1. Session: Title of the session

1.1. Shared Vocabularies to Support the Creation of Energy Urban Systems Models

L. Madrazo	RAMON LLULL UNIVERSITY (ARC ENGINEERING AND ARCHITECTURE LA SALLE), SPAIN	madrazo@salleurl.edu
G. Nemirovski	ALBSTADT-SIGMARINGEN UNIVERSITY (FACULTY OF BUSINESS AND COMPUTER SCIENCE), GERMANY	nemirovskij@hs-albsig.de
A. Sicilia	RAMON LLULL UNIVERSITY (ARC ENGINEERING AND ARCHITECTURE LA SALLE), SPAIN	sicilia@salleurl.edu

Abstract

The problem of carbon emission reduction in urban areas cannot be constrained to a particular geographical area or scale, nor is it the concern of a particular discipline or expert: it is a systemic problem which involves multiple scales and domains and the collaboration of experts from various fields. The aim of models of urban energy systems is to identify the processes that determine the energy intensity in a specific urban area. Such models can help experts to understand the systems' behaviour and take measures to improve its performance. The application of semantic technologies can help to create urban energy models which integrate the knowledge from experts in various domains. The goal of the SEMANCO research project is to create a comprehensive framework –i.e. methods and tools– using semantic technologies which enable experts from different domains to devise and deploy urban energy models that help various stakeholders –planners, consultants, policy makers– to understand the complexity underlying carbon reduction in urban areas. A key component of the project is the Semantic Energy Information Framework (SEIF) which facilitates the link between the tools which are intrinsic to an energy model and the required data. This paper describes the process and results obtained in the development of this semantic framework. In particular, the paper discusses the creation of its underlying ontology, that is, the vocabulary shared by different domain experts which is necessary to access the contents of the different data sources required by an energy model. The configuration of the urban energy models and the access to the semantic data and the tools that characterise them take place through the SEMANCO integrated platform. Therefore, the current state of the development of this platform is also presented in the paper.

Key words

Semantic technologies, ontologies, urban energy systems, urban energy models

1 Urban energy systems and energy models

Urban energy systems have been defined as “the combined process of acquiring and using energy to satisfy the demands of a given urban area” (Keirstead and Shah, 2013, p.273), whereas an energy system model is “a formal system that represents the combined processes of acquiring and using energy to satisfy the energy service demands of a given urban area” (Keirstead et al., 2012, p.6). A model of an urban energy system fulfils two main purposes: to understand the current state of the system and to help to take decisions to influence its future evolution (Shah, 2013). An urban energy model is expected to provide answers to questions formulated by actors involved in the improvement of the urban energy system’s efficiency. For example, it should enable those actors to address questions such as how much energy is consumed in an urban area, what is that energy used for, how can that consumption be reduced and what are the connections between urban density and energy demand.

A model, according to the definition of Echenique (1972, p.164) is “a representation of a reality, in which the representation is made by the expression of certain relevant characteristics of the observed reality and where reality consists of the objects or systems that exist, have existed or may exist”. Such ‘representation’ is built with a set of abstractions that is, with the methods, data and tools that make the theoretical framework of the model. These capture the internal structure and the dynamics of a system as perceived by the observers. In the case of urban energy models, a multiplicity of these abstractions comes into play, in so far as there are multiple experts and knowledge domains involved in understanding how an urban energy system works. These include experts in energy supply and demand, in transportation networks, in building stock evaluation, in socioeconomic analysis and in environmental policy-making. The multiple models built from the particular point of view of the different observers need to be integrated to create urban energy models which span across various disciplines (Shah, 2013).

One inherent difficulty with urban energy models is the delimitation of the boundaries of the energy systems they represent. As Steinberg and Weisz (2013) have contended, the limits of an energy system can be established in two ways: adopting a ‘production’ perspective, by considering fixed geographical limits based on physical or administrative territorial divisions or, from a ‘consumption’ perspective, by establishing unfixed limits which take into account economic exchanges linked to energy use. As these authors argue, the answers to questions which can be informed by a model –for instance, how much energy a type of building consumes in a city –depend on the limits of the system. Urban energy assessments, therefore, need to include an explicit definition of the systems’ boundary since “arbitrary, or ill-defined, system boundaries defy the very purpose of urban energy assessments: to guide public and private sector policies and decisions and to allow comparability and credibility of the entire process” (Steinberg and Weisz, 2013, p.54).

Ultimately, the value of a model relies on the availability and reliability of the data with which the model operates. Energy related information is dispersed in numerous databases and open data sources and it might have different levels of quality. It is also continuously changing, since urban energy systems are dynamic entities in continuous transformation. Moreover, the information which is required by integrated urban energy models is heterogeneous since it is generated by different applications in various domains. The effectiveness of an energy model depends on having access to the data required for a particular purpose (for example, to compare alternative solutions to reduce energy consumption in an urban area) and on assuring the reliability of the data which is handled by the model, the input data as well as the output data.

2. Semantic technologies and urban energy models

The application of semantic technologies can help to overcome some of the difficulties which are intrinsic to the development of urban energy systems models, in particular those concerning the integration of multiple domains and the accessibility to the data. Ontologies can be used to create shared vocabularies which help experts from different fields to establish relationships between certain objects of an urban energy system according to their knowledge and experience. An ontology, as formulated by Gruber (1992), stands for “a description (like a formal specification of a program) of the concepts and relationships that can exist for an agent or a community of agents”. Considering this definition, an ontology can be thought of as collectively constructed knowledge that various experts have about an urban energy system. In fact, building a common vocabulary is itself, a knowledge construction process by which the knowledge that the different domain experts have on the issue at stake is made explicit and formal. At this point, there is a fundamental distinction to be made with previous concepts of urban energy models. An urban energy model supported by ontologies built by a group of experts is not just an abstraction of a complex system (e.g. an isomorphism of the system’s structure) but it stands for a way of thinking from multiple perspectives about a complex problem which is embodied in the ontology. In other words, a model is not a representation of a simplified reality, but a representation of a complex reality as conceptualised by experts and formalised in the ontology.

Ontologies can serve to foster communication between the semantically modelled data and the various software applications used by experts. The connections between tools and the data they handle can be captured by the ontologies. This way, when a tool is used within a particular energy model, the data which the tool needs as input can be retrieved via ontologies (in the case of SEMANCO, this function is fulfilled by the Semantic Energy Information Framework). This makes it possible to create multiple urban energy models of an urban energy system, each one with its own set of tools and associated data. This way, semantic technologies can facilitate the interoperability between the semantically modelled data and the variety of tools with which an urban energy model operates.

