Extending the SAREF ontology for building devices and topology*

María Poveda-Villalón and Raúl García-Castro

Ontology Engineering Group, Universidad Politécnica de Madrid, Spain
{mpoveda, rgarcia}@fi.upm.es

Abstract. In recent years, approaches to model different domains that interact in the IoT landscape are constantly emerging, such as the building information one, which includes related sensors, devices and appliances. The SAREF ontology represents a reference model for smart appliances, originally focused on the smart home domain. This work presents a SAREF extension for building devices as well as their location.

Keywords: Ontology, Building devices, IFC, Smart Appliances

1 Introduction

On the one hand, a more efficient interaction and integration of actors, methods and tools during the different phases of the building life cycle is being demanded in the Architecture, Engineering and Construction (AEC) and Facilities Management (FM) fields. Along its life cycle, multiple tools interact with building models to extract information for different purposes (e.g., energy demand, appliance characteristics, etc.). Therefore, there are missing mechanisms easing the data exchange between actors thorough the complete building cycle, along with tools for interoperability.

On the other hand, the quantity of things that are being made available through the Internet is constantly growing[1] carrying with them the inherent heterogeneity and diversity of the IoT landscape. Given this situation, some solutions embrace semantic technologies in order to alleviate interoperability problems. In this sense, numerous ontologies have been defined to cover the IoT domain in many ways [1]. One example of these ontologies is the SAREF (Smart REFerence Ontology), a reference model for smart appliances that focuses on the smart homes, and provides an important contribution to enable IoT semantic interoperability, adopted by ETSI as a Technical Specification [2].

Undoubtedly, building related information and building objects play a crucial role in IoT systems and applications due to the need for contextualising IoT information. The ISO standard data model Industry Foundation Classes (IFC) [3] supports interoperability between building-related data and tools; therefore,

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[1] http://www.businessinsider.com/there-will-be-34-billion-iot-devices-installed-onearth-by-2020-2016-5

we decided to extend the SAREF ontology with the subset of this standard related to devices and appliances. This approach fills the gap between building related devices and the SAREF ontology and has been developed in the context of the STF 513 "Maintenance & Evolution of SAREF Reference Ontology" ETSI project.

In this paper, a modular approach for transforming a subset of IFC concept is presented, being this fact the main characteristic of this work compared to existing efforts (Section 2). In particular, the paper will focus on the ontological requirements extraction (Section 3) and ontology implementation (Section 4) activities. Finally, an overview of the resulting ontology, identified as SAREF4BLDG, is provided (Section 5) before closing with some concluding remarks (Section 6).

2 Related Work

Some of the first attempts to semantic conversion, considering RDF technologies, of IFC include the approach presented in [4] where a XSLT transformation file is proposed to transform the XML schema of a IFC 2x2 model into an OWL file; the work of [5] and OntoSTEP [6] that proposes an OWL-DL version of STEP. More recents efforts are the ifcOWL ontology and related transformations from EXPRESS files into RDF instance data following the ifcOWL ontology like the approach presented by Pawels and Terkaj [7].

While most of existing approaches aims at transforming EXPRESS file or the IFC model as a whole, and from an architectural point of view, in this work we focus on a modular approach. In this approach only devices are considered and the transformation method follows both automatic translation and modelling decisions based on ontology development patterns. In addition, this works aims at filling the gap between IFC architectural point of view and the IoT landscape, for what the transformation is linked to SAREF ontology.

3 Ontology Requirements Specification

Traditional techniques for ontology requirements elicitation include both the elicitation requirements from reference literature and documentation in the domain of interest and interviews with domain experts. In the particular of SAREF4BLDG no domain experts were part of the project partners, therefore the access to such a role has been restricted to acquittances and members of the AEC research community who disinterestedly answered questions, provided resources and acts as consultants with limited involvement.

The purpose of the SAREF4BLDG ontology is to extend the information of IFC models to include smart devices data annotations, focusing on: (a) the devices, including appliances, described in IFC and on their attributes; and (b) how to locate such devices in buildings.

It is not trivial to extract all the devices described within IFC4 as they do not belong to one unique hierarchy hanging from a top "Device" concept. IFC4 is organized by views and in each view several devices could be included. For example, the core specification contains transport elements as devices, the shared part of the specification contains shading devices and each specific domain contains its own devices, for example actuators and alarms in the controls domain.

