# Created in Close Interaction with the Industry: The Smart Appliances REFerence (SAREF) Ontology

Laura Daniele(✉), Frank den Hartog(✉), and Jasper Roes

TNO - Netherlands Organization for Applied Scientific Research, The Hague, Netherlands
{Laura.Daniele,Frank.denHartog,Jasper.Roes}@tno.nl

**Abstract.** Around two thirds of the energy consumed by buildings can be traced back to the residential sectors and thus household appliances. Today, most appliances are highly intelligent and networked devices, in principle being able to form complete energy consuming, producing, and managing systems. Reducing the use of energy has therefore become a matter of managing and optimizing the energy utilization at a system level. These systems are technically very heterogeneous, and standardized interfaces on a sensor and device level are therefore needed. Many of the required standards already exist, but a common architecture does not, resulting in a too fragmented and powerless market. To enable semantic interoperability for smart appliances we therefore developed SAREF, the Smart Appliance REFerence ontology. In this paper we present SAREF and describe our experience in creating this ontology in close interaction with the industry, pointing out the lessons learned and identifying topics for follow-up actions.

**Keywords:** Smart appliances · Internet of things · Ontologies · Semantic interoperability · Device abstraction layer · Smart grids

## 1 Introduction

An important goal for society is to achieve higher energy efficiency. More than 40 % of the total energy consumption in the European Union comes from the residential and tertiary sector of which a major part are residential houses [1]. Energy using and producing Products (EupPs), also called appliances, that are inherently present in the buildings' ecosystem are the main culprits. An appliance is an instrument or device designed for a particular use or function. Home appliances are electrical/mechanical machines which accomplish some household functions, such as cleaning or cooking. Nearly all devices intended for domestic use fit this broad definition, including refrigerators, stoves, toasters, air conditioners as well as PCs, TVs, and light bulbs. They are typically classified as either major appliances (or White goods), small appliances (or Brown goods), or consumer electronics (or Shiny goods).

More and more appliances are highly intelligent ("smart") and networked devices, forming complete energy consuming, producing, and managing systems. Reducing the use of energy and production of greenhouse gasses is therefore not only a matter of


R. Cuel and R. Young (Eds.): FOMI 2015, LNBIP 225, pp. 100–112, 2015.
DOI: 10.1007/978-3-319-21545-7_9

increasing the efficiency of the individual devices. It also encompasses managing and optimizing the energy utilization at a system level. The ability to extend such systems flexibly and dynamically with new applications and devices, in line with the needs of the user and available budget, is a key requirement for mass market adoption of these systems. Inevitably these systems will consist of devices and sensors from different vendors, which requires open interfaces at various reference points in the system architecture. Here, an open interface is defined as a public standard for connecting software to software and hardware to hardware.

Remote configuration, management and control of networked devices for energy saving measures is possible if they are able to communicate with service platforms from different local service providers. This requires external access on a semantic level to every device that is part of the system in a well standardized way. Many relevant standards already exist. Some are industry standards or proprietary de facto standards and others are formal standards. However, a common architecture does not yet exist. The individual standards existing today each cover relatively small parts of the problem, sometimes overlapping and competing [2]. Consequently, the current market is too fragmented to accelerate the creation, uptake and required scalability of the envisioned heterogeneous systems of appliances.

Part of what is needed is a unified data model for appliances, a reference ontology. The creation of device and technology abstraction layers and corresponding common Application Programming Interfaces (APIs) are enabled by such an ontology and can be addressed, without the need to know specifics of the various standards [3], by developers of energy-saving application developers for generic types of appliances. By explicitly specifying recurring core concepts in the smart appliances domain, the relationships between these concepts, and mappings to other concepts used by different assets/standards/models a reference ontology offers this. Instead of creating translations between all individual assets, which has been the dominant approach in the literature so far (see e.g. [4, 5]), the mappings between concepts allow translation from specific assets to the reference ontology.