In the SEMANCO project, semantic technologies are used to create a comprehensive framework which supports the creation –collaboratively and over time– of urban energy systems models. These models represent the combined knowledge of the different experts involved in the evaluation and planning of the system. This framework includes procedures to build an ontology model (i.e. shared vocabularies) and a multiuser platform. The latter enables different users (planners, consultants, policy makers) to create urban energy models and to develop and assess different scenarios to improve the performance of the urban energy system.

3 Using ontologies to model experts’ knowledge

Ontology design is a process by which the knowledge that experts, from one or numerous domains, have is made explicit. In the case of energy urban systems, different experts –planners, consultants, policy makers– know about a particular part of the overall system. Their knowledge is determined by the tools and methods in their particular disciplines, by their experience, and by the information they have at any given moment.

Typically, the knowledge of experts arises as they are confronted with the solution to specific problems. To make this knowledge explicit so that it can be formalised as ontologies, a use case methodology has been applied in three cases studies: Manresa (Spain), Copenhagen (Denmark) and Newcastle (United Kingdom).

Within the SEMANCO project, a case study refers to the delimitation of research scope to a geographic location and to the factors that influence the problem of carbon reduction in a particular urban area. That is, to the stakeholders involved the planning issues at stake and the energy policy agenda (Madrazo, 2012). A use case, on the other hand, is a framework which encapsulates data, tools and users and the interactions between them in to fulfil a specific goal within an urban energy system (for instance, reducing carbon emissions at the district level). A use case, therefore, stands for a pre-conceptualization of a model which represents an urban energy system, as thought by experts within a particular context (Figure 1).

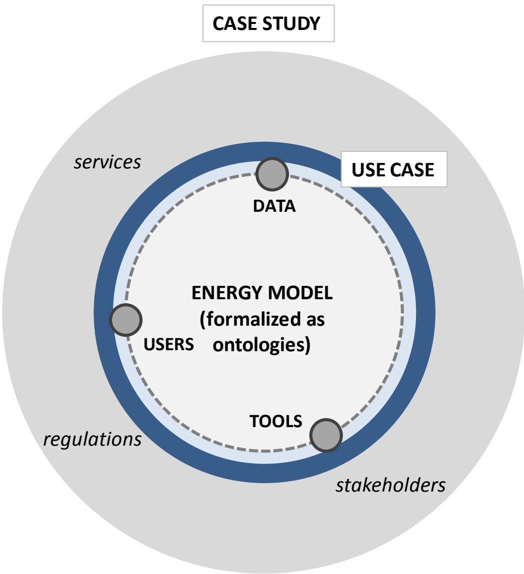

Figure 1. A use case as a pre-conceptualization of the energy model within the context of a case study

To solve the complex problem described by a use case, a series of discrete actions –called *activities*, in the language of the project– need to be undertaken (Figure 2).

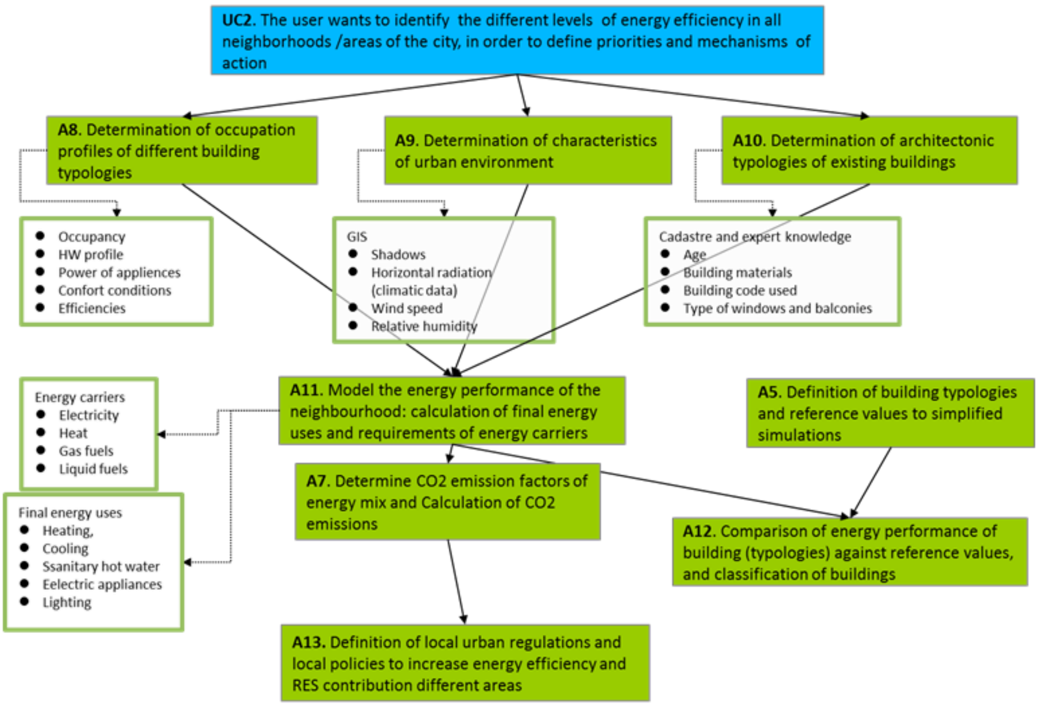

Figure 2. An example of a use case, its activities and the data associated to them.

Use cases and activities defined in this way give rise to a network by which the same activities can be shared by different use cases (Figure 3).

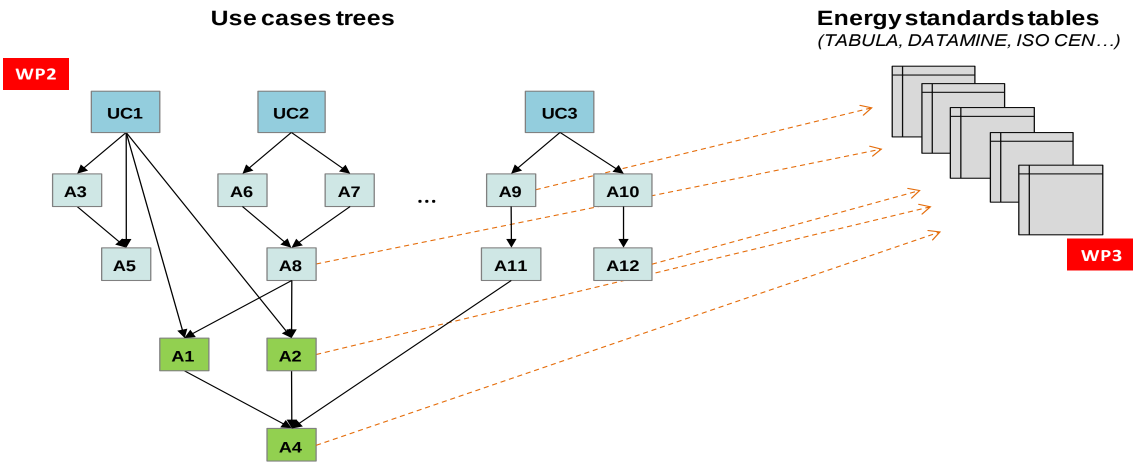

Figure3. Network of activities connected to different use cases

In SEMANCO, use cases and activities are defined by means of templates (Figures 4 and 5) which were specifically created for this purpose. The terms and units of measurement used in the templates are derived from international standards and/or established by the research community. The templates provide enough detail for experts to define a specific issue, while the use of terms based on standards assures that the contents can be transformed into the ontology. Therefore, use cases and activities defined by means of templates are the first step in the construction of a shared vocabulary which can then be formalised as an ontology.

