



HAL
open science

Semantic Modeling of Trustworthy IoT Entities in Energy-Efficient Cultural Spaces

Konstantina Zachila, Konstantinos Kotis, Asimina Dimara, Stamatia Ladikou,
Christos-Nikolaos Anagnostopoulos

► **To cite this version:**

Konstantina Zachila, Konstantinos Kotis, Asimina Dimara, Stamatia Ladikou, Christos-Nikolaos Anagnostopoulos. Semantic Modeling of Trustworthy IoT Entities in Energy-Efficient Cultural Spaces. 17th IFIP International Conference on Artificial Intelligence Applications and Innovations (AIAI), Jun 2021, Hersonissos, Crete, Greece. pp.364-376, 10.1007/978-3-030-79157-5_30 . hal-03789019

HAL Id: hal-03789019

<https://inria.hal.science/hal-03789019v1>

Submitted on 27 Sep 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License



This document is the original author manuscript of a paper submitted to an IFIP conference proceedings or other IFIP publication by Springer Nature. As such, there may be some differences in the official published version of the paper. Such differences, if any, are usually due to reformatting during preparation for publication or minor corrections made by the author(s) during final proofreading of the publication manuscript.

Semantic modeling of trustworthy IoT entities in energy-efficient cultural spaces

K. Zachila¹[0000–0002–1900–6096], K. Kotis¹[0000–0001–7838–9691], A. Dimara^{1,2}[0000–0001–9372–7070], S. Ladikou¹, and C.N. Anagnostopoulos¹[0000–0002–4496–275X]

¹ University of the Aegean, Dept. of Cultural Technology and Communication, Intelligent Systems Lab, Greece

² Centre for Research and Technology Hellas, Information Technologies Institute, Greece

cti20010@ct.aegean.gr, kotis@aegean.gr, adimara@iti.gr, sladikou@aegean.gr, canag@aegean.gr

Abstract. In this paper, an ontology related to energy-efficient cultural spaces is presented. Specifically, this research work concerns ongoing efforts towards engineering the Museum Energy-Saving Ontology (MESO) towards meeting the following objectives: a) to represent knowledge related to the trustworthy IoT entities that are deployed in a museum i.e., things (e.g. exhibits, spaces), sensors, actuators, people, data, applications; b) to deal with entities' heterogeneity via semantic interoperability and integration, especially for 'smart' museum applications and generated data; c) to represent knowledge related to saving energy e.g., lights, air-conditioning; d) to represent knowledge related to museum visits and visitors towards enhancing visiting experience while preserving comfort; e) to represent knowledge related to environmental conditions towards protecting and preserving museum artwork via continuous monitoring. The human-centered collaborative, agile and iterative methodology is followed, namely HCOME, towards the development of an evolved, 'live' and modular ontology, while SWRL rules and SPARQL queries are used for its preliminary evaluation.

Keywords: Building Energy Management System · Museum · Energy-saving · Ontology · IoT

1 Introduction

Nowadays, energy-saving issues have awakened the research community's interest due to the more and more increasing global electricity demand [22]. An excessive use of energy is believed to derive from public and industrial buildings to cover their daily load requirements in the context of the provision of their services [18]. Thus, the necessity of developing energy-efficient buildings could be proved beneficial. Notably, the improvement of buildings' energy efficiency leads to Building Energy Management Systems (BEMS) [12]. BEMS objectives include but not

limited to: a) the continuous management of energy towards energy consumption optimization (direct contribution); b) the optimization of buildings' visiting conditions towards enhancing visitors experience and comfort (indirect contribution), c) the optimization of buildings' environmental conditions towards the protection and preservation of artifacts (indirect contribution).

The application of BEMS in the context of energy-saving [12] at cultural spaces, and especially at the museums' spaces, is an evolving recent research interest. The protection and preservation of artworks and ancient objects isolated in museums, leads to the necessity of continuous monitoring of the environmental factors and indoor conditions like temperature, humidity and CO_2 . This monitoring involves Internet of Things (IoT) entities, which may be considered as an integral part of BEMS, to reduce energy consumption without: a) sacrificing humans' visiting experience and comfort indoor levels, and b) sacrificing artworks' protection and preservation.