In the past a number of workshops and projects involving the research community and the energy efficiency industry (see e.g. [6]) already explored this field. They concluded that defining a useful and applicable unified data model should in principle be possible. In industrial automation a similar approach has already been taken before [7]. To propose this high-level model, the European Commission (EC) launched a standardization initiative, to be conducted by ETSI's Smart Machine-to-Machine (M2M) Technical Committee. The EC invited TNO to perform a preparatory study on the available semantics assets for the interoperability of smart appliances, and to map them into a reference ontology.

The study finished in April 2015, and this paper presents the final result, i.e. the Smart Appliance REFerence (SAREF) ontology. Special attention is given to our experience in working in close interaction with the industry, pointing out lessons learned and identifying topics for follow-up actions. The paper is structured as follows. The next section describes our approach. We then lay out the main classes and properties of the SAREF ontology, followed by our findings regarding working with the smart home industry. The final sections of the paper conclude the paper and discuss the future work.

## 2 Approach

The work was divided in the following main tasks:

- Take stock of the so-called *assets* in the smart appliances domain, in order to relate the study to the existing work from academia and industry, and select a suitable sub-set that could be used as basis for the creation of a reference ontology. In the context of the study, an asset is defined as a source that presents a project, a set of documents, a standard, a working group, a committee, a paper, or a web page that is somehow related to energy management and/or home appliances. The assets we analyzed were mostly published in the form of a specification, a standard, a project deliverable, an UML data model, an XML schema, in a few cases a scientific paper, or sometimes just a PowerPoint presentation. In the end, we processed 47 assets as they were published in June 2014 or before, and created a short list of 23 assets. The short-listed assets were selected solely based on how well each covered the scope of the project and if the asset provided concrete semantic specifications, preferably in the form of OWL or XML files. A more detailed description of this task can be found in [8].
- Extract the semantics, often implicitly, from the assets in the short list and create a corresponding formal representation in RDF/OWL. The content and level of details of these assets was different, but it generally included either 1) explicit data models or ontologies from which we could define a semantic coverage in a more or less straightforward manner, or 2) protocol descriptions or low-level data container specifications with implicit semantics. The resulting RDF/OWL representations can be downloaded at the project website,[1] which also provides natural language descriptions of their main classes and properties. We acknowledge that our interpretation of the assets as captured in these RDF/OWL representations may not always reflect the original intention of the assets "owners". During the project we therefore actively solicited reviews by the stakeholders and updated the RDF/OWL representations.
- Create SAREF as a shared model of consensus to facilitate the matching of existing assets in the smart appliances domain. Since a large amount of work was already being done in the smart appliances domain, we have not invented anything new but harmonized and aligned what was already there - namely the 23 assets in the short list mentioned above. The SAREF ontology was created in a bottom-up fashion to be as close as possible to the intended use of its stakeholders, such as appliance manufacturers, standardization bodies and API developers. The translation from SAREF to specific assets is allowed by mappings, thereby reducing the need to create translations between individual assets: only 47 translations are needed between the reference ontology and the assets, vs. 47x46 = 2162 translations without the reference ontology. SAREF is based on the fundamental principles of *reuse and alignment* of concepts and relationships that are defined in the existing assets, *modularity* to allow separation and recombination of different parts of the

[1] https://sites.google.com/site/smartappliancesproject/ontologies.

ontology depending on specific needs, *extensibility* to allow further growth of the ontology, and *maintainability* to facilitate the process of identifying and correcting defects, accommodate new requirements, and cope with changes in (parts of) SAREF. Using the SAREF ontology, different assets owned by different stakeholders can keep using their own terminology and data models, but still can relate to each other through their common semantics. In other words, the SAREF ontology enables semantic interoperability in the smart appliances domain.

The study was performed in a very transparent manner to allow all stakeholders to provide input and follow the work. For this we installed an Expert Group[2] that reviewed all our deliverables before publication, and after publication all deliverables were open for review by all interested parties. Review comments were accommodated for in subsequent deliverables. As such, the final project deliverable wrapped up the results obtained in a very interactive and iterative process involving many stakeholders during the whole project execution. We took a multi-channel approach to solicit for review comments: within the span of a year we organized four workshops for stakeholders together with the EC and ETSI,[3] in which we presented the deliverables and work done, and provided an opportunity for stakeholders to provide us with feedback. Besides this quarterly interactive heartbeat of face-to-face gatherings, we had continuous interaction with all involved parties by email, LinkedIn, and the projects' websites, and by attending additional related events such as ETSI and Home Gateway Initiative (HGI) meetings.