Acronym	UC10
Goal	To calculate the energy consumption, CO2 emissions, costs and /or socio-economic benefits of an urban plan for a new or existing development.
Super-use case	None
Sub-use caseUC9	
Work process	Planning
Users	1. Municipal technical planners 2. Public companies providing social housing providers 3. Policy Makers
Actors	4. Neighbour's association or individual neighbours: this goal is important for them to know the environmental and socio-economic implications of the different possibilities in the district or environment, mainly in refurbishment projects. They use to ask these questions to the municipality 5. Mayor and municipal councillors: In order to evaluate CO2 emissions impact of different local regulations or taxes
Related national/local policy framework	6. Sustainable energy action plan (Covenant of Mayors) 7. Local urban regulations (PGOUM, PERI, PE in Spain) 8. Technical code of edification and national energy code (CTE, Calener in Spain)
Activities	9. A1.- Define different alternatives for urban planning and local regulations 10. A2.- Define systems and occupation (socio-economic) parameters for each alternative 11. A3. Determine the characteristics of the urban environment 12. A4. Determine the architectural characteristics of the buildings in the urban plans 13. A5. Model or measure the energy performance of the neighbourhood 14. A6. Calculate CO2 emissions and energy savings for each proposed intervention 15. A7. Calculate investment and maintenance costs for each proposed intervention

Figure 4. Template to define a use case

Acronym	A1
Super-activity/use case	UC10
Sub-activities	A2, A3, A4
Goal	Define different alternatives for urban planning and local regulations
Urban Scale	Micro-Meso
Users	1. The municipality (councilors of urban planning, housing, environment and countryside, …) (stakeholder) 2. Urban planners 3. Public company of social housing 4. Owner/promoter of the building (stakeholder) 5. Neighbor's association (stakeholder) 6. Consultants and technicians from Engineering and consultancy companies 7. Supply companies (i.e. supply company of district heating)
Related national/local policy framework	▪ Sustainable energy action plan (SEP from Covenant of Mayors) ▪ Local regulations 8. National energy codes (Código Técnico and certificación energética in Spain, DECC 2012 and HECA in UK, and Heat Planning Act, and danish Planning regulation in Denmark)
Issues to be addressed	1. To define the comparison of different CO2 emissions scenarios of urban planning, according to local energy requirements acts and/or Plans, in order to select the most efficient urban planning alternative in next steps. 2. To select a set of technologies, and local regulation in order to evaluate their CO2 impact ▪ To select different scenarios to evaluate the socio-economic impact of different measures ▪ To define alternative building performance levels in order to calculate scenarios of improvement of energy efficiency

Input Data			
Name	**Description**	**Domain**	**Format**
Local regulations and requirements	Local regulations related to Energy Efficiency, RES, and CO2 emissions, as well as Local Urban regulation that can affect to de different proposals to implement	Energy efficiency Urban planning	Maps, and technical requirements
List of objectives from different users	List of scenarios of energy performance, energy supply, and/or urban planning	Energy efficiency Urban planning	Documents

Figure 5. Template to define an activity within a use

case

Activities templates include references to the data sources required to perform the activities, as well as specifications of the tools and the data required. Altogether, the information collected through the use case and activities templates, in each case study, provide the specifications required to develop the semantic energy framework and the tools associated to it (Figure 6).

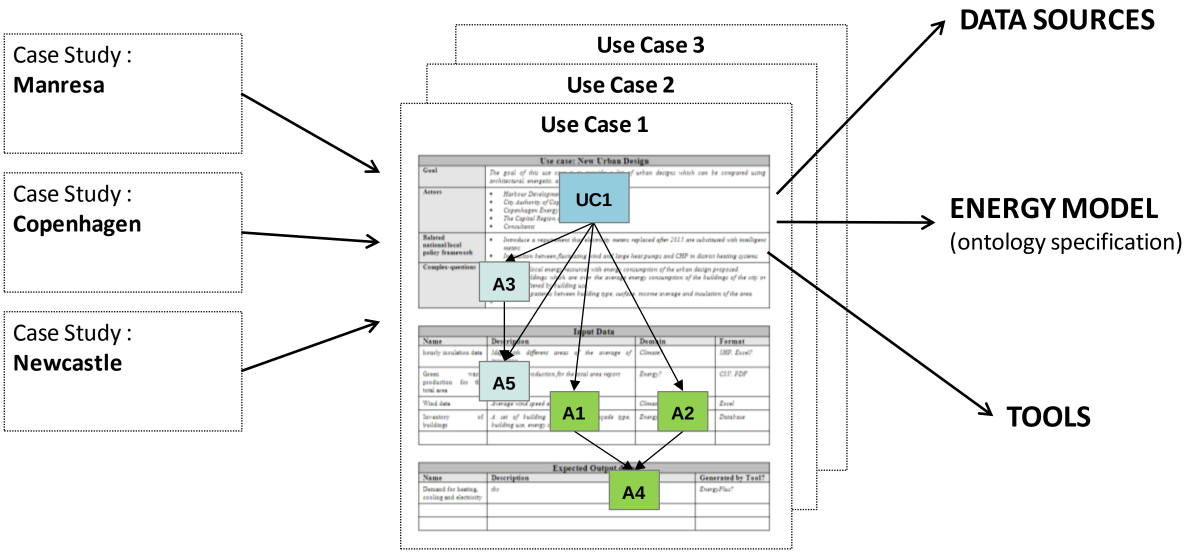

Figure 6. Use cases as links between case studies and the technological development of the project

4 Semantic Energy Information Framework (SEIF)

The Semantic Energy Information Framework (SEIF), developed in SEMANCO, is the nexus between the distributed data sources and the tools using the semantically modelled data (Figure 7). The access to the tools takes place via an integrated platform, which provides services for different types of user.