In this paper, an ontology for the formal representation of knowledge related to BEMS's trustworthy IoT entities deployed in museums is presented, namely, the Museum Energy-Saving Ontology (MESO). The proposed ontology's aim is to represent trustworthy IoT entities deployed in a cultural space/building such as a museum, along with the representation of knowledge related to BEMS' direct and indirect abovementioned contributions (objectives). MESO is engineered following an agile, human-centered, collaborative and iterative approach to the engineering of modular, evolved and "live" ontologies, namely the Human-centered Collaborative Ontology Engineering Methodology (HCOME)[17]. The objectives of the presented ontology are: a) to represent knowledge related to the trustworthy IoT entities that are deployed in a museum i.e., things (e.g, exhibits, spaces), sensors, actuators, people, data, applications; b) to deal with entities' heterogeneity via semantic interoperability and integration, especially for 'smart' museum applications and generated data; c) to represent knowledge related to saving energy e.g., lights, air-conditioning; d) to represent knowledge related to museum visits and visitors towards enhancing visiting experience while preserving comfort; e) to represent knowledge related to environmental conditions towards protecting and preserving museum artwork via continuous monitoring.

The paper is structured as follows: Section 2 presents related work on BEMS semantics and related ontologies. Section 3 presents specific requirements and design issues for the semantic modeling of trustworthy IoT entities in energy-saving museums. Section 4 presents the ongoing work on the engineering of Museum Energy Saving Ontology (MESO) and a preliminary evaluation via SPARQL query answering and SWRL rules reasoning. Finally, Section 5 discusses the current and future work on this research line, and concludes the paper.

2 Related Work

An efficient and intelligent energy management of a building has significant advantages. The BEMS is a progressed method for monitoring and controlling the power/energy load requirements of a building. A BEMS is capable of managing

the energy balance of a building while monitoring and controlling other essential indoor parameters/conditions such as temperature, humidity, lights, heating and ventilation systems, towards regulating/adjusting comfort levels of the residents/visitors. "Smart" buildings are equipped with sensors, devices and actuators needed for their (automated) deployment and integration of a BEMS. As a result, in order to provide interoperability support for the building automation systems (BAS), while facilitating their seamless collaboration, communication and decision-support level operation, ontologies are of key importance.

Current trends in energy management represent the importance of using ontologies mainly for sensor/actuator and energy-related data. Several energy-based systems have been tested and implemented in various use case scenarios like households and public buildings. Some of the most deployed building- and energy-related ontologies are presented in the following paragraphs[11]:

- KNX IoT Ontology [4]. This ontology represents knowledge about various types of commonly used data points as defined in the KNX specification, like data points for heating, ventilation, and air-conditioning (HVAC), data points for load management, and data points for metering. KNX IoT is a state of the art technology and it supports the communication between various components like miscellaneous equipment. KNX is an open protocol that may support applications like indoor comfort but has a limited support for features like safety and security. The main objective of KNX ontology is to extend the KNX integration into the IoT to facilitate mobile automatic building management while ensuring that all devices can communicate via a shared language. KNX ontology can be easily adopted especially for small scale markets like smart home applications. KNX ontology is accessible from KNX web page [4].
- Smart Appliances REference (SAREF) ontology [5]. This ontology serves as a common conceptual model that can support the communication of existing standards, protocols and data-models mainly for smart appliances that use the ETSI TS 103 267: "SmartM2M" Smart Appliances Communication framework [8]. The SAREF's initial data point is each smart device providing specific blocks while allowing recombination and division of various parts of the ontology. The main disadvantage of SAREF is that it does not support all sensors and equipment that usually exist in a building. The SAREF ontology aims to enable interoperability between different solutions, providers, protocols, sensors in the IoT while contributing to the development of a bigger scale market like smart cities. SAREF can be easily adopted for many sectors as health, smart grid, energy management and others by reusing its classes. It is accessible from SAREF's formal web page [5].
- SAREF4ENER ontology [7]. This OWL-DL ontology is tailored to the energy domain and extends SAREF ontology. In order to enable a communication and inner connection of different data models, the Italy- and Germany-based industry association made by EEBus [1] and Energy@Home [2] created the SAREF4ENER ontology. SAREF4ENER is used as a Customer Energy Manager (CEM) for smart grids and smart homes enabling demand

response strategies. SAREF4ENER ontology has two types of classes, i.e., classes reused from other ontologies, like SAREF, and classes introduced in SAREF4ENER. This extension provides the ability to reuse SAREF4ENER classes as an overall ontology schema. The main objective of this ontology is to facilitate smart energy management while adapting users' preferences. One of its main disadvantages is that the data model has no pre-defined classes referring to electricity price. It is accessible from SAREF4ENER formal web page [7].