In order to select the subset of IFC4 relevant in the context of a SAREF extension, the boundaries of the concepts that would be included are delimited by the term "device", that is, every entity that can be classified as a device would be taken into account. In some cases, the concepts are easily recognised because the term 'device" is included in the identifier, for example "shading **device**". However, in other cases, the description of the entities had to be reviewed in order to check whether the concept actually represents a device. For example, the IFC description of the term "Controller"[2] reads as "A controller is a **device** that monitors inputs and controls outputs within a building automation system.".

In addition, some concept definitions do not contain the term "device" as part of their description but a hypernym of it. That is, they are a more specific type of device. In these cases, we have made use of WordNet [8] web service[3] in order to identify whether such terms are devices, including them therefore in the requirements for the building extension of SAREF. For example, the definition of "lamp" in IFC4 reads "A lamp is an artificial light source such as a light bulb or tube" giving no evidence of whether a lamp is a device. In this case we searched for "lamp" in WordNet and looked for its list of inherited hypernyms observing that "device" is listed as part of the inherited hypernyms; therefore, we have included lamp within the requirements. Following this procedure we included the following eight concepts: lamp, dumper, filter, space heater, valve, audio visual appliance, communication appliance and electric appliance.

After selecting the concepts of interest, the requirements were extended adding the properties defined for such concepts. In this case not just all the properties defined in IFC4 were added, some of them were discarded. More precisely, for all the devices selected the "Reference" property was discarded as it can be either mapped (a) to the element URI (in the sense of identifier) or (b) to a `rdfs:label`. The property "Status" has been also discarded as it indicates whether the element previously existed or is a new item in a retrofitting project and that is out of scope of this SAREF4BLDG. The properties whose expected type is defined as "P_TABLEVALUE" were also discarded, for example the property "Spectrum".

4 Ontology Implementation

In the first step for transforming the extracted requirements to OWL, an `owl:Class` together with its additional information as shown in Listing 1.1 was created for each concept selected from the IFC documentation. For each class extracted from the IFC specification, `rdfs:label` and `rdfs:comment` annotations have

[2] http://www.buildingsmart-tech.org/ifc/IFC4/Add1/html/schema/ifcbuildingcontrols domain/lexical/ifccontroller.htm
[3] http://wordnet.princeton.edu/

been generated including the identifier and an excerpt of the definition provided in the IFC online documentation. In addition, provenance information has been including using the PROV-O ontology.[4] In our case, the property **prov:hadPrimarySource** is used to link each class with (a) the online document in IFC describing the concept and (b) the online document in IFC describing the properties defined for such concept.

In order to create these classes, a CSV file containing all the devices selected from IFC, their description extracted from IFC, the URLs defining the concepts and their properties were created. From this tabular data, mappings to RDF and OWL metamodels were created using OpenRefine.[5] More precisely for each row it was created: an **owl:Class** declaration (line 2 in Listing 1.1); an **rdfs:label** with the class name (line 3 in Listing 1.1); an **rdfs:comment** with the class definition (line 4 in Listing 1.1); and as many **prov:hadPrimarySource** statements as URLs defined for provenance (lines 8 and 11 in Listing 1.1). Finally, links to the https://w3id.org/ifc/IFC4_ADD1# ontology have been established by means of the property **rdfs:seeAlso** (line 14 in Listing 1.1)