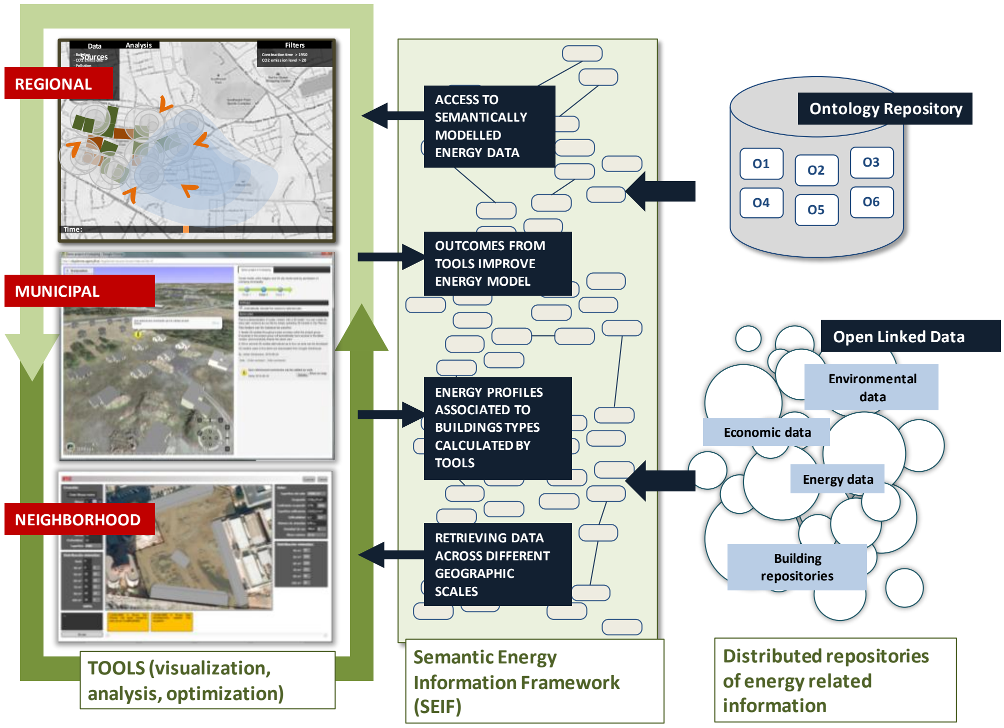

Figure 7. SEIF as a bridge between data and tools

The SEIF has three main goals:

- Integrating proprietary data which is presently off-line or/and heterogeneously structured into a consistent knowledge base, making the data accessible for information discovery and retrieval purposes.
- Providing a bridge between different domains (city planning and energy provision) and contents (consumption data, pollution sources, simulated energy profiles and benchmarks).
- Gathering outputs generated by the tools developed in the project –tools for design evaluation and energy simulation, visualisation and modelling at urban scale, and analysis and optimisation processes– in order to create a distributed knowledge base.

4.1 The ontology building process: creating a semantic energy model

The process of creating an ontology requires a methodological approach to avoid redundant work, to reduce design errors, and to be replicable in other contexts. Generic processes are described by Gruber (1995) and Uschold and King (1995) assuming that ontology design will follow the same process as software development: identification of the requirements, development, evaluation and documentation. This approach is further elaborated by Fernandes, Guizzardi and Guizzardi (2011). A survey of methodologies for ontological design can be found in Fernández-López (1999). However, these methodologies mostly focus on modelling the conceptualisation of a specific domain, rather than on the integration of data sources in ways that support querying using federated access. Besides, it can be argued that a methodology per se is not enough. Rather, it should be supported by design patterns, document templates, tools or platforms which guide developers along the process. Since no methodological approach takes into account the integration of data sources and their querying using federated access, it has been necessary to develop an ontology design process (Nemirovski, Nolle, Sicilia, Ballarini and Corrado, 2013).

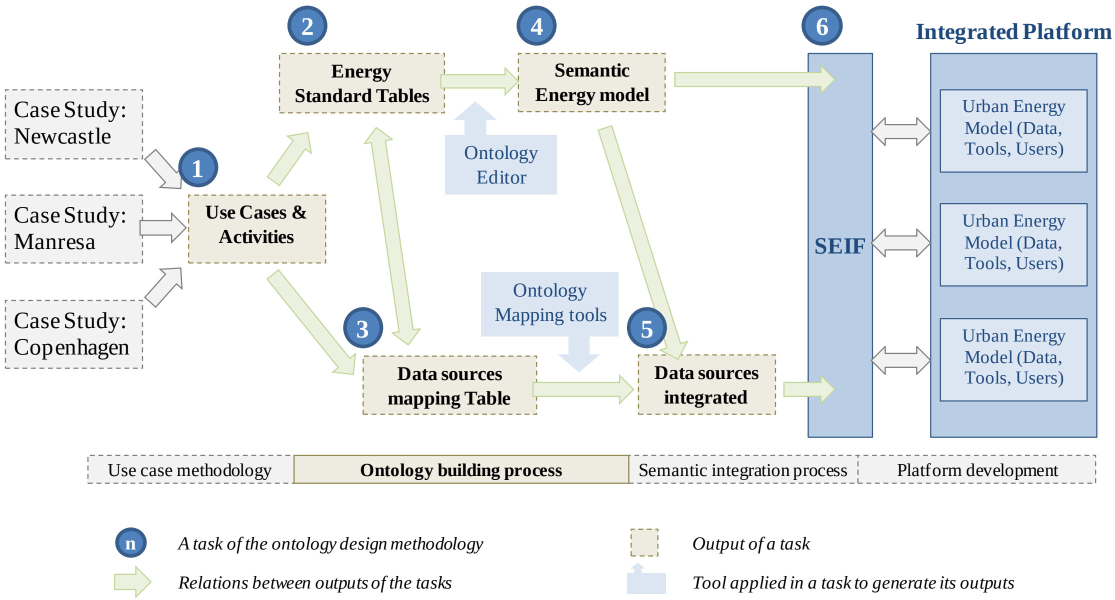

Figure 8. The processes and methods employed to build the SEIF

The methods and processes followed to create the SEIF are summarised in Figure 8. It starts with a description of use cases and activities –according to the use case methodology– from which energy standard tables containing the terms and definitions of the vocabulary which are then transformed into an ontology. In parallel, the data sources are identified and the contents mapped to the terms of the energy standard tables. Finally, the ontology is mapped to the data sources to transform them into Resource Description Framework (RDF) data. Both the semantic energy model (a model of the urban energy system represented as global ontology) and the RDF data sources make the SEIF.

The goal of the process outlined above is twofold: to design a semantic energy model as a formal ontology and to integrate data sources by reorganising them according to the ontology structure. The resulting semantic energy model is a formal global ontology embracing the terminology and relations needed to integrate the data sources and query them in a unified way. This way, the semantic integration process converts the data sources to RDF in accordance with the global ontology.

