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# Sustainable Design of Buildings using Semantic BIM and Semantic Web Services

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**Abstract**

In response to the growing concerns about climate change and the environment, sustainable design of buildings is increasingly demanded by building owners and users. However, fast evaluation of various design options and identification of the optimized design requires application of design analysis tools such as energy modeling, daylight simulations, and natural ventilation analysis software. Energy analysis requires access to distributed sources of information such as building element material properties provided by designers, mechanical equipment information provided by equipment manufacturers, weather data provided by weather reporting agencies, and energy cost data from energy providers. Gathering energy related information from different sources and inputting the information to an energy analysis application is a time consuming process. This causes delays and increases the time for comparing different design alternatives. This paper discusses how Semantic Web technology can facilitate information collection from several sources for energy analysis. Semantic Web enables sharing, accessing, and combining information over the Internet in a machine process-able format. This would free building designers to concentrate on building design optimization rather than spending time on data preparation and manual entry into energy analysis applications.


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*Keywords:* Semantic BIM, Semantic Web Services, Sustainable Design, Energy Analysis.

## 1. Introduction


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The use of fossil fuels to produce the energy consumed in buildings has exerted a tremendous strain on the environment. Today, buildings are responsible for more than 40 percent of global energy used, and as much as one third of global greenhouse gas emissions, both in developed and developing countries (http://www.unep.org/sbci/pdfs/SBCI-BCCSummary.pdf). The large amount of energy used in buildings makes improvements in energy efficiency of buildings an important step for lowering carbon emission. Among the most important ways to improve building energy efficiency are [1] :

- Optimizing building's envelop, glazing and mechanical systems
- Proper building orientation and massing
- Optimized lighting and shading
- Use of passive solar and natural ventilation

In response to the growing concerns about climate change and the environment, sustainable design of buildings is increasingly demanded by building owners and users. However, fast evaluation of various design options and identification of the optimized design requires application of design analysis tools such as energy modeling, daylight simulations, and natural ventilation analysis software that require access to dispersed sources of data. The data obtained from various sources are often incompatible in terms of format. As a result, considerable time is necessary to assemble the data into a format that can be used by energy analysis programs.

This paper is based on the premise that disparate sources of data necessary for building energy analysis must be created using Semantic Web standards [2-4] and made available to energy analysis software as semantic web services [5] . Building energy analysis requires access to the building's geometry, material properties, mechanical equipment specifications, and climate information for the building location. This data must be available for automatic discovery and retrieval by building energy analysis applications. Semantic Web and Semantic Web Service technologies provide the information architecture for making large volumes of geographically dispersed data available to powerful computing resources, thus allowing the widespread automation of data access and analysis.

The objective of this paper is to present the architecture of a building energy analysis knowledge system that automates discovery and retrieval of energy related information. This would free building designers to concentrate on building design optimization rather than spending time on data preparation and manual entry into energy analysis applications.

## 2. Semantic technology and semantically defined building information

Semantic Web provides a network of connected data over the Internet that is machine process-able [6]. Semantic Web allows sharing information on the web [7] and drawing conclusions on data that are generated in other sources [8]. The graph data structure of Semantic Web enables applications used during design, construction, and service life of a building project to easily combine and connect geographically dispersed information related to the building [9,10].

In Semantic Web, ontologies are used to define the concepts and the relationships among the concepts in a domain [11]. A knowledge base is an information repository created based on an ontology for collecting, editing, and sharing information [12]. Computer applications that use semantically defined information must first import the ontologies that define the data and become aware of the organization of data. Semantic Web provides distributed knowledge based systems that can be easily integrated (http://www.obitko.com/tutorials/ontologies-semantic-web/ontologies.html).

Web service technology allows computer applications to communicate information over the Internet [13]. However, web services have a number of limitations: (1) they provide syntactic interoperability which requires data be transferred in a specific format, (2) interfaces of a web service must not change, otherwise, applications communicating with the service break, and (3) the content of a message exchanged with a web service cannot be interpreted by computers; this prevents any workflow automation. To add semantics to the content of a web service message, the content must be formally and explicitly conceptualized using ontologies.

