a data space or introducing a system of systems approach, and in situations requiring interoperability across apps and organizations.

The main elements in the NGSI-v2 model are entities, attributes, and metadata, as shown in Fig. 3.

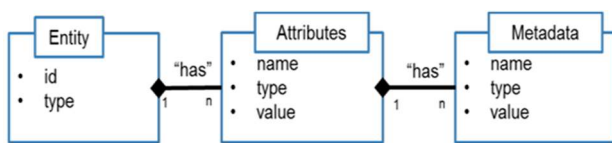


Fig. 3. NGSI data model [37]

An entity represents any physical or logical object as a sensor or a room. Each entity has an identifier and a type that describe the “thing” represented by the entity. An entity can have one or more context attributes, or properties, and each attribute has a name (what kind of property), an attribute type (the NGSI value type of the attribute value), an attribute value (the actual data). Attributes have metadata, which are characterised by a name (describing the role of the metadata), a type (describing the NGSI value type of the metadata value), and a value containing the actual metadata.

The Orion Context Broker [38] is an implementation of the Publish/Subscribe Context Broker GE and offers access to it via NGSI-v2 REST API. The Orion Context Broker offers:

- registration of context provider applications;
- retention of current instances of harmonized context data entities;
- updating context information;
- being notified when changes on context information occur or with a given frequency
- querying context information.
- short term storage for historical harmonized context data entities;
- storage of any analytics and intelligence results which become additional context data.

Orion-LD [39] is a Context Broker for context data management which supports both the NGSI-LD and the NGSI-v2 APIs. It is a fork of the original Orion Context Broker extending support to add NGSI-LD and linked data concepts.

The FIWARE Catalogue [40] offers several GEs that facilitate the interface with the IoT, robots, and third-party systems for gathering valuable context information or trigger

actions in response to context updates. FIWARE provides GEs called NGSI Agents that allow to simplify the management and the integration of devices by collecting data from devices through heterogeneous protocols and translating them into the NGSI standard platform language. NGSI Agents may also facilitate the integration of vertical solutions (e.g., smart meters, smart industry, smart building, energy storages, etc.) and of other sources of data (e.g., energy management systems) with the FIWARE ecosystem. Besides the Agents already present in the FIWARE Catalogue, libraries are made available by FIWARE to create custom NGSI Agents. NGSI Agents also allow to send commands to devices.

NGSI standard allows to request data from many systems. By sharing data models, it is possible to have a full interoperability by having how to request for data and what structure has the retrieved data. Data models define the harmonised representation formats and semantics that will be used by applications both to consume and to publish data.

Smart Data Model is a program led by FIWARE, among others to curate open licensed data models. It includes four elements: the schema, that is the technical representation of the model defining the technical data types and structure; the specification, that is a written document for human readers; a Uniform Resource Identifier (URI) with a working Uniform Resource Locator (URL) with basic data about the attribute or the entity, and the examples of the payloads for NGSIv2 and NGSI-LD versions.

Within the DEDALUS project, Smart Data Model is what will allow to use also the DEDALUS ontology in FIWARE ecosystem providing the semantic interoperability. The FIWARE Context Broker will be part of the interoperability middleware that will be in charge of ensuring the communication between IoT platforms and the DEDALUS value-added services. The Context Broker will also send back data/information from the value-added services to the IoT platforms. Furthermore, by using shared data models, the Context Broker may provide semantic interoperability ensuring that semantic meaning can be programmatically retrieved from the data itself.

VI. CONCLUSIONS

Interoperability is crucial within the context of smart buildings. However, despite the efforts, there is still a need for assuring full interoperability, not only in the data integration, but also in the services use. Interoperability goes beyond data acquisition, but also formatting and data structures. These aspects are defined by the three levels of interoperability: technical, structural and semantic.

This work has focused on semantic interoperability through the reuse of existing ontologies. For that end, a methodology to assure interoperability in demand response services has been described. Firstly, an analysis of the current ontologies has been made in order to understand the possibilities by means of pros and cons. Once ontologies are discussed, the selection of the most suitable is performed, where extensions are also proposed so that the full semantic interoperability could be achieved in the demand response program.

Next steps are mainly centred into the application of the ontology in the services’ development to find potential aspects to improve. Future work will primarily involve updating the ontology to new releases to meet emerging needs.

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