In the following sections the six main tasks involved in the ontology building process are explained and the outcomes achieved are described.

4.1.1 Vocabulary capture

The first task of the ontology design process is to capture the base terminology for the ontology, that is to say, to make the knowledge that domain experts have about the issues related to a use case explicit. By means of use cases, experts describe how actors, tools, and data relate to each other in order to fulfil a specific goal under a specific policy framework. The activities encompassed by a use case are described in form of requirements and competency questions following current approaches, such as the Neon methodology (Suárez-Figueroa et al., 2012). This way, the data sources required to carry out the activities are identified and briefly described.

The output of the process of vocabulary capture is 14 use cases and 44 activities defined through templates. The actors considered in the use cases encompass social housing providers, city councils, building owners and energy consultants. The policy frameworks considered are local urban regulations, Covenant of Mayors, national building codes, UK Fuel Poverty Strategy among others. The activities deal with a wide range of issues examples include the identification of areas with high instances of fuel poverty the calculation of the potential of local solar gains, and the calculation of the CO_2 emissions of buildings and urban areas.

4.1.2 Building an initial vocabulary

In the second task, the use cases and activity specifications are analysed with the goal of defining an initial vocabulary. This is a categorised set of terms connected by simple relations such as subsumption (is) and aggregation (has). To build the initially vocabulary it is necessary to identify the data categories, to scrutinise the existing international standards for energy modelling and to create energy standard tables, which are a set of semantically structured terms, including objects, attributes and standard definitions.

The data categories are divided in two major groups: 1. those which concern data on energy systems, energy quantities and boundary conditions, and 2. those concerning contextual data. The first group contains the categories of energy data (e.g. CO_2 emission coefficient, CO_2 emissions, delivered energy, energy demand, energy supply etc.), climatic data (e.g. air temperature, solar irradiance, wind speed, relative humidity etc.), and building technical data (e.g. space heating systems, energy generator, mechanical ventilations, type of walls etc.). Contextual data includes energy costs (e.g. running costs and refurbishment costs), environmental data (e.g. air pollutants and air quality), legislative constrains such as energy performance requirements, geographical and land registry data (e.g. land lots, land value, land classification, etc.), socio-economic and demographic data (e.g. gender, level of education, tenure, income etc.).

The resulting vocabulary requires a common and shared terminology. With this purpose, international technical standards, research projects, and European directives were consulted to obtain the definitions of the terms, the relations between concepts and the symbols and units of the quantities.

The initial vocabulary is specified in the form of an energy standard table. Each category in this table contains numerous terms identified by the various activities. The initial vocabulary contains the description of the terms, and the relations between terms and, in this regard, it can be equated with a formal ontology specification.

Building an initial vocabulary is an important intermediate step towards the design of a semantic energy model. It simplifies formal ontology coding significantly by using a formal language, such as OWL. This task was carried out following the methodology for structuring and semantically modelling energy and contextual data developed in the SEMANCO project (Corrado and Ballarini, 2012, 2013).

The initial vocabulary is composed of 24 categories including building use, climate and building geometry. Around 1000 terms were collected including; descriptions, references, units, and type of data. 18 standards (e.g. ISO/IEC CD 13273-1[1], ISO/IEC CD 13273-2[2], EN 15603[3] and the EN ISO 15927-1[4]) and 16 references (e.g. research project, public recommendations, European directives) were used to create the energy standard tables.

4.1.3 Mapping data sources to vocabularies

The goal of the third task is to map the data entities of the data sources –identified in the activities of the use cases– to the initial vocabulary. If a target data source is a relational database, then the fields of their tables are mapped to the terms of the initial vocabulary. The mappings are specified by data owners and domain experts using a table template. For example, Table 1 shows the mappings of the Manresa census data source.

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[1]ISO/IEC CD 13273-1:2012. Energy efficiency and renewable energy sources. Common international terminology. Part 1: Energy Efficiency.
[2]ISO/IEC CD 13273-2:2012. Energy efficiency and renewable energy sources. Common international terminology. Part 2: Renewable Energy Sources.
[3]EN 15603:2008. Energy performance of buildings - Overall energy use and definition of energy ratings..
[4]EN ISO 15927-1:2002. Hygrothermal performance of buildings. Calculation and presentation of climatic data. Part 1: Monthly and annual means of single meteorological elements.

Data source	Data name (in the Data source)	Data name (in the vocabulary)	Data category (in the vocabulary)
Manresa census	ID	Building	Building
Manresa census	NUMCOD	Address	Building
Manresa census	DOMCOD	Address	Building
Manresa census	ADRDESC	Address	Building
Manresa census	TITULACIO	Education_Level	Housing
Manresa census	SEXE	Household_Type	Housing

Table 1. An activity description

As illustrated in Table 1, the term 'Address' contains in the initial vocabulary it is mapped to the terms NUMCOD, DOMCOD and ADRDESC from the targeted data source. This information is used as an input for the fifth task -Mapping data sources- explained later. Unfortunately, not all of the terms contained in the data sources can be univocally mapped to the initial vocabulary, so it is necessary that an ontology expert deals with some of the less evident mappings. In these cases, ontology experts have three alternatives: to modify/extend the initial vocabulary (which is the most often selected choice); to implement non-trivial mapping preferences; or to specify complex queries.

Nine different data sources have been mapped to the initial vocabulary including census and cadastre records, building typologies, neighbourhoods, energy coefficients among others. In total, more than 60 mappings are established between the data entities of the data sources and the initial vocabulary.

4.1. 4 Ontology coding

The fourth task is focused on the codification of the semantic energy model, as a formal ontology based on the *DL-Lite*$_A$ formalism which outperforms most other description logic formalisms when managing data distributed in heterogeneously structured sources (Poggi et al., 2008). The coding of the semantic energy model is carried out by SEMANCO's ontology editor (Figure 9) described by Wolters, Nemirovski and Nolle (2013). This editor provides a user-friendly interface which facilitates the participation of domain experts in the ontology building process. Besides, the editor supports the coding of *DL-Lite*$_A$ axioms to represent domains and ranges of object properties which require the processing of reasoning. These two features are the main reasons for the development of a bespoke editor instead of using an existing one such as Protégé[5] or TopBraid Composer[6]. The SEMANCO ontology editor offers the user two simultaneous views of an ontology: one for editing the taxonomy of concepts, and another one for editing the graph of non-subsumption relations.