## 3 The SAREF Ontology

SAREF focuses on the concept of device, which we define as *"a tangible object designed to accomplish a particular task in households, common public buildings or offices. In order to accomplish this task, the device performs one or more functions*". Examples of devices are a light switch, a temperature sensor, an energy meter, a washing machine. A washing machine is designed to wash (task) and to accomplish this task it performs the start and stop function. The `saref:Device` class and its properties are shown in Fig. 1, together with the `saref:BuildingSpace` and `saref:BuildingObject` classes.

A `saref:Device` must have some properties that uniquely characterize it, namely its model and manufacturer (`saref:hasModel` and `saref:hasManufacturer` properties, respectively). Optionally, a description of the device can also be provided (`saref:hasDescription` property). The `saref:isLocatedIn` object property relates the `saref:Device` class to the `saref:BuildingSpace` class, whereas a building space defines the physical spaces of the building where a device is located, such as a kitchen or a living room. A building space contains devices or building objects (the `saref:BuildingObject` class), which are objects in the

2 https://sites.google.com/site/smartappliancesproject/expert-group.

3 http://www.etsi.org/news-events/events/890-2015-04-dg-connect-etsi-workshop-on-smart-appliances-4, and links therein.

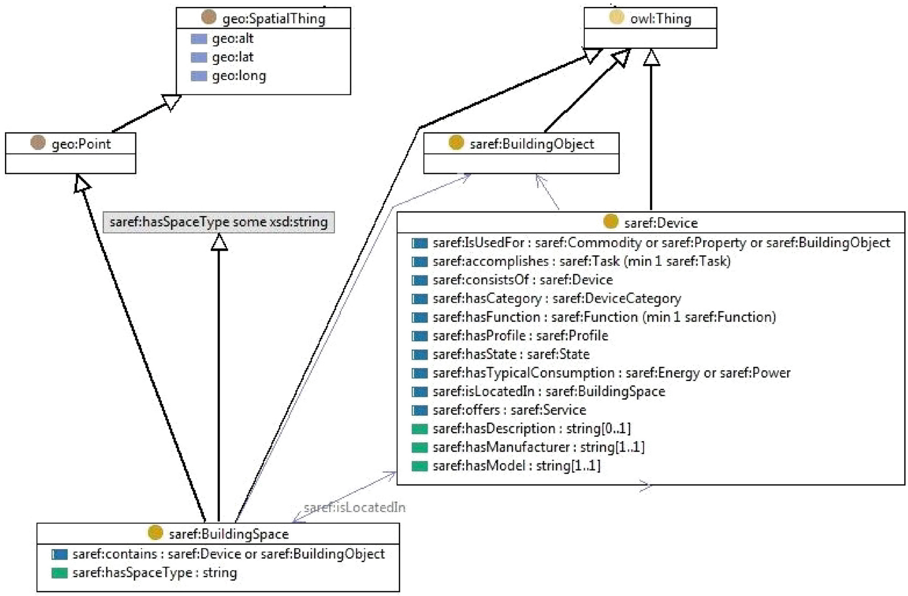


**Fig. 1.** Device, building space and building object classes

building that can be controlled by devices, such as doors or windows that can be automatically opened or closed by an actuator. A building space has also a `saref:hasSpaceType` property that can be used to specify the type of space, for example, the living room or the bedroom. The `saref:BuildingSpace` class provides the link to the FIEMSER data model,[4] which exhaustively covers building related concepts, and takes into account other building-related approaches such as IFC.[5] Moreover, a building space is a `geo:Point` characterized by a certain altitude, latitude and longitude, which are provided by the W3C WGS84 geo positioning vocabulary.[6]

The `saref:hasCategory` object property relates the `saref:Device` class to the `saref:DeviceCategory` class, which provides a way to classify devices into certain categories. When analyzing the semantic assets described in [9] we have identified three main semantic groups, namely 1) devices and sensors, and their specification in terms of functions, states, and services (represented the `saref:FunctionRelated` class), 2) energy consumption information and profiles to optimize energy efficiency (`saref:EnergyRelated`), and 3) concepts coming from building related data models (`saref:BuildingRelated`).