- SAREF4BLDFG ontology [6]. This ontology is an extension of SAREF tailored in the building domain. Its main modification is the adaptation to the Industry Foundation Classes (IFC) [3] standard for buildings' data and information. As a result, main building information about the building life cycle enables the missing interoperability between various building actors, like architects, and building applications, like construction. SAREF4BLDG is also an OWL-DL ontology that reuses SAREF classes and also has new classes which include IFC devices and other physical objects in building spaces. It is accessible from SAREF4BLDFG's web page [3].

The above list of BEMS-related ontologies is not exhaustive. In this paper, we acknowledge the existence of other related ontologies that due to space limitations, their presentation is not provided. Specifically, we acknowledge the widely-used ontologies of ThinkHome [21], BASont [20], DogOnt [9] and RE-COGNITION ontology [14]. The aforementioned ontologies have been examined, along with the ontologies presented in this paper, to investigate their suitability for reusing them in MESO.

The Semantic Sensor Network (SSN) ontology [10] and the Sensor Observation, Sample and Actuator (SOSA) ontology [13] aim to represent knowledge about entities, relations and activities included in sensing, sampling and actuation in a flexible and coherent way. The SSN/SOSA has been reused in several IoT-related ontologies and is a main/base candidate for reuse in the proposed ontology (MESO) either directly or indirectly (via the reuse of ontologies that already import SSN/SOSA).

The IoT ontology developed in the work of Kotis and Katasonov (2013) [16], supports the automated deployment of IoT entities in heterogeneous IoT environments. It mainly serves as a semantic registry for the registration of devices/systems, as well as for the registration of applications that utilize the services provided by those devices/systems. In further work on this line of research [15], a simple and extensible trust model for representing IoT entities was proposed. This model is integrated in IoT ontologies to ensure the deployment of trustworthy IoT entities. In our work, the representation of trustworthy entities are of particular importance to meet the objectives of MESO ontology, therefore this IoT trust model is reused.

In the related work of Vlachidis (2017) [23], the structure and development of the CrossCult Knowledge Base is described. The authors define the CrossCult Upper-level ontology by using the standard cultural heritage ontology CIDOC-

CRM¹. In addition, the proposed ontology incorporates a vocabulary for historical related data with a commonly agreed structure and tries to consolidate different cultural heritage data. The CrossCult ontology is reused in the proposed ontology to fulfil the objectives of our work (objective b).

In the work of Martini (2016) [19], the developed ontology represents the knowledge about the emigration phenomena, extracted from the data of the virtual Emigration museum. Based on the ontology of CIDOC-CRM the proposed system tries to automatically translate plain text that includes emigration information into Resource Description Framework scheme (RDF). This work partially fulfils the objectives of our work (objective d).

3 Semantic modeling of cultural BEMS

In this paper, the semantic modeling of trustworthy IoT entities in saving-energy museums is proposed, and implemented via the engineering of a new ontology, namely, MESO. This decision is made since related work (ontologies) individually do not fully cover the aim and objectives of our work. Having said that, MESO reuses a number of classes and properties already defined in well-known ontologies such as the SSN/SOSA ontology, the SAREF4BLDG ontology, the Geonames ontology, the CrossCult ontology, and the CIDOC-CRM ontology.

MESO is engineered by a collaborative team of stakeholders (knowledge engineers, domain experts and knowledge workers), following the three distinct engineering phases of the ontology engineering life-cycle proposed in the HCOME methodology, i.e., the Specification, the Conceptualization and the Exploitation phases. Each phase consists of specific processes and tasks that are performed in either the personal space of stakeholders or in a shared space (where they collaboratively discuss, design, implement and evaluate ontological classes and properties related to the domain). The detailed description of the updated HCOME methodology is out of the scope of this paper. However, the main processes and tasks of the methodology are presented in section 3 and 4 of this paper.