To extend the capabilities of web services in the direction of dynamic interoperability, Semantic Web and web service technologies are combined to create Semantic Web Services. Semantic Web Service technology uses ontologies to semantically define web services [14]. This can automate service discovery, composition, and execution [15].

Researchers have investigated the application of Semantic Web technologies to building energy modeling. Kofler et al. [16] developed a smart home system that orchestrates all energy facilities in a home. The system uses a knowledge base of various energy parameters and facilities as well as energy providers in order to make energy efficient decisions on behalf of the home users. Kim et al. [17] developed a semantic material name matching system for automatically looking up building material property values and entering them into a building energy analysis application. In this paper, we present the results to date of an ongoing research on developing knowledge-based systems for expediting the evaluation of a building design for energy efficiency.

## 3. Semantics-based architecture for energy analysis

Energy analysis requires information from several sources including:

1. Building element properties such as element surface area, thickness, heat transfer coefficient, and thermal mass. In AEC domain, designers create a BIM and specify building element properties.
2. Mechanical equipment specifications such as capacity, type of fuel, and energy consumption. Equipment manufacturers maintain and provide such information.
3. Weather information at the building location. For energy analysis one can retrieve historical weather information from weather reporting agencies. Based on the elevation and distance of the building project to the closest weather station, a program can simulate weather conditions for the building project.
4. Energy cost information. Based on the type of energy required for mechanical equipment, one can retrieve energy cost information from energy providers.

Semantic Web technology allows various sources of information to be made available in a format that can be searched and retrieved over the Internet by energy analysis applications. Fig. 1 shows the architecture of an energy analysis application that we developed for accessing distributed sources of information over the Internet. As Fig. 1 shows, the information necessary for energy analysis must be semantically described and published as semantic web services. We represented the building model as a semantically defined knowledge base (BIM knowledge base) that can be queried over the Internet using SPARQL query language [4]. Web Ontology Language (OWL) is recommended by W3C [3]as the standard ontology language. We used OWL for creating the knowledge bases and OWL-S [5] to identify which services must be accessed, prepare input messages for those services, execute web services, and integrate data returned from the web services.