A `saref:Device` must accomplish at least one function, and can be used for the purpose of i) offering a commodity, such as `saref:Water` or `saref:Gas`; ii) sensing, measuring and notifying a property, such as `saref:Temperature`,

[4] http://www.fiemser.eu/?page_id=112.

[5] http://www.buildingsmart-tech.org/ifc/IFC4/final/html/.

[6] http://www.w3.org/2003/01/geo/wgs84_pos.

saref:Energy or saref:Smoke, or iii) controlling a building object, such as a saref:Door or a saref:Window. Moreover, a device may consist of other devices (saref:consistsOf property). For example,

– a washing machine is a device that has category saref:Appliance, accomplishes the task saref:Washing and performs an actuating function of type saref:StartPauseFunction. From an energy related perspective, a washing machine also belongs to the category saref:Load;
– a smoke sensor is a device that consists of a sensor, has category saref:Sensor, performs the saref:SensingFunction and saref:EventFunction, and is used for the purpose of sensing a property of type saref:Smoke and notifying that a certain threshold has been exceeded;
– a door switch is a device that consists of a switch, has category saref:Actuator, performs the saref:OpenCloseFunction and is used for the purpose of controlling a building object of type saref:Door;
– an energy meter is a device that consists of a meter, has category saref:Meter, performs the saref:MeteringFunction and is used for the purpose of measuring the saref:Energy property.

A function is represented with the saref:Function (see Fig. 2) and is defined as *"the functionality necessary to accomplish the task for which a device is designed"*. It must have at least one command (saref:hasCommand min 1 saref:Command). Examples of functions are the saref:ActuatingFunction (allows to *"transmit data to actuators, such as level settings (e.g., temperature) or binary switching (e.g., open/close, on/off)"*, saref:SensingFunction (allows to "*transmit data from sensors, such as measurement values (e.g., temperature) or sensing data (e.g., occupancy)"*), saref:MeteringFunction (allows to *"get data from a meter, such as current meter reading or instantaneous demand"*), and saref:EventFunction (allows to "*notify another device that a certain threshold value has been exceeded"*.)

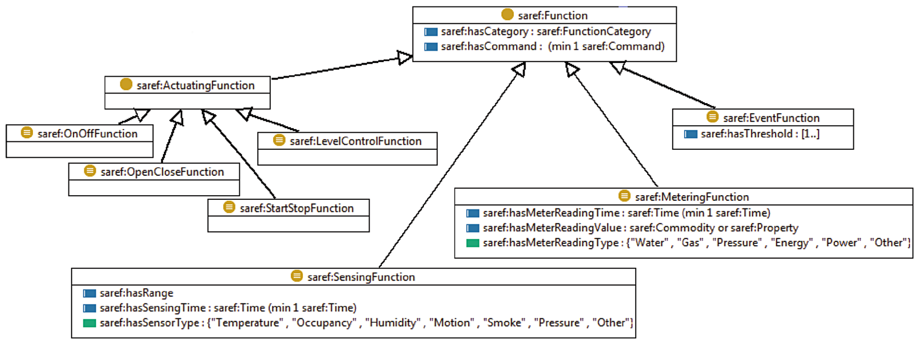


**Fig. 2.** Function class and its properties

Examples of Actuating Functions are the saref:OnOffFunction (allows to "*switch on and off an actuator"*, and has the commands saref:OnCommand, saref:OffCommand and saref:ToggleCommand), and the saref:Level-ControlFunction (allows to *"do level adjustments of an actuator in a certain range (e.g., 0 %-100 %), such as dimming a light or set the speed of an electric motor"*).