Each class was then manually classified according to the hierarchy proposed in IFC[6] under the corresponding class of the device's hierarchy (line 5 in Listing 1.1). In order to create this hierarchical structure the following consideration should be taken into account. IFC defines the concept "Element"; however, this concept is too broad to be reused since it refers to devices and any other element that can appear in a building. This issue also appears in other levels of the hierarchy; for example, IFC defines the concept "Distribution elements" which contains devices but also many other elements that are not devices. In this case we have created the class **s4bldg:DistributionDevice** in order to restrict the use to devices. This decision has been taken for the following classes: **s4bldg:BuildingDevice**, **s4bldg:DistributionDevice**, **s4bldg:DistributionControlDevice** and **s4bldg:DistributionFlowDevice**.

```
1  ### Class definition
2  s4bldg:Compressor rdf:type owl:Class ;
3    rdfs:label "Compressor"@en ;
4    rdfs:comment "A compressor is a device that compresses a fluid
       typically used in a refrigeration circuit."@en ;
5    rdfs:subClassOf s4bldg:FlowMovingDevice ;
6
7  ### Provenance information for class definition
8    prov:hadPrimarySource <http://www.buildingsmart-tech.org/ifc/IFC4/Add1
       /html/schema/ifchvacdomain/lexical/ifccompressor.htm> ;
9
10 ### Provenance information for class properties
11   prov:hadPrimarySource <http://www.buildingsmart-tech.org/ifc/IFC4/Add1
       /html/schema/ifchvacdomain/pset/pset_compressortypecommon.htm> ;
12
13 ### Mapping to ifcOWL classes
14   rdfs:seeAlso <https://w3id.org/ifc/IFC4_ADD1#IfcCompressor> .
```

Listing 1.1. Example of turtle code of a class definition

[4] https://www.w3.org/TR/prov-o/
[5] http://openrefine.org/
[6] http://www.buildingsmart-tech.org/ifc/IFC4/Add1/html/annex/annex-c/common-use-definitions/all.htm

For each class, its associated properties described in IFC have been transformed into object or datatype properties. IFC datatypes “logical”, “boolean”, “natural”, “integer”, “string”, and “{string}”, have been transformed into datatype properties with ranges `xsd:boolean`, `xsd:boolean`, `xsd:nonNegativeInteger`, `xsd:integer`, `xsd:string`, and `xsd:string`, respectively. IFC datatypes “ratio”, “real ratio”, “normalised ratio”, “positive ratio”, and “Real” (associated to a P_SINGLEVALUE), have been transformed into object properties that would link to an instance of `saref:Measurement`. The IFC datatype “Real” (associated to a P_BOUNDEDVALUE) has been transformed into two object properties (one for maximum value and another for minimum value) that would be used to link to an instance of `saref:Measurement`. The IFC datatype “Complex” has been transformed into an object property with open range.

Taking into account such datatype transformations, an object property or datatype property is created for each property selected from IFC specification. It should be clarified that a given property could be defined for more than one concept in IFC, for example the property “refrigerant class” is defined for the the concepts “compressor”, “condenser”, and “evaporator”. In this case, one property is created for the energy source and a local axiom defining a universal restriction is created for each class in which the property can be applied.

The naming of the created object and datatype properties is consistent with the naming used in IFC. More precisely, the names of the properties in the ontology are the names assigned in IFC transformed into “mixedCase” starting with lowercase. For example, the property “RefrigerantClass”[7] has been transformed into the object property `s4bldg:refrigerantClass`.

Listing 1.2 shows the RDF code generated for the `s4bldg:refrigerantClass` datatype property and the local axiom for the such property defined in the `s4bldg:Compressor` class. As it can be observed, the datatype property does not have a domain defined as it can be applicable to more than one concept. Leaving the domain open allows the inclusion of more concepts in the ontology that could have that property, while defining the domain as the union of the classes that can have that property when creating the ontology would not have been as sustainable solutions as the current one in case of extensions.

```
###  https://w3id.org/def/saref4bldg#refrigerantClass
:refrigerantClass rdf:type owl:DatatypeProperty ;
                  rdfs:range xsd:string ;
                  rdfs:comment "Refrigerant class used by the compressor
    . CFC: Chlorofluorocarbons. HCFC: Hydrochlorofluorocarbons. HFC:
    Hydrofluorocarbons."@en ;
                  rdfs:label "refrigerant class"@en .

###  https://w3id.org/def/saref4bldg#Compressor
:Compressor rdf:type owl:Class ;
            rdfs:subClassOf [ rdf:type owl:Restriction ;
                              owl:onProperty :refrigerantClass ;
                             owl:allValuesFrom xsd:string
                              ] .
```

Listing 1.2. Example of turtle code of a local universal restriction axiom definition

[7] Property extracted from http://www.buildingsmart-tech.org/ifc/IFC4/Add1/html/schema/ifchvacdomain/pset/pset_compressortypecommon.htm

5 Details of the SAREF4BLDG ontology

SAREF4BLDG is an OWL-DL ontology that extends SAREF with 72 classes (67 defined in SAREF4EBLDG and 5 reused from the SAREF and geo,[8] 179 object properties (177 defined in SAREF4EBLDG and 2 reused from the SAREF and geo ontologies), and 83 data type properties (82 defined in SAREF4EBLDG and 1 reused from the SAREF ontology).