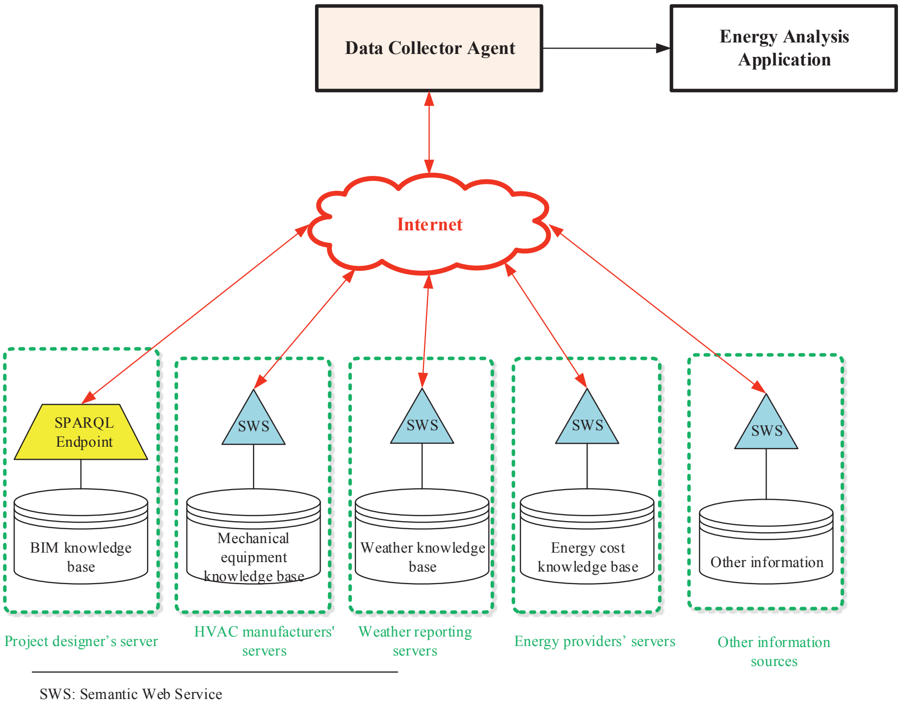


**Fig. 1. Energy related information exposed as semantic web services**

## 4. Semantically-defined BIM knowledge base

In this study, we created a BIM knowledge base in RDF/OWL format. Fig. 2 shows the process for creating this knowledge base. In an earlier study, we presented an ontology-based building information modeling approach [18]. In this study, we converted a BIM created using Autodesk Revit (http://usa.autodesk.com) to RDF/OWL format and saved it in an OpenRDF Sesame triplestore (http://www.openrdf.org). Sesame provides a SPARQL Endpoint interface for querying, adding and editing RDF information over the Internet. We used Appache Jena and Pellet Reasoner to enhance the knowledge base with reasoning power of description logic. An energy analysis application can directly access the SPARQL Endpoint interface of the knowledge base to query for BIM element properties such as geometric dimensions and material properties.