Depending on the function(s) it performs, a device can be found in a corresponding saref:State. For example, a switch can be found in the saref:OnOffState, which is characterized by the values "ON" or "OFF". A device also offers a service (the saref:Service class), which is a representation of a function to a network that makes this function discoverable, registerable and remotely controllable by other devices in the network. A service must specify the device(s) offering the service, the function(s) to be represented, and the input and output parameters necessary to operate the service. For example, a light switch can offer the service of remotely switching the lights in a home through mobile phone devices that are connected to the local network. This remote switching service represents the saref:OnOffFunction, it must have a saref:State as input parameter, e.g., with value "ON", and it must have a saref:State has output parameter, namely with value "OFF" in this example since the input state value was "ON".

The saref:Profile class (see Fig. 3) allows to describe the energy (or power) production and consumption of a certain device using the saref:hasProduction and saref:hasConsumption properties. The production and consumption can be calculated over a time span (the saref:hasTime property) and, eventually, associated to some costs (the saref:hasPrice property). The saref:Time class allows to specify the "time" concept in terms of instants or intervals according to the W3C Time ontology[7] referred to with the time: prefix.

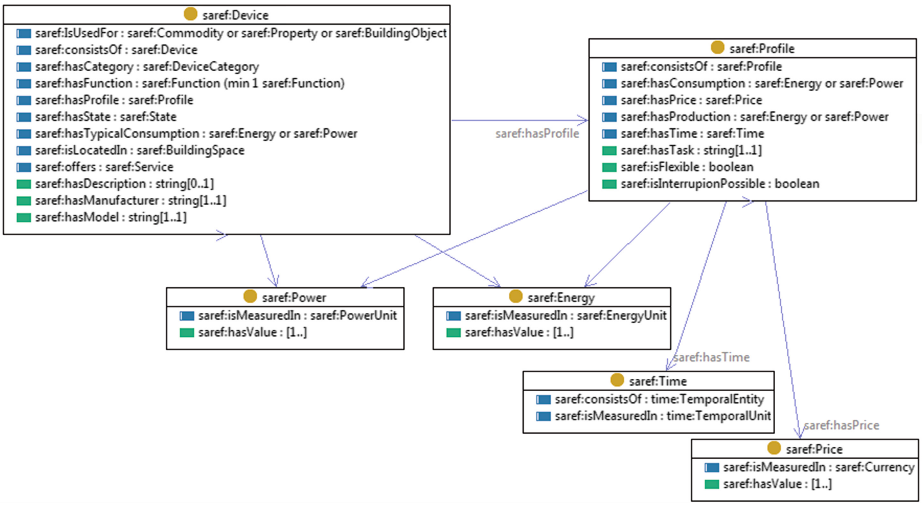


**Fig. 3.** Profile, Power, Energy, Time and Price classes with their properties

[7] http://www.w3.org/TR/owl-time/.

## 4 Discussion

In this section we present our experiences regarding the continuous involvement of a very heterogeneous industrial ecosystem in the creation process of the SAREF ontology. Although the tender issued by the European Commission for the development of a reference ontology for smart appliances in collaboration with ETSI M2M clearly indicated the need of using semantics and ontologies, we noticed that the industrial stakeholders were far from familiar with the world of semantics and, to some extent, even reluctant to the idea of using ontologies as a means of data model standardization. Practitioners from industry often heard about ontologies before, but could not recognize the added value compared to their traditional techniques using, for example, UML data models or XML schemas. Therefore, it took some time and effort to clarify the benefits of ontologies in solving the interoperability problems that the industrial community is currently facing.

For instance, many of our industry collaborators did not know how to open and read an .owl file, and were reluctant to install an ontology editor locally, often because their IT department did not allow them to do so. Also, the creation of an ontology in OWL was perceived as having to give up their current way of modelling (UML, XML, etc.) and do all the work again from scratch, even though we emphasized that automatic RDF/OWL code generation tools exist. It also took a while before industry realized that by having the reference ontology as a common basis, nobody needs to give up their own model: a simple mapping to SAREF suffices. And as specific data models evolve in the future, so will SAREF. However, when we started our analysis, most stakeholders were afraid that we would not consider their specific assets, and that they would miss the SAREF train once and for all. This fear was probably ingrained by a long history of stakeholders (often competitors in the market) already collaborating with each other to reach some level of interoperability, but without agreeing on which of the data models involved was more suitable, as nobody would resign to giving up years of work on their own model in favor of the other.

On the other hand, academic researchers, for which it was totally obvious that a reference ontology would enable the interoperability that was missing, often lacked the ability to translate the high-level concepts to practical implications, or to compromise on e.g. model complexity if practicality was a bottleneck for adoption. In other words, there was a gap between the conceptual thinking of the scientific researchers and the more practical point of view of the industry. The lesson learned is that an aggressive and impatient push of academically well-researched methodologies and technology, even if they are mature enough, does not foster their adoption in a community of practitioners. In contrast, a key factor of success in our study according to the stakeholders' feedback, was to gradually introduce the new concept, explain it in simple terms, make extensive use of examples and be practical, i.e. be receptive to the feedback from the engineers. This allowed us to earn the necessary trust from the practitioners, and establish a suitable level of communication to bridge the gap between conceptual and practical thinking during the process.

A concrete example of the above is an observation about upper ontologies. A comment we received from the Expert Group was that SAREF does not contain explicit references to foundational upper ontologies such as, for example, DUL[8] or SUMO[9]. We acknowledge that the use of these ontologies is a best practice in ontology engineering, but we argue that the smart appliances industry - main user of SAREF - is rather pragmatic and not acquainted with high-level upper ontologies. In our opinion, introducing these ontologies at the first release of SAREF would have complicated its understanding and, consequently, its adoption by the smart appliances industry. In any case, SAREF has been built and on a solid ontological foundation, being based on DUL. Moreover, SAREF has mappings to the W3C SSN[10] ontology, which is in turn related to DUL. Therefore, the current version of SAREF includes an indirect reference to DUL through the W3C SSN ontology. Thus, when dealing with practical applications of formal ontologies in industry, it is not trivial to produce an artifact with a proper conceptual foundation and, at the same time, easy to use by practitioners. Compromises need to be made that depend on the context and the domain under consideration.

Another key factor of success, demonstrated by the enthusiastic participation of the community to the project's stakeholder workshops, was to have an interactive and iterative approach in the creation of SAREF, characterized by the early involvement of the stakeholders. For example, we assessed additional assets after we collected the feedback from the stakeholders at the first two workshops in Brussels and Sophia Antipolis, although the assessment task was in principle finished, and we concluded that in addition to the short-listed assets in [8], CENELEC EN50491, ZigBeeHA and Adapt4EE should also be considered in the creation of the reference ontology. ZigBeeHA[11] and Adapt4EE[12] were expressed in OWL, which allowed us to include them straightforwardly in our catalogue of RDF/OWL ontologies, while CENELEC EN50491 only provided a pdf specification with associated XSDs. It will be a major undertaking to translate the CENELEC specification to an ontology, and we advise this to be done in future work. Nevertheless we were able to take the most relevant content of the CENELEC specification into account when constructing SAREF. As another example, we were also able to (qualitatively) validate the usability of the modular approach used to create SAREF in a dedicated session with some stakeholders - namely representatives of CENELEC, ETSI M2M, and HGI - organized after the 2nd workshop in Sophia Antipolis. After the session we could conclude that a reference ontology built with such modularity in mind was intuitive and well understood by different stakeholders. Moreover, we noticed that several of the considered assets had a similar modular approach for combining devices, functions and commands, e.g., DogOnt (PowerOnt), OSGi DAL, CENELEC, DECT ULE, KNX, SeemPubs, UPnP and Z-Wave. Therefore, the building blocks of the SAREF ontology should be intuitive for these stakeholders also. The lesson learned here is twofold. On the one hand, our approach created a lot of overhead work, since more interactions were necessary- e.g., via e-mail, phone calls, web conferences, face to face meetings – including more

8 http://ontologydesignpatterns.org/wiki/Ontology:DOLCE+DnS_Ultralite.

9 http://www.adampease.org/OP/.

10 http://www.w3.org/2005/Incubator/ssn/ssnx/ssn.

11 http://elite.polito.it/ontologies/zigbee.html.

12 http://www.adapt4ee.eu/.

revisions of the work, instead of one (major) revision on the final result. On the other hand, this guaranteed a higher practical quality of the outcome, reflecting the wishes and intentions of the community in an optimal way, and above all creating the necessary trust into our work, increasing the likelihood of a strong acceptance of the results.

The final observation concerns the trade-off between carrying out ontology engineering activities in a manual or an automatic way. Several of the assets we analyzed were expressed as UML data models and XML schemas, and we initially thought that an automatic generation of RDF/OWL from UML and XSDs would be beneficial. However, we then decided to perform the task manually, mainly given the large amount of models to be translated in a short time, and the (limited) resources that could be allocated for the translation task. In fact, it was more effective to create the RDF/OWL representations of the assets top-down, i.e. extracting the semantics from the natural language descriptions and class diagrams (or XSDs) provided by the assets, rather than bottom-up, by first automatically generating RDF/OWL, and then having to edit the results in order to make proper ontologies out of it. Furthermore, in collaboration with the READY4SmartCities project[13], we performed an experiment with automatic mappings using dedicated software for ontology matching[14] to support the manual mappings we provided in [9]. This experiment took as input our initial 20 short-listed RDF/OWL ontologies and produced some interesting matching results[15]. For example, it showed that the DogOnt, OSGi DAL, FIEMSER and Seempubs ontologies had the highest number of exact matching among each other. Therefore, these assets could be used as a solid common basis for creating our reference ontology. The results obtained with the automatic ontology matching were then checked against our manual results. The conclusion was that this experiment validated our results, supporting our mappings and the choice of core concepts proposed as a basis to build the reference ontology. However, we could not have run these experiments within a reasonable time without the support of the experts of the READY4SmartCities project. The lesson learned is that the support of tools for automatic translation and matching is definitely beneficial, but still needs a certain degree (which can be a lot) of human intervention. These tasks would probably be best performed with the combined use of automatic tools and manual work. However, this should be thoroughly assessed depending on the study and its context, the type and number of models under consideration, and the amount of time and resources available.

## 5 Future Work

The scope of SAREF is currently limited to an indoor managed domain, such as a building managed by a building manager or an apartment managed by a user. This scope also includes the outdoor premises that belong to the considered indoor managed

[13] http://www.ready4smartcities.eu/.

[14] Exact match algorithm, LogMapLite, YAM ++.

[15] http://al4sc.inrialpes.fr/onid/1420470368391/9235; http://al4sc.inrialpes.fr/onid/1420470148730/6339; http://al4sc.inrialpes.fr/onid/1420470114201/6506.

domain, in other words, a pergola that is part of the building is also within the scope, as well as a sensor located under that pergola. Therefore, the smart city domain is currently not considered, i.e., if the same sensor located under the pergola is also found in a street, then the sensor in the street is out of the scope of SAREF. However, since in principle the sensor in the street can be also defined using the SAREF definition of device, nothing prevents us in the future to extend the scope of SAREF to outdoor domains (e.g., smart cities) also, not managed by building managers or apartment users but e.g. an administrative manager of the city council. Moreover, the scope of the study in which SAREF was developed is somewhat different from what is the so-called Internet of Things (IoT), which covers more device types, such as personal health devices, smart watches, and toys, but excludes the building spaces' information models.

Current work in ETSI is aimed at adopting the SAREF ontology as a Technical Specification (TS), and to facilitate the industry to maintain and extend SAREF further (since our project has ended in spring 2015). The ontology should also be integrated in the current ETSI M2M architecture [10] and related OneM2M architecture, which describes the overall end-to-end M2M functional architecture, including the identification of the functional entities and the related reference points.

Next to the work in ETSI and OneM2M, Energy@Home and EEBus are also in the process of matching their data models to SAREF. This may result in concepts and elements still missing in the current version of SAREF and to be added in the next version. Both organizations intend to use the mappings to SAREF to simplify the mapping of information between their own models.

## 6 Conclusions

In this paper we presented the SAREF ontology and our experiences regarding the continuous involvement of a very heterogeneous industrial ecosystem in the creation process of SAREF. We identified 47 semantic assets that characterize the state of the art in the smart appliances domain. Of these 47, we selected 23 for the development of a reference ontology, based on how well each covered the scope of the project and if the asset provided concrete semantic specifications, preferably in the form of OWL or XML files. The goal of creating SAREF was to explicitly specify recurring core concepts, the relationships between these concepts, and mappings to other concepts used by different assets/standards/models in the smart appliances domain. The translation from SAREF to specific assets is allowed by mappings, thereby reducing the amount of translations between individual assets with 98 %. SAREF was created using the fundamental principles of r*euse and alignment* of concepts and relationships defined in existing assets, *modularity* to allow separation and recombination of different parts of the ontology depending on specific needs, e*xtensibility* to allow further growth of the ontology, and *maintainability* to facilitate the process of identifying and correcting defects, accommodate new requirements, and cope with changes in (parts of) the ontology.

From our experiences regarding the involvement of the practitioners in the creation process of SAREF, we conclude that there was a gap between the conceptual thinking of the scientific researchers and the more practical point of view of the industry. A key factor of success in our study was to gradually introduce the new concept, explain it in simple terms, make extensive use of examples and be receptive to the feedback from the engineers. Compromises needed to be made depending on the context and the domain under consideration. Another key factor of success was to take an interactive and iterative approach in the creation of SAREF, characterized by the early involvement of the stakeholders. Although this created a lot of overhead work, this guaranteed a higher practical quality of the outcome, reflecting the wishes and intentions of the community in an optimal way, and above all creating the necessary trust into our work, increasing the likelihood of a strong acceptance of the results.

We finally conclude that the support of tools for automatic translation and matching is definitely beneficial, but still may need a significant amount of human intervention. These tasks would probably be best performed with the combined use of automatic tools and manual work. However, this should be thoroughly assessed depending on the study and its context, the type and number of models under consideration, and the amount of time and resources available. In our case it turned out to be more effective to create the RDF/OWL representations of the assets by manual extraction of the semantics from the natural language descriptions and class diagrams (or XSDs) provided.

**Acknowledgments.** This work has been partly funded by the European Commission under contract number 30-CE-0610154/00-11.

## References

1. Mertens, R., et al.: Manual for Statistics on Energy Consumption in Households. Publications Office of the European Union, Luxembourg (2013)
2. den Hartog, F.: Consumer Networking Standardization: Trends and Research Opportunities, IEEE Webcast Tutorial. IEEE, New York (2011)
3. Starsinic, M.: System architecture challenges in the home M2M network. In: Proceedings of Applications and Technology Conference (LISAT), 2010 Long Island Systems, pp. 1–7, May 2010
4. Kim, S.H., Kang, J.S., Park, H.S., Kim, D., Kim, Y.-J.: UPnP-ZigBee internetworking architecture mirroring a multi-hop ZigBee network topology. IEEE Trans. Consum. Electron. **55**, 1286–1294 (2009)
5. Delphinanto, A., et al: architecture of a bi-directional bluetooth-UPnP Proxy. In: Proceedings of the 4th IEEE Consumer Communications and Networking Conference, pp. 34–38, January 2007
6. Segovia, R., (ed.): ICT for a low carbon economy, eeBuilding data models, energy efficiency vocabularies & ontologies. In: Proceedings of the 4th Workshop organised by the EEB Data Models Community ICT for Sustainable Places, Nice, France, 9th-11th September, 2013, Brussels: European Commission (2014)
7. Granzer, W., Kastner, W.: Information modeling in heterogeneous building automation systems. In: Proceedings of the 9th IEEE International Workshop on Factory Communication Systems (WFCS), pp. 291–300. Lemgo, 21–24 May 2012

8. den Hartog, F., Daniele, L., Roes, J.: Toward semantic interoperability of energy using and producing appliances in residential environments. In: 12th Annual IEEE Consumer Communications and Networking Conference (CCNC 2015), Las Vegas, USA, pp. 162–167. IEEE Press (2015)
9. Daniele, L., den Hartog, F., Roes, J.: Study on semantic assets for smart appliances interoperability, D-S4 final report. European Commission, Brussels (2015)
10. ETSI TS 102 690 v2.1.1, Machine-to-Machine communications (M2M); Functional architecture, ETSI (2013)