The Specification phase is comprised of two processes. In the first process, the aim, objectives and the team of stakeholders are specified. Specifically, regarding the MESO ontology, the aim is to represent the knowledge related to trustworthy IoT entities deployed in energy-saving museums' smart environments, to support the interoperability and integration of entities, data, processes and systems.

The aim and objectives of the proposed ontology were already described in the Introduction section 1.

The ontology engineering (OE) team is comprised of two knowledge workers (users of a BEMS), two knowledge/ontology engineers, and a museum expert (expert in museum studies and in the management of cultural spaces).

In the second process of the Specification phase, the requirements of the ontology are specified and a selective list of domain-specific example queries is shaped to support this process. A representative list is presented below (an one-to-one correspondence between objectives and requirements is considered):

¹ <http://www.cidoc-crm.org/>

- **Objective (a)** (trustworthy IoT entities’ representation and management)
 1. Which exhibits are located in room "UoAMuseumRoomA1"?
 2. How many sensors (all kinds) are hosted by platform "IoTmuseumPlatformLG"?
- **Objective (b)** (interoperability and integration)
 1. What is the temperature in the rooms that ongoing visits take place (right now)?
 2. For observations that are made for painting "Painting01" of room "UoAMuseumRoomA1" at 09.00 on 15/01/2021, what is its status in terms of its lamp brightness level (energy) and nearby visitors?
- **Objective (c)** (energy saving)
 1. Is there an activation of the light device in "UoAMuseumRoomA2" at 15.30 on 15/11/2020?
 2. Is there an activation of the heating device in "UoAMuseumRoomA1" on 25/11/2020?
- **Objective (d)** (enhancing visiting experience and comfort)
 1. Which rooms have been visited by "visitor01"?
 2. Which exhibit was the most popular in July?
- **Objective (e)** (environmental conditions)
 1. How many temperature measurements have been made in room "UoAMuseumRoomA1" between 09.00 and 17.00 on 07/12/2020?
 2. How many humidity measurements were made in room "UoAMuseumRoomA1" and "UoAMuseumRoomA2" on 30/11/2020 between 18.00 and 20.00 , with values greater than 60%?

During the Conceptualization phase, the team formulates scenarios for the use of cultural BEMS based on ontological requirements. A selective representative list of scenarios are listed below:

- **Requirement (a)** (trustworthy IoT entities representation and management):
 - Count all the sculptures of the museum that are related to visits made by trustworthy students (with a trust degree more than 0.8).
 - Name all the trustworthy paintings of the museum created by "Picasso" (paintings that were created by Picasso with a trust degree more than 0.9).
- **Requirement (b)** (interoperability and integration):
 - If there are more than two visitors in room "UoAMuseumRoomA1" close to (nearby) an exhibit, classify this exhibit as an "interesting exhibit in room UoAMuseumRoomA1", turn up the light of this exhibit, and lower the light of the remaining exhibits in the room. This scenario is related to objectives (c) and (d) at the same time.
 - If the temperature of room "UoAMuseumRoomA1" and room "UoAMuseumRoomA2" is less than 18 degrees Celsius, and there are visits in progress in these rooms, then activate the heating device in the rooms that those visits take place, and deactivate other sources of energy in the remaining rooms of the building. This scenario is related to objectives (c), (d) and (e) at the same time.

- **Requirement (c)** (energy saving):
 - If there are no visitors in room "UoAMuseumRoomA1", then turn the lights off (or all the sources of energy).
 - If the museum's internal and external temperature is between 20 and 30 degrees Celsius, then keep the heating and cooling devices off.
- **Requirement (d)** (enhancing visiting experience and comfort):
 - When a visitor enters the museum for the first time, send him a message (e.g., SMS or tweet) with the number and types of rooms, the number and collections of exhibits, and the average duration of a visit per room.
 - If a visitor comes out of the museum, then send him a message with the names of the exhibits he liked most based on the observations he made during his/her visit.
- **Requirement (e)** (environmental conditions):
 - If the temperature in room "UoAMuseumRoomA1" is less than 18 degrees Celsius, then activate the heating device (for visitors' comfort).
 - If the humidity in room A is more than 55%, then activate the humidifier device (for exhibits protection).