[5] http://protege.stanford.edu
[6] http://www.topquadrant.com/products/TB_Composer.html

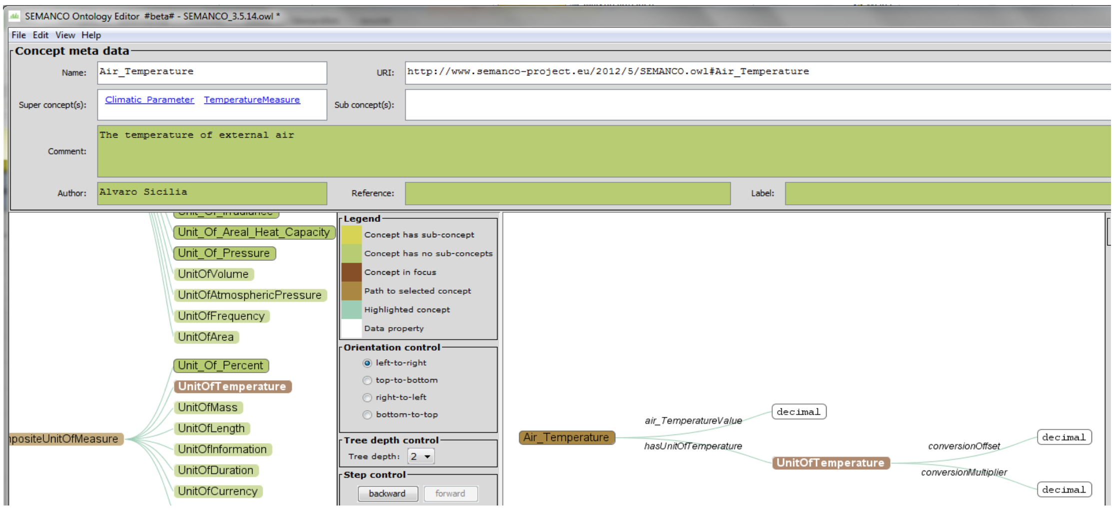

Figure 9. SEMANCO's ontology editor (© Albstadt-Sigmaringen University)

Annotations are key components of an ontology, which enable users to understand its structure and the criteria adopted in their conceptualisation. The ontology editor enables users to define four types of annotation properties for each concept; label, comment, reference and author. The values of the annotation properties are taken directly from the energy standard tables; such as the name, the description and the reference.

Following a modular approach to ontology design, the semantic energy model is built with modules of the Suggested Upper Merged Ontology (SUMO). In this way, each concept of the semantic energy model is subsumed at least by one concept of SUMO. SUMO was selected, rather than DOLCE, PROTON, General Formal Ontology (GFO), and Basic Formal Ontology (BFO) because of its simplicity of understanding, applicability for reasoning and inference purposes, the ability to apply units of measurement to data, and the number of concepts it contains related to the urban planning domain.

The outcome of this task is the creation of a global ontology based on the SUMO upper-ontology encompassing 592 concepts and 468 relations implemented with 3459 axioms in $\textit{DL-Lite}_A$ style.

4.1.5 Mapping data sources

The aim of this task is to apply the informal mappings produced in the previous task to transform the contents of the data sources into RDF resources. After coding the mappings, using a formal language of a dedicated middleware, the data stored in relational databases becomes available for SPARQL querying in terms of the target global ontology.

These mappings are implemented with declarative mapping languages, which offer rich expressive features helping to adjust rigid relational schemas to real cases. In SEMANCO for D2RQ (Bizer and Cyganiak, 2007) was selected. It is supported by the D2R server, a mature and stable lightweight middleware. Nevertheless, other software products, such as Quest (Rodriguez-Muro and Calvanese, 2012) using standard mapping language R2RML are also being tested.

The creation of such mappings is a complex process, which involves experts from different domains with different skills. The process requires them to understand both the structure of the ontology and the data sources. To support their work, two environments were developed using D2RQ and R2RML language. The OWL mapping extractor to extract an OWL ontology file and a D2RQ mapping file from the structure of a relational database, and the ontology mapping collaborative web environment that provides a graphical interface to assist non- ontology experts to implement the mappings (Figure 10).

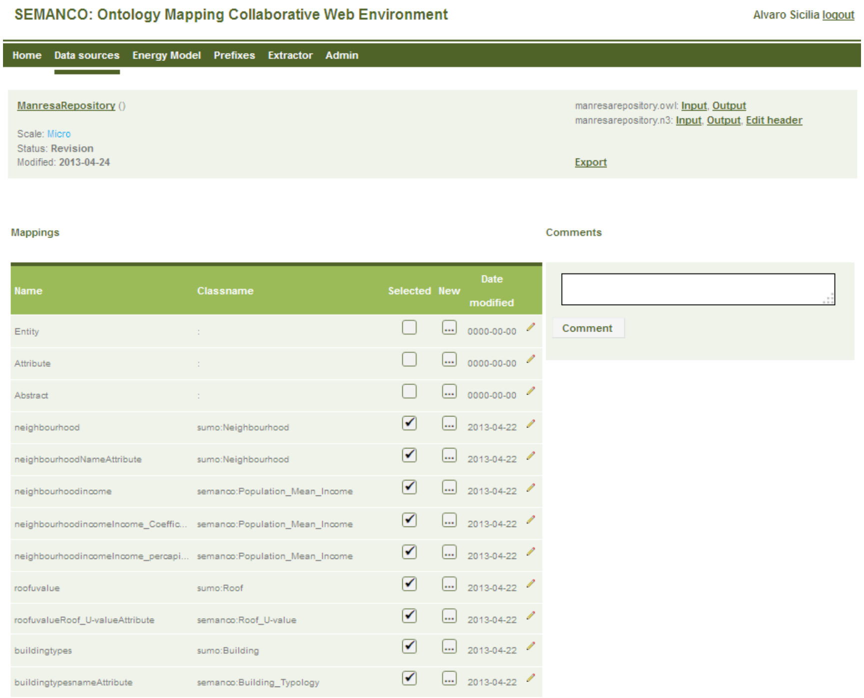

Figure 10. Ontology mapping environment with the mappings created for the Manresa database (© ARC Engineering and Architecture La Salle)

Typically, 90% of these mappings are automatically generated by the ontology mapping environment, while the remaining 10% are coded manually because they are too different to the general cases.

As a result of this task, 9 data sources have been semantically integrated using more than 400 mappings automatically generated by the ontology mapping tool. More than 3 million RDF triples have been generated.

4.1.6 Evaluation

In this task the quality of the ontology created in the previous stages of the process is evaluated. In particular, three properties have been evaluated: intelligibility that is the ability of experts that use the ontology to understand the ontology structure; mapping compliance ensuring the complete correspondence of the mapping with the ontology; and computational efficiency regarding the ability of the ontology to support conjunctive querying on high efficiency level, for example, with a comparatively short response time.

The intelligibility test was carried out at the early stages of the ontology development, with two independent groups of users: a group of computer science students and another made up of experts in the field of building energy. The positive scores obtained in the test were 97.30% for computer science students and 91.20% for domain experts.

5 Integrated Platform

The SEMANCO integrated platform is the front-end for users, with different profiles, to interact with the semantic data using the tools associated to a model of an urban energy system. The open structure of the platform enables an urban energy model to be enhanced when new tools and data –either from existing data sources or from the data generated by the different applications– become available.

In the integrated platform, both the experts' knowledge, captured through the use case methodology (use case and activities templates), as well as the links to the external data sources are available through the SEIF (Figure 11). This combination of knowledge and information constitutes the base for creating energy models for a particular urban area.

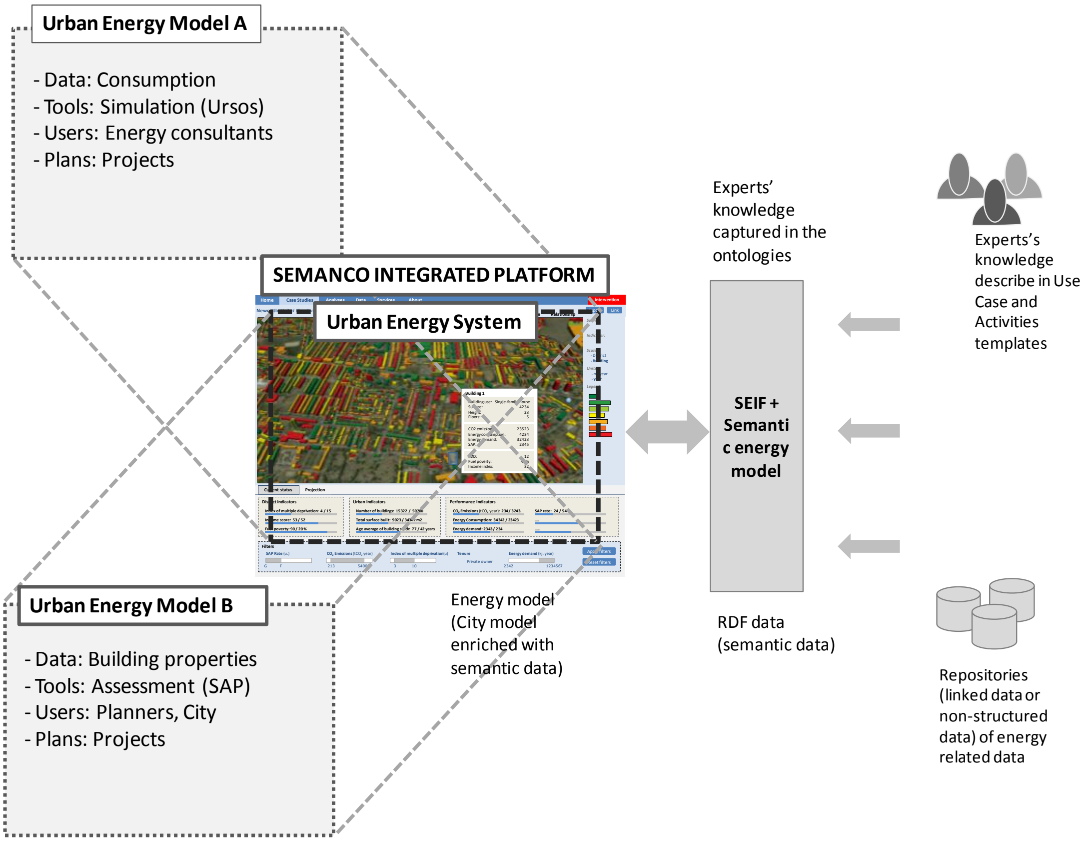

Figure 11. Different models providing partial views of the overall urban energy system

Urban energy models are constructed in an asynchronous manner by adding energy related information to a geometric model created with the 3dMaps software of Agency9 (a project partner). For this purpose, the platform provides different kinds of tools:

- Embedded; tools which are part of the platform and developed specifically for it.
- Interfaced; existing tools (e.g. simulation, assessment) which can interact with other tools and services in the platform.
- External; existing tools that can use data exported from the platform and generate data that can be imported to it.

Within a particular energy model domain experts can represent the existing conditions of the urban system (descriptive model), analyse the future evolution of the system (predictive model), explore different scenarios for future development (exploratory model) and propose improvement plans and evaluate projects to improve the performance of the urban energy system (planning model)[7] using multicriteria decision analyses tools[8].

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[7] These four types of models are identified in Echenique (1972).

[8] Yamaguchi and Shimoda (2010) provide an example of the application of a set of tools to analyse alternatives to improve energy performance in a district within a given energy model.

Figure 12. Integrated platform (© SEMANCO)

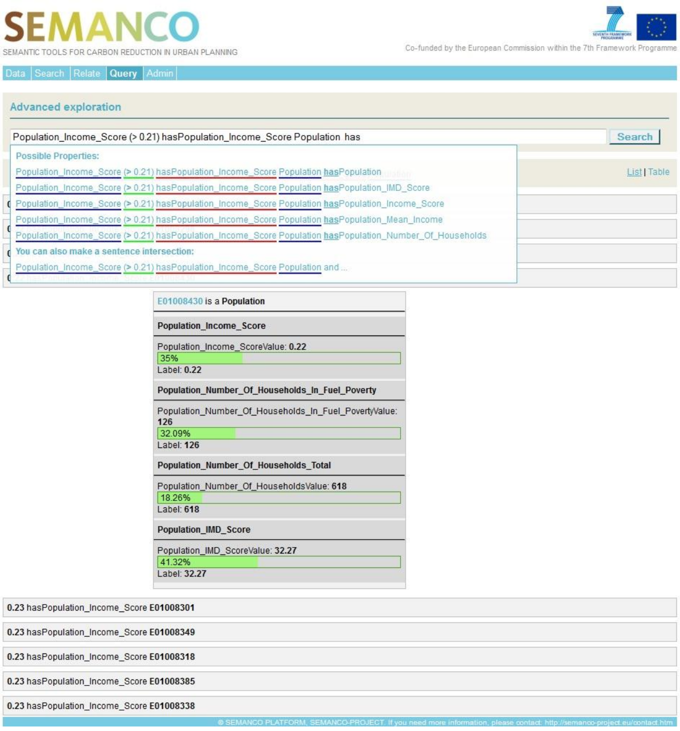

Figure 13. Semantic data explorer (© ARC Engineering and Architecture La Salle)

The platform has been designed to support services for four user groups:

- Domain experts. They collaborate in the construction of an energy model (e.g. describing use cases and activities, defining terms of the ontology), and/or they interact with the model (e.g. extracting reports, enriching the energy model with new data). They produce and evaluate alternative plans to improve the performance of the urban energy system, and they provide advanced data analyses services to other experts.

- Ontology engineers. They collaborate with domain experts in the maintenance and enhancement of the system's ontology. With this purpose, they use the tools developed for the project to create the energy model as a global ontology (Ontology Editor), to carry out the semantic integration process (Ontology mapping environments), and to verify the outputs of the process (Semantic data explorer).
- Platform developers. They assist experts in the integration of new tools and data in the platform.
- Non-experts. They interact with the platform –either by themselves or assisted by a domain expert– to visualize the energy data using different tools provided by the platform (3Dmodels, tables and diagrams), to extract the information they need and derive conclusions from it.

Once the project is completed, the integrated platform will provide a generic structure to support the development of services based on the exploitation of the semantic data and the tools interacting with them. Most important, it will be possible to incorporate into the platform additional energy systems from urban areas other than the three case study areas included in the SEMANCO project.

6 Conclusions

In the first two years of the SEMANCO project partners have devised and implemented a methodology to capture experts' knowledge –that is, the implicit knowledge, which experts possess that emerges as they are confronted with a particular problem concerning the performance of an urban energy system– with the purpose of creating a semantic framework to support decision making in energy efficient urban planning. This knowledge has been formalised as a global ontology created with the participation of domain experts and ontology engineers. As a result, a Semantic Energy Information Framework (SEIF) has been created, which provides access both to the experts' knowledge, captured by the terms and relations that form the ontology, and to information required by different energy models based on the ontology. A prototype of the integrated platform, which is currently being finalised, will facilitate access to the energy models for different types of users. Overtime, the use of the platform's services will support the addition of more energy related data, as well as enhancing the system's ontology with new terms and relations. SEMANCO's platform will provide a generic, flexible and open, structure that facilitates the continuous development of complex models of urban energy systems carried out with the participation of the different users and stakeholders.

The results of the SEMANCO project are therefore contributing to the development of integrated urban energy models which can help agents involved to improve the efficiency of urban energy systems by enabling a better understanding of the complexity of the issues involved. In this regard, the most relevant outputs of the project are not its end-products (e.g. the integrated platform and the various tools devised to build the ontologies) but rather, the comprehensive semantic framework which integrates energy accounting methods, energy related data, and energy assessment tools.

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8 References

1. Bizer, C. and Cyganiak, R. 2007. D2RQ – Lessons learned. Position paper at the W3C Workshop on RDF Access to Relational Databases, Cambridge, United Kingdom.

2. Corrado, V., and Ballarini, I. 2012. SEMANCO Deliverable 3.2: Guidelines for Structuring Energy Data. Accessed July 31, 2013 at website: http://semanco-project.eu/index_htm_files/SEMANCO_D3.2_20130121.pdf

3. Corrado, V., and Ballarini, I. 2013. SEMANCO Deliverable 3.3: Guidelines for Structuring Contextual Data. Accessed July 31, 2013 at website http://semanco-project.eu/index_htm_files/SEMANCO_D3.3_20130321.pdf

4. Echenique, M. H. 1972. Models: A discussion. In L. Martin and L. March (editors) Urban space and structures. London: Cambridge University Press.

5. Fernandes, B.C.B., Guizzardi, R.S.S. and Guizzardi, G. 2011. Using Goal Modelling to Capture Competency Questions in Ontology-based Systems. Journal of Information and Data Management, Vol. 2, No 3, pp. 527-540.

6. Fernández-López M. 1999. Overview of methodologies for building ontologies. In Proceedings of the IJCAI-99 workshop on ontologies and problem-solving methods: lessons learned and future trend, Stockholm, Sweden.

7. Gruber, T. R. 1992. A Translation Approach to Portable Ontology Specifications. Accessed July 31, 2013 at website http://www-ksl.stanford.edu/kst/what-is-an-ontology.html

8. Gruber, T. 1995. Towards principles for the design of ontologies used for knowledge sharing. In International Journal of Human Computer Studies, Vol. 43 (5-6), pp. 907-928.

9. Keirstead, J., Jennings, M., and Sivakumar, A. 2012. A review of urban energy system models: approaches, challenges and opportunities. Renewable and Sustainable Energy Reviews, 16(6), pp. 3847–3866. Accessed July 31, 2013 at website https://spiral.imperial.ac.uk/bitstream/10044/1/10206/4/review.pdf

10. Keirstead, J., and Shah, N. (editors). 2013. Urban Energy Systems: An Integrated Approach. Urban energy systems : an integrated approach. London: Routledge.

11. Madrazo, L. (editor) 2012. SEMANCO Deliverable 1.8: Project Methodology. Accessed July 31, 2013 at website http://semanco-project.eu/index_htm_files/SEMANCO_D1.8_20120921.pdf

12. Nemirovski G., Nolle A., Sicilia Á., Ballarini I., and Corrado V.2013. Data Integration Driven Ontology Design, Case Study Smart City. The Semantic Smart City Workshop (SemCity-13), Madrid, Spain.

13. Poggi, A., Lembo, D., Calvanese, D, De Giacomo, G. Lenzerini, M and Rosati, R. 2008. Linking data to ontologies. Journal on Data Semantics, pp. 133–173.

14. Rodríguez-Muro, M. and Calvanese, D. 2012. High Performance Query Answering over DL-Lite Ontologies. In Proceedings of 13th International Conference on Principles of Knowledge Representation and Reasoning (KR 2012), pp. 308-318.

15. Shah, N. 2013. Modelling urban energy systems. In J. Keirstead and N. Shah (eds.) Urban Energy Systems. An Integrated Approach. London and New York: Routledge.

16. Steinberger, J. and Weisz, N. 2013. City walls and urban hinterlands: the importance of system boundaries. In A. Grubler and D. Fisk (editors) Energizing Sustainable Cities. Assessing Urban Energy. London: Routledge.

17. Suárez-Figueroa, M.C., Gómez-Pérez, A., Motta, E. and Gangemi., A. 2012. Ontology Engineering in a Networked World. Berlin: Springer.

18. Uschold, M. and King, M. 1995. Towards methodology for building ontologies. Workshop on Basic Ontological Issues in Knowledge Sharing, held in conjunction with IJCAI-95, Cambridge, United Kingdom.

19. Wolters, M. Nemirovski G, and Nolle, A. 2013. ClickOnA: An Editor for DL-LiteA based Ontology Design. 26th International Workshop on Description Logics. Ulm, Germany.

20. Yamaguchi, Y. and Shimoda, Y. 2010. District-scale simulation for multi-purpose evaluation of urban energy systems. Journal of Building Performance Simulation, Vol. 3, Issue 4.