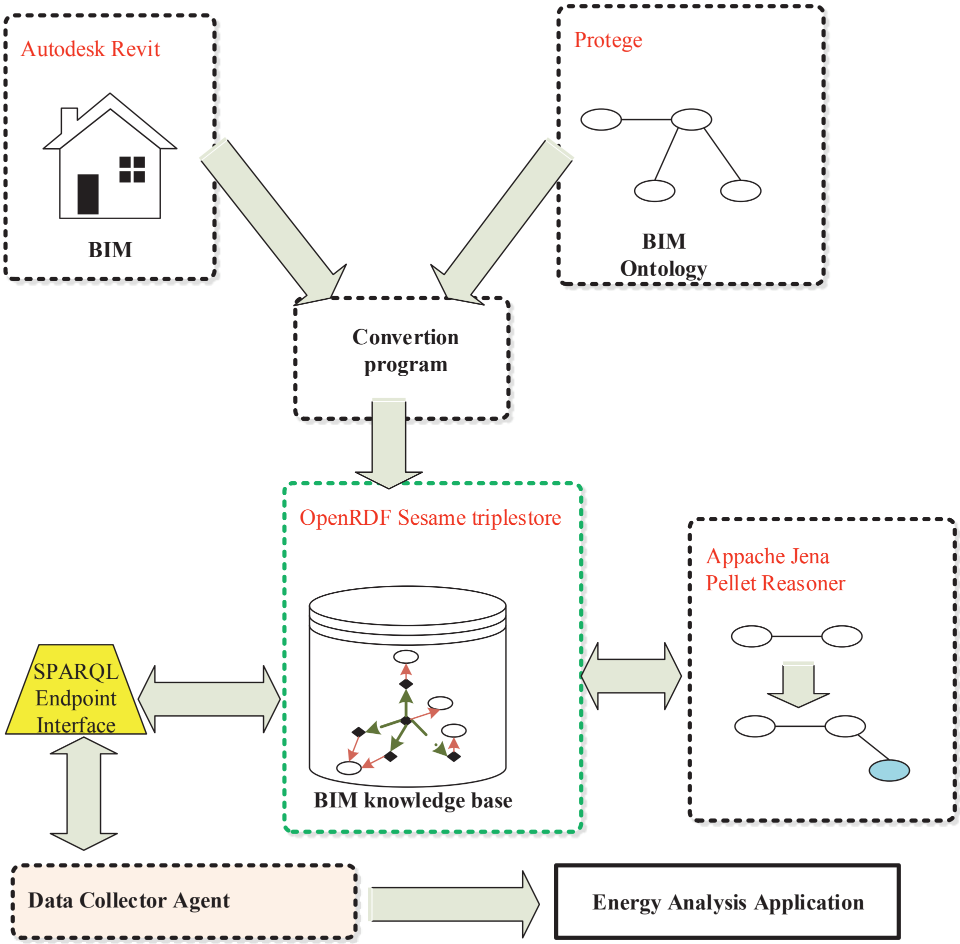


**Fig. 2. The process of creating a BIM knowledge base**

An exterior wall will be used to show how building knowledge is presented in the BIM knowledge base. The exterior wall belongs to a building referred to as RecCenter. The exterior wall, as shown in Fig. 3a, is named wall212 and hosts a door and two windows. In semantic modeling, every entity must have a unique resource identifier (URI). Fig. 3b shows the 128-bit unique identifiers (www.guidgenerator.com) used as URIs for the building and its elements in the RecCenter knowledge base. In Fig. 3b, muso and mudo represent the URIs of the ontologies we developed to represent building element types and element design properties [18]. Fig. 3c shows wall212 in the RecCenter knowledge base in RDF/OWL format. The graph in Fig. 3c only shows the relationships between wall212 and the elements it hosts; the full building knowledge base includes the relationships among all building elements.