The implementation process of the Conceptualization phase is presented in Section 4 for presentation reasons.

Last but not least, the Evaluation phase is conducted. A preliminary evaluation of the engineered ontology has been performed by implementing specific scenario-based SWRL rules and running SPARQL queries against the current version of MESO ontology. The ontology along with the example queries are available at Github (<https://github.com/KotisK/MESO>) for further evaluation from the BEMS community of interest and practice. Alternatively, the ontology and the queries may be downloaded from <http://i-lab.aegean.gr/kotis/Ontologies/Meso/>.

4 The Museum Energy Saving Ontology (MESO)

MESO is implemented in OWL using Protégé 5.5². Its latest version is publicly available (<https://github.com/KotisK/MESO>) along with example queries for further evaluation and criticism by the BEMS community (and other related communities) of interest and practice. For the presentation of the ontology's capabilities, specific scenarios have been engineered, as proposed by the HCOME methodology, already described in section 3. The scenario which fully covers the interoperability and integration capabilities of the ontology is highlighted here: *If there are more than two visitors in UoAMuseumRoomA1 close to (nearby) an exhibit, classify this exhibit as an "interesting exhibit in UoAMuseumRoomA1", turn up the light of this exhibit, and lower the light of the remaining exhibits in the room.* This scenario is saving energy of the museum (lower of turn off lights that are not needed) while at the same time enhances user experience (turn up

² <https://protege.stanford.edu/>

lights on a particular exhibit of specific interested nearby visitors to assist in focus).

The main ontological classes and properties of MESO that have been used in the evaluation scenarios and queries are presented in this section. The related namespaces (of the proposed and reused ontologies) along with their prefixes are:

- meso:<<http://i-lab.aegean.gr/kotis/Ontologies/Meso/Meso.owl#>> (the proposed ontology),
- cross:<<http://www.crosscult.eu/UserModel#>> (CrossCult ontology),
- sosa:<<http://www.w3.org/ns/sosa/>> (SOSA ontology),
- saref:<<http://saref.etsi.org/saref4bldg/>> (SAREF4BLDG ontology),
- geonames:<<http://www.geonames.org/ontology#>> (Geonames ontology),
- crm:<<http://erlangen-crm.org/160714/>> (CIDOC-CRM ontology)
- iot:<<http://i-lab.aegean.gr/kotis/Ontologies/IoT/IoT-trust-onto.owl#>> (IoT-trust ontology).

4.1 Ontology Classes

The main classes that are used in the evaluation scenarios and queries are listed below:

- **meso:MuseumVisit** subclass of cross:Visit, represents the visits of visitors in the museum.
- **meso:ExhibitProximity** subclass of sosa:ObservableProperty, represents the proximity between an exhibit and a visitor.
- **meso:Exhibit** subclass of crm:E22_Man-Made_Object, represents the paintings and sculptures that are hosted in a museum.
- **meso:ExhibitProximityObservation** subclass of sosa:Observation, represents the observations of the proximity between an exhibit and a visitor.
- **meso:InterestingExhibitProximityObservation** subclass of sosa:Observation, represents the interesting exhibits.
- **meso:ObservationToHighLevelEnergy** subclass of sosa:Observation, represents the observations result in turning up the light of an exhibit.
- **meso:SmartLamp** subclass of saref:Lamp, represents the lamps brightening the exhibits.

4.2 Ontology Properties

The main properties of MESO that are used in the evaluation scenarios and queries are listed below:

- **meso:visits** represents the action of a meso:Visitor that visits a meso:MuseumRoom.
- **sosa:madeBySensor** represents the relation between an sosa:Observation and the corresponding sosa:Sensor.

