From Linked Data to Linked Services: 
Developing Information Services for Sustainable Buildings

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Abstract
In near future, it is expected that a large part of the existing building stock in Europe would need renovation and refurbishment in order to comply with energy efficiency and sustainability standards. The stakeholders (investors, architects, construction companies) need an adequate information support in order to make more informed decisions for specific renovation and refurbishment cases for which complex reasoning mechanisms are needed. The goal of the present work was to develop an architecture and implementation of an information system facilitating the publishing, searching and discovery of construction services over the World Wide Web (WWW) in a very refined way. The approach relies on Semantic Web technologies, the Web Ontology Language (OWL), the Resource Description Framework (RDF) and the Linked Data principles. It is shown that by using Linked Data and Services it is possible to incorporate complex information about the sustainability aspects of products and services, such as new Energy Efficiency (EE) approaches and Renewable Energy Sources (RES), which may then be applied to specific renovation and refurbishment cases.

Keywords: Linked Data, Linked Services

1 Introduction
It is expected that a large part of the existing building stock in Europe would need renovation and refurbishment in order to comply with energy efficiency and sustainability standards. For example, in Slovenia there are over 300,000 single family homes that would need renovation in the upcoming years. Hence, it is important to provide adequate services to the various investors in order to achieve greater energy efficiency and sustainability of these buildings. The stakeholders, such as building owners, architects, energy inspectors, materials, equipment and technology providers, designers need an adequate information support in order to be able to make more informed decisions in particular renovation and refurbishment cases.

The present approach aims at developing an information technology support for those activities related to energy efficient and renewable energy sources in buildings that are currently under way or will be introduced in near future. The complexity of information integration in this area arises from the fact that the various products and services are very diverse and multiple complex criteria must be used in their selection. An important goal of the present study was therefore to develop a model of an information system that can be used by the construction companies to offer materials, products and services for building renovation and refurbishment over the World Wide Web (WWW).

Particular goals of the study were to develop:

- an appropriate architecture and a system prototype for the collection, processing and manipulation of data on building products and services;
- a model of products and services that takes into account the energy efficiency and sustainability aspects of the various materials, building products and services; and
- analytic capabilities, such as possibilities for comparisons based on building types and energy and sustainability indicators.

The first step in this process was to develop a model of a knowledge base of energy efficient and renewable energy sources, and buildings-related products and services. The approach also had to take into account European and Slovenian Law and guidelines for achieving sustainable buildings.
2 Related Works

Recently developed information technologies, such as OntoWiki [1] allow the conceptual modelling, creation and development of open and complex knowledge bases. The OntoWiki technology allows