During the development of the SAREF4BLDG extension the Linked Open Terms[9] lightweight methodology was followed. SAREF4BLDG has been made available according to the best practices for publishing ontologies in the Web[10]. The ontology is published implementing content negotiation mechanism under the persistent URI **https://w3id.org/def/saref4bldg#** and licensed under the Creative Commons CC BY 4.0 license.[11]

Figure 1 presents an overview of the classes and some general 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 reused class `geo:SpatialThing` in order to reuse the conceptualisation for locations already proposed by the geo ontology. The building objects (`saref:BuildingObject`) and building spaces (`saref:BuildingSpace`) model has been adapted from SAREF.

The modelling for measurements, depicted in Figure 1, represents an n-ary pattern that allows users to relate different measurements for different properties using different units. That is, the `saref:Measurement` class aims at describing a measurement of a physical quantity (using the `saref:hasValue property`) for a given `saref:Property` and according to a given `saref:UnitOfMeasure`.

The main contribution of this extension is the representation of the devices defined in the IFC standard and their connections to SAREF. In this sense, a hierarchy consisting in 62 classes has been created taking into account the subset of the IFC hierarchy related to devices, as defined in the buildingSMART documentation,[12] and adding several classes to clarify its categorisation.

Figure 1 also shows the first five levels of the hierarchy (of the six total levels). Since transport elements (`s4bldg:TransportElement`) and vibration isolations (`s4bldg:VibrationIsolation`) are not classified under IFC elements, they belong directly to the class `s4bldg:Device`. The building elements are divided into `s4bldg:ShadingDevice` and `s4bldg:DistributionDevice`. In fact, most of the device types included in IFC belong to the distribution device category which contains the classes `s4bldg:DistributionControlDevice` and `s4bldg:DistributionFlowDevice` (the hierarchy under this last class is partially shown in the figure.

[8] http://www.w3.org/2003/01/geo/wgs84_pos#
[9] http://lot.linkeddata.es/
[10] https://www.w3.org/TR/swbp-vocab-pub/
[11] http://purl.org/NET/rdflicense/cc-by4.0
[12] http://www.buildingsmart-tech.org/ifc/IFC4/Add1/html/annex/annex-c/common-use-definitions/all.htm

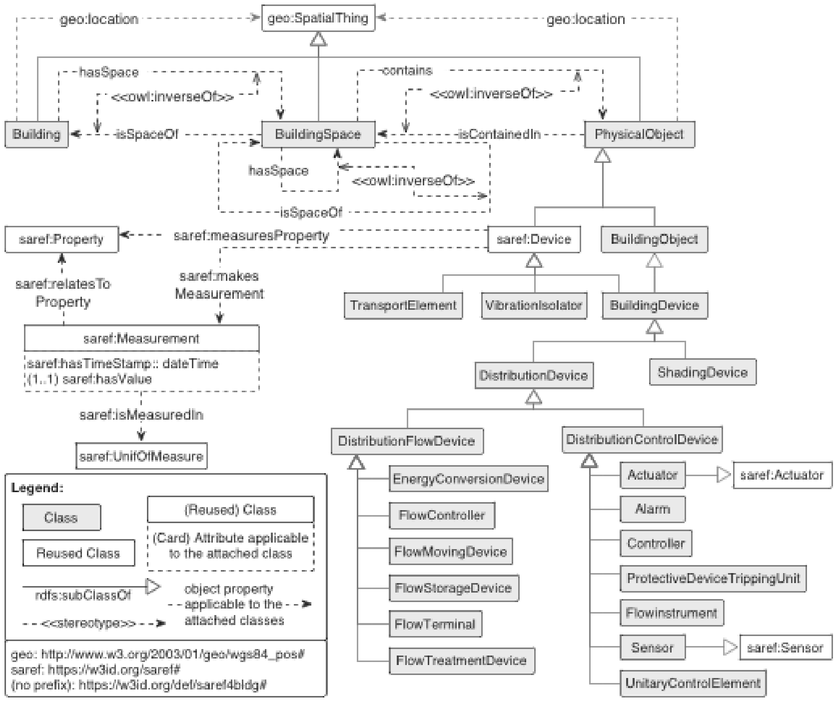

Fig. 1. General overview of SAREF4BLDG extension. Adapted from [9].