- **sosa:hasFeatureOfInterest** represents the relation between an sosa:Observation and the observed meso:Exhibit.
- **sosa:observedProperty** represents the relation linking an sosa:observation to the observed property e.g., meso:ExhibitProximity.
- **meso:nearByVisitors** subproperty of geonames:nearby, represents the number of visitors (cross:Visitor) close to an meso:Exhibit.
- **meso:brighteningLevel** represents the brightening level (Low, Medium, High) of a meso:SmartLamp that meso:lights an meso:Exhibit.
- **meso:lights** (inverse of meso:isLightedBy) represents the relation linking a meso:SmartLamp to an meso:Exhibit.
- **sosa:resultTime** represents the timestamp of a completed observation.

4.3 SPARQL queries and SWRL rules

In order to evaluate the proposed ontology a list of selective representative SPARQL queries answered by MESO is presented below:

- **Which exhibits are located in UoAMuseumRoomA1?**

```
PREFIX geonames:<http://www.geonames.org/ontology#>
PREFIX meso:<http://i-lab.aegean.gr/kotis/Ontologies/Meso/Meso.owl#>
SELECT ?x
WHERE { ?x geonames:locatedIn meso:UoAMuseumRoomA1 }
```

- **How many sensors (all kinds) are hosted by IoTmuseumPlatformLG?**

```
PREFIX sosa:<http://www.w3.org/ns/sosa/>
PREFIX meso:<http://i-lab.aegean.gr/kotis/Ontologies/Meso/Meso.owl#>
SELECT (COUNT(?x) AS ?numOfSensors)
WHERE { meso:IoTmuseumPlatformLG sosa:hosts ?x }
```

- **Which rooms have been visited by Visitor01?**

```
PREFIX meso:<http://i-lab.aegean.gr/kotis/Ontologies/Meso/Meso.owl#>
SELECT ?x
WHERE { meso:Visitor01 meso:visits ?x }
```

- **What temperature measurements have been made in UoAMuseumRoomA1 between 09.00 and 17.00 on 07/12/2020?**

```
PREFIX xsd:<http://www.w3.org/2001/XMLSchema#>
PREFIX sosa:<http://www.w3.org/ns/sosa/>
PREFIX meso:<http://i-lab.aegean.gr/kotis/Ontologies/Meso/Meso.owl#>
SELECT ?Observations
WHERE {
?Observations sosa:hasFeatureOfInterest meso:UoAMuseumRoomA1.
?Observations sosa:resultTime ?resultTime
FILTER(?resultTime >="2020-12-07T09:00:12Z"^^xsd:dateTime &&
?resultTime <="2020-12-07T17:00:12Z"^^xsd:dateTime). }
```

- **For observations that are made for Painting01 (in UoAMuseumRoomA1) at 09.00 on 15/01/2021, what is its status in terms of its lamp brightness level and nearby visitors?**

```
PREFIX xsd:<http://www.w3.org/2001/XMLSchema#>
PREFIX sosa:<http://www.w3.org/ns/sosa/>
PREFIX meso:<http://i-lab.aegean.gr/kotis/Ontologies/Meso/Meso.owl#>
SELECT ?observation ?numberOfvisitors ?brightness
WHERE {
?observation sosa:hasFeatureOfInterest meso:Painting01.
?observation meso:nearByVisitors ?numberOfvisitors.
?observation meso:brighteningLevel ?brightness.
?observation sosa:resultTime ?resultTime.
FILTER(?resultTime="2021-01-15T09:00:12Z"^^xsd:dateTime)
}
```

Considering the specific scenario already mentioned, the Semantic Web Rule Language (SWRL) is used to implement rules for the definition of semantically rich axioms related to the specific interoperability/integration scenarios (see Fig. 1).

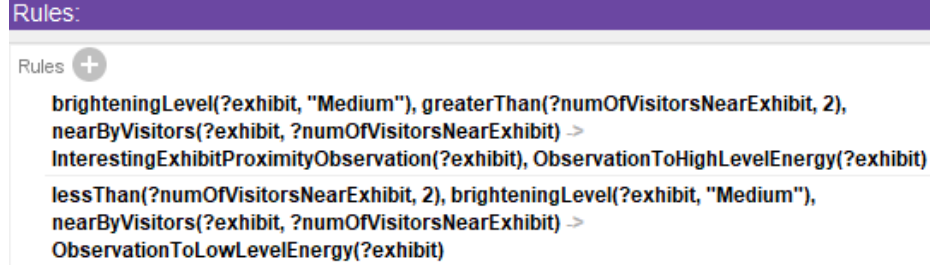


Fig. 1. Scenario-based SWRL rules in MESO (depicted in Protégé 5.5.)