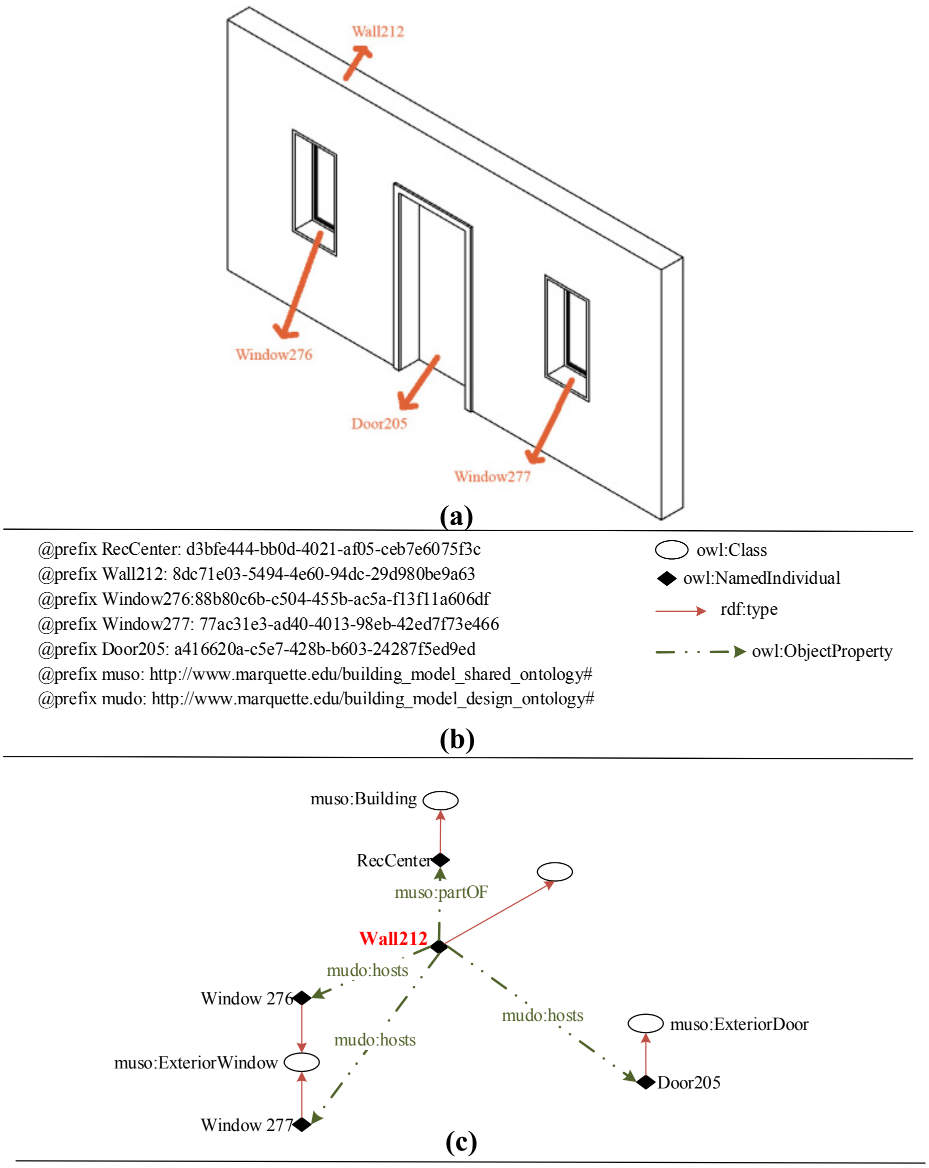


**Fig. 3. (a) 3d view of a wall element; (b) Prefixes and URIs; (c) partial graph of wall212 in the BIM Knowledge base**

Fig. 4 shows how properties of a building element are represented in the BIM knowledge base. In Fig. 4 only Wall212 properties such as its surface area, thickness, heat transfer coefficient, and thermal mass are shown. Each of the properties shown in Fig. 4 is a multi-valued property that must be defined using a unit and a value. For example, Wall212_Area property defines the value of the wall area equal to 14.56 and SquareMeter as its unit of measurement. We used QUDT ontology [19] to represent units of measurements. All other BIM element properties are defined in a similar manner in the BIM knowledge base.