As we can observe in Figure 1, some classes defined in SAREF4BLDG are also defined in the SAREF ontology, apart from the already explained `s4bldg:Device`. More precisely, this occurs in the classes `s4bldg:Actuator` and `s4bldg:Sensor` that extend the classes `saref:Actuator` and `saref:Sensor`, respectively. This decision has been taken because in the SAREF4BLDG extension these concepts refer to specific sensors and actuators that are placed in or related to buildings.

6 Conclusions and future work

One of the main obstacles when trying to reuse existing IFC translation into OWL is the lack of a modular approach in which a view of a specific aspect is provided. In this work, the modularisation of a concrete type of elements has been carried out. As main lesson learnt, we can claim that extracting requirements in a systematic and consistent way is not a trivial activity even less with lack of domain experts as part of the project team.

It is worth noting that the translations into an OWL ontology should not be taken as a straight automatic process. Modelling decision according to best practices should be made both before and after the transformation process.

One important outcome of this work has been the impact of the resulting SAREF4BLDG on the SAREF ontology. For example, the concepts and properties related to building were moved to the SAREF4BLDG extension and the proposed model for measurements were adopted by SAREF in its second version.

Regarding future work, we can mention that the current list of building devices should not be considered exhaustive. It might be needed to extend the hierarchy in the case of new devices related to buildings are included in IFC or needed for a particular use case. It is expected that concrete use cases reuse the existing classes to represent their devices or specialise some classes to cover specific device types (e.g., by creating a hierarchy of boiler devices under `s4bldg:Boiler`). Another example of this extension could be carried out by including those specific devices provided as values of the property “type” in IFC. For example, the concept lamp could be further extended with subclasses as “flourescent”, “halogen”, etc. according to the enumeration provided by the IfcLampTypeEnum property.[13] In this case, domain knowledge would be needed, for example to be able to identify subtypes within the list provided by the property.

References

1. Gyrard, A., Bonnet, C., Boudaoud, K., Serrano, M.: LOV4IoT: A second life for ontology-based domain knowledge to build Semantic Web of Things applications. In: Future Internet of Things and Cloud (FiCloud), IEEE (2016) 254–261
2. ETSI TS 264 411 - v1.1.1: SmartM2M; Smart Appliances; Reference Ontology and oneM2M Mapping. Technical report, ETSI (2015)
3. ISO: ISO 16739:2013 - Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries. International Standardization Organization (2013)
4. Beetz, J., Van Leeuwen, J., De Vries, B.: An ontology web language notation of the industry foundation classes. In: Proceedings of the 22nd CIB W78 Conference on Information Technology in Construction. Volume 2006., Technical University of Dresden Dresden (2005) 670
5. Agostinho, C., Dutra, M., Jardim-Gonçalves, R., Ghodous, P., Steiger-Garção, A.: EXPRESS to OWL morphism: making possible to enrich ISO10303 Modules. In: Complex Systems Concurrent Engineering. Springer (2007) 391–402
6. Krima, S., Barbau, R., Fiorentini, X., Sudarsan, R., Sriram, R.D.: Ontostep: OWL-DL ontology for step. National Institute of Standards and Technology, NISTIR **7561** (2009)
7. Pauwels, P., Terkaj, W.: EXPRESS to OWL for construction industry: Towards a recommendable and usable ifcOWL ontology. Automation in Construction **63** (2016) 100–133
8. Miller, G., Fellbaum, C.: WordNet: An electronic lexical database (1998)
9. ETSI TS 103 410-3 - v1.1.1: SmartM2M; Smart Appliances Extension to SAREF; Part3: Building Domain. Technical report, ETSI (2017)

[13] http://www.buildingsmart-tech.org/ifc/IFC4/Add1/html/schema/ifcelectricaldomain/lexical/ifclamptypeenum.htm