Based on the above SWRL rules and Pellet³ reasoning engine, the identification (via reasoning i.e., automated classification of instances) of interesting exhibits and energy-related observations (based on sensing visitors' proximity to exhibits and observation of exhibits' lamp brightness level) is realized. The first rule states that if the brightness level of the exhibit lamp is "Medium" and there are more than two visitors near the exhibit, then classify this observation as a) an interesting-exhibit observation and b) an observation to high level energy, meaning that the level of energy (light) for the lamp of the exhibit of this observation must be raised to high. The second rule states that if the brightness level of the exhibit's lamp is "Medium" and less than two visitors are nearby this, then classify this as an observation to low level energy, meaning that the level of energy (light) for the lamp of the exhibit of this observation must be raised to low. The example rules defined in MESO automatically classify (semantically describe) exhibit proximity observations (meso:ExhibitProximityObsrvation) as interesting-exhibit proximity observations (meso:InterestingExhibitProximityObsrvation) and/or observations that must apply a change (decrease or increase) to the level of light (energy) of the observed exhibit (meso:ObservationToHighLevelEnergy or meso:ObservationToLowLevelEnergy). The specific time and location of the observations made are specified via geonames:locatedIn (for meso:Exhibit) and sosa:resultTime properties (for sosa:Observation).

5 Conclusion and Future Work

This paper presents first steps towards of an ongoing work towards engineering an ontology for the representation of trustworthy IoT entities that harmonically are deployed in an energy-saving museum. MESO ontology represents, in an

³ <https://www.w3.org/2001/sw/wiki/Pellet>

integrated and interoperable manner, knowledge related to a) trustworthy IoT entities and energy saving; b) enhancing of visiting experience and comfort; c) museum's environmental conditions' monitoring. MESO reuses well-known ontologies such as SOSA, CrossCult, and SAREF4BLDFG. Following the methodological approach of human-centered collaborative and agile ontology engineering, namely HCOME, the aim and objectives of the proposed ontology have been initially specified, and then specific requirements-based queries and scenarios have been realized, conceptualized and implemented using OWL and SWRL semantics. To illustrate the capabilities of MESO so far (v 0.7), a saving-energy and visiting experience interoperability and integration scenario has been presented, based on corresponding implemented classes, properties, queries and rules.

The proposed ontology is shaped in the presented version (0.7) as a result of collaborative engineering (edit, evaluation) using Protege 5.5 and WebProtege, as well as Google docs, e-mails and video-conferencing meetings. During the development of this version, the ontology engineering team has been focused on the implementation of the specific selected scenarios and example queries, as presented in this paper, with an emphasis on the interoperability and integration objectives (considering cases of energy-saving along with visiting and exhibits-related objectives). The limitation of our work, as presented in this paper, is that the selected scenarios and queries do not accentuate integrated knowledge related to the trustworthiness of IoT entities.

Future work will be focused on the completion of MESO, defining additional classes and properties linked to SOSA, CrossCult, SAREF4BLDFG and SAREF4ENRG ontologies, fully covering the ontological objectives and requirements presented in this paper. Furthermore, although the trustworthiness of the museum's IoT entities is represented in the current version of the ontology (via the IoT-trust-onto and the TrustworthinessObject class), this is not adequately demonstrated i.e., by fully reusing our related work on IoT-trust ontology and fuzzyOWL2 semantics. Finally, a complete version of MESO will be evaluated in the context of a real application setting (a "smart" museum setting).

References

1. Eebus, url: <https://www.eebus.org/contact/> , accessed: 2021-02-10
2. Energy@home, url: <http://www.energy-home.it/SitePages/Home.aspx> , accessed: 2021-02-10
3. Industry foundation classes, url: <https://www.buildingsmart.org/standards/bsi-standards/industry-foundation-classes/> , accessed: 2021-02-10
4. Knx ontology, url: <https://www.knx.org/knx-en/for-professionals/benefits/knx-internet-of-things/> , accessed: 2021-02-09
5. Saref ontology, url: <https://ontology.tno.nl/saref/> , accessed: 2021-02-09
6. Saref4bldg, url: https://www.etsi.org/deliver/etsi_ts/103400_103499/10341003/01.01.01_60/ts_10341003v010101p.pdf , accessed: 2021-02-10
7. Saref4ener ontology, url: <https://saref.etsi.org/saref4ener/v1.1.2/> , accessed: 2021-02-10
8. Appliances, S.: Smartm2m; smart appliances; reference ontology and onem2m mapping (2017)

9. Bonino, D., Corno, F.: Dogont-ontology modeling for intelligent domotic environments. In: International Semantic Web Conference. pp. 790–803. Springer (2008)
10. Compton, M., Barnaghi, P., Bermudez, L., Garcia-Castro, R., Corcho, O., Cox, S., Graybeal, J., Hauswirth, M., Henson, C., Herzog, A., et al.: The ssn ontology of the w3c semantic sensor network incubator group. *Journal of Web Semantics* **17**, 25–32 (2012)
11. Cuenca, J., Larrinaga, F., Curry, E.: A unified semantic ontology for energy management applications. In: WSP/WOMoCoE@ ISWC. pp. 86–97 (2017)
12. Doukas, H., Patlitziannas, K.D., Iatropoulos, K., Psarras, J.: Intelligent building energy management system using rule sets. *Building and environment* **42**(10), 3562–3569 (2007)
13. Haller, A., Janowicz, K., Cox, S., Le Phuoc, D., Taylor, K., Lefrançois, M.: Semantic sensor network ontology (2017)
14. Ioannidis, Moschos, Sortsi, Sidoras: Deliverable d3.1-re-cognition common information model and device managers. In: HORIZON GA 815301 (2020), https://re-cognition-project.eu/wp-content/uploads/2020/07/D-3.1_compressed.pdf
15. Kotis, K., Athanasakis, I., Vouros, G.A.: Semantically enabling iot trust to ensure and secure deployment of iot entities. *International Journal of Internet of Things and Cyber-Assurance* **1**(1), 3–21 (2018)
16. Kotis, K., Katasonov, A.: Semantic interoperability on the internet of things: The semantic smart gateway framework. *International Journal of Distributed Systems and Technologies (IJDST)* **4**(3), 47–69 (2013)
17. Kotis, K., Papasalouros, A., Vouros, G.A., Pappas, N., Zoumpatianos, K.: Enhancing the collective knowledge for the engineering of ontologies in open and socially constructed learning spaces. *J. UCS* **17**(12), 1710–1742 (2011)
18. Liu, Y., Chen, H., Zhang, L., Wu, X., Wang, X.j.: Energy consumption prediction and diagnosis of public buildings based on support vector machine learning: A case study in china. *Journal of Cleaner Production* **272**, 122542 (2020)
19. Martini, R.G., Araújo, C., Librelotto, G.R., Henriques, P.R.: A reduced crm-compatible form ontology for the virtual emigration museum. In: New advances in information systems and technologies, pp. 401–410. Springer (2016)
20. Ploennigs, J., Hensel, B., Dibowski, H., Kabitzsch, K.: Basont-a modular, adaptive building automation system ontology. In: IECON 2012-38th Annual Conference on IEEE Industrial Electronics Society. pp. 4827–4833. IEEE (2012)
21. Reinisch, C., Kofler, M., Iglesias, F., Kastner, W.: Thinkhome energy efficiency in future smart homes. *EURASIP Journal on Embedded Systems* **2011**, 1–18 (2011)
22. van Ruijven, B.J., De Cian, E., Wing, I.S.: Amplification of future energy demand growth due to climate change. *Nature communications* **10**(1), 1–12 (2019)
23. Vlachidis, A., Bikakis, A., Kyriaki-Manessi, D., Triantafyllou, I., Antoniou, A.: The crosscult knowledge base: A co-inhabitant of cultural heritage ontology and vocabulary classification. In: European Conference on Advances in Databases and Information Systems. pp. 353–362. Springer (2017)