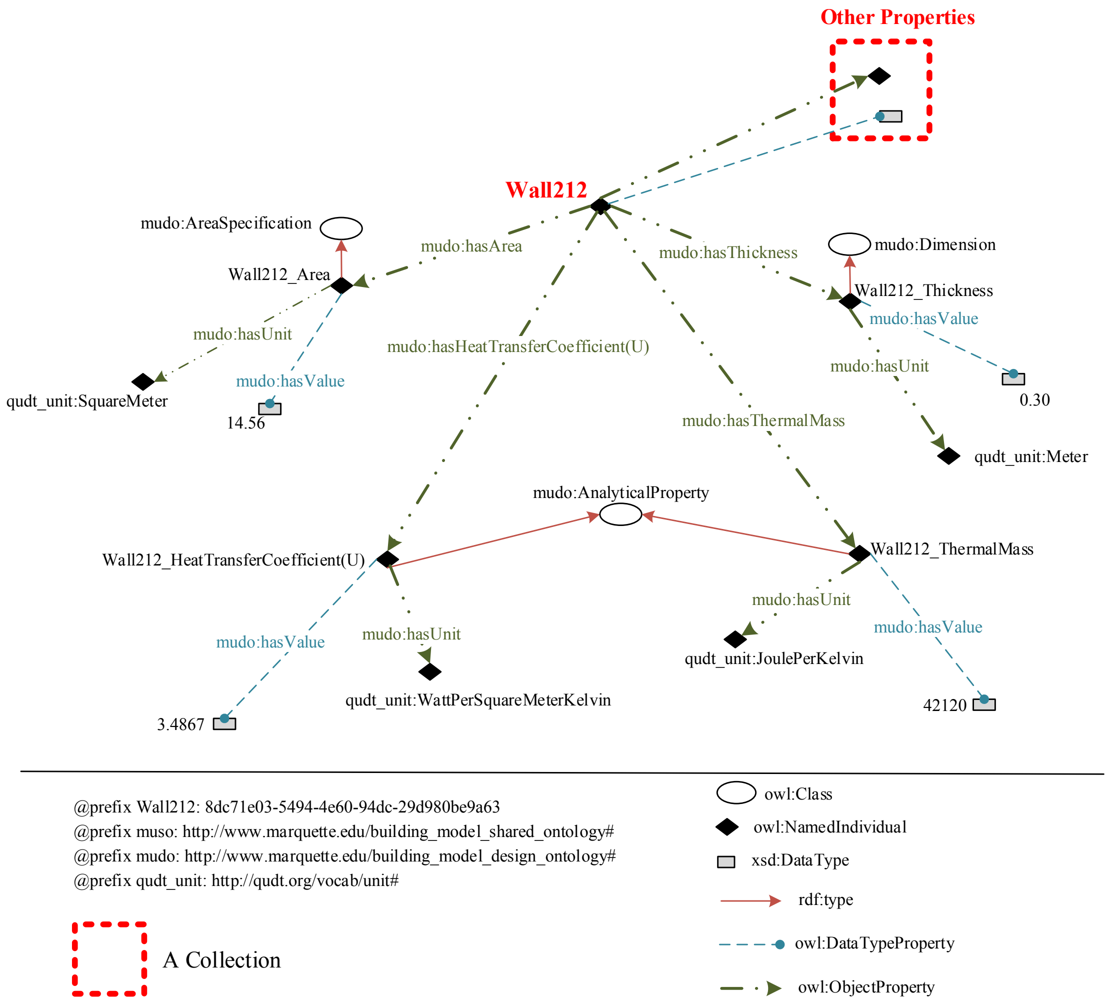


**Fig. 4. Wall212 properties in the BIM knowledge base**

The Data Collector Agent (see Fig. 1) developed in this study submits SPARQL queries to the BIM knowledge base and requests building element properties that must be input into the energy analysis program.

## 5. Mechanical equipment knowledge base

For energy cost analysis, properties of mechanical equipment used in a building are necessary. Mechanical equipment ontologies can be used by equipment manufacturers to semantically define their products and product efficiencies. We used the study by Hitchcock et al. [20] as the base for developing ontologies for a heating equipment and a cooling system. We used Good Relations (GR 2008) ontology to semantically define mechanical equipment product offerings as semantic web services. Good Relations ontology allows businesses to semantically define information such as their company, product descriptions, store location, price, warranty and shipment information. We created semantic web services for an HVAC equipment on a server in our computer lab.

## 6. Weather knowledge base

National Oceanic and Atmospheric Administration (NOAA) (http://www.noaa.gov/) publishes historical weather and climate data (http://www.ncdc.noaa.gov/cdo-web/). The information that NOAA provides are not in RDF/OWL format. We developed a weather knowledge base for Milwaukee, Wisconsin, using the weather ontology published at URI: http://www.scs.ryerson.ca/~bgajdero/msc_thesis/code/ontologies/weather-ont-t2.owl, using weather information from NOAA. The weather ontology allowed us to semantically define information such as weather description, temperature, date, time, station ID, latitude, and longitude. We published the weather knowledge base as a semantic web service on a server in our computer lab.

## 7. Energy cost knowledge base

The energy analysis application that we used in this study calculates the energy cost for heating a building project using properties of the mechanical equipment used in the building model. It uses energy cost information that must be obtained from energy providers. An energy ontology is required to model energy cost information for different types of energy during a year. We used the ontology developed at https://www.auto.tuwien.ac.at/ for energy modeling. The ontology URI is: https://www.auto.tuwien.ac.at/downloads/thinkhome/ontology/EnergyResourceOntology.owl#.

The ontology allows modeling information such as energy type (e.g. electric, oil, natural gas), energy provider information, date, energy demand, energy supply, and energy cost. Using the ontology, we developed an energy provider semantic web service on a server in our computer lab.

## 8. Energy analysis application

The focus of this study was the development of a semantics-based data collector agent software (see Fig. 1) for obtaining the required information to input into a building energy analysis application. There are a large number of open source and commercial building energy analysis programs (http://apps1.eere.energy.gov/buildings/tools_directory/). Each program requires a different set of input data. The prototype application we developed in this study does not use a ready-made software tool for energy analysis. The energy analysis module in this paper (see Fig. 1) consists of a simple building heating cost calculation algorithm that we programmed [21].

## 9. Summary and Conclusion

An energy analysis application requires information collected from several sources. These sources of information include a BIM created by project designers, mechanical equipment information published by equipment manufacturers, weather information provided by weather agencies, and energy cost information published by energy providers. The aim of this study was to demonstrate a new architecture that allows fast evaluation of the energy efficiency of a new design. The knowledge based system we developed can automatically access distributed semantically defined sources of information over the Internet and input the information into an energy analysis program. To be accessible to our application, an information source must be formatted as an OWL knowledge base and accessible as a SPARQL Endpoint or a Semantic Web Service interface. This approach would allow the information to be published by the original creator or owner of the information and accessed and used by client programs over the Internet. This architecture also guarantees access to up-to-date and reliable information with minimal human involvement for retrieval and transfer of the information to an energy analysis application.

## 10. References

[1] E Krygiel, B Nies, Green BIM: successful sustainable design with building information modeling, John Wiley & Sons 2008.
[2] G Klyne, JJ Carroll. Resource description framework (RDF): Concepts and abstract syntax, (2006).

[3] S Bechhofer, F van Harmelen, J Hendler, I Horrocks, DL McGuinness, PF Patel-Schneider, et al. OWL Web Ontology Language Reference. W3C Recommendation (2004), World Wide Web Consortium, http://w3c.org/TR/owl-ref. (2009).
[4] E Prud'Hommeaux, A Seaborne. SPARQL query language for RDF, W3C recommendation. 15 (2008).
[5] D Martin, M Burstein, J Hobbs, O Lassila, D McDermott, S McIlraith, et al. OWL-S: Semantic markup for web services, W3C member submission. 22 (2004) 2007-2004.
[6] D Allemang, J Hendler, Semantic web for the working ontologist: effective modeling in RDFS and OWL, Elsevier 2011.
[7] P Hitzler, M Krotzsch, S Rudolph, Foundations of semantic web technologies, Chapman and Hall/CRC 2011.
[8] H Knublauch, D Oberle, P Tetlow, E Wallace. A semantic web primer for object-oriented software developers, W3c working group note, W3C. (2006).
[9] M Niknam, S Karshenas, A Semantic Web Service Approach to Construction Cost Estimating, (2013) 484-491.
[10] M Niknam, S Karshenas, A Social Networking Website for AEC Projects, (2014) 2208-2215.
[11] TR Gruber. A translation approach to portable ontology specifications, Knowledge acquisition. 5 (1993) 199-220.
[12] NF Noy, DL McGuinness. Ontology development 101: A guide to creating your first ontology, (2001).
[13] D Martin, M Burstein, D Mcdermott, S Mcilraith, M Paolucci, K Sycara, et al. Bringing semantics to web services with OWL-S, World Wide Web. 10 (2007) 243-277.
[14] B Grasic, V Podgorelec. Automating ontology based information integration using service orientation, WSEAS Transactions on Computers. 9 (2010) 547-556.
[15] D Fensel, FM Facca, E Simperl, I Toma. Web Service Modeling Ontology, Semantic Web Services. (2011) 107-129.
[16] MJ Kofler, C Reinisch, W Kastner. A semantic representation of energy-related information in future smart homes, Energy Build. 47 (2012) 169-179.
[17] K Kim, G Kim, D Yoo, J Yu. Semantic material name matching system for building energy analysis, Autom.Constr. 30 (2013) 242-255.
[18] S Karshenas, M Niknam, Ontology-Based Building Information Modeling, (2013) 476-483.
[19] R Hodgson, PJ Keller, J Hodges, J Spivak. QUDT–Quantities, Units, Dimensions and Data Types Ontologies. 2013, URL http://qudt.org. (2013).
[20] RJ Hitchcock, N Nisbet, C Wilkins, M Tanis, R Haenninen, T Laine. *Ontology for Life-Cycle Modeling of Heating, Ventilating, and Air Conditioning (HVAC) Systems: Experimental Applications Using Revit*. Ontology for Life-Cycle Modeling of Heating, Ventilating, and Air Conditioning (HVAC) Systems: Experimental Applications Using Revit. (2012).
[21] JD Spitler. Thermal load and energy performance prediction, Building performance simulation for design and operation. (2011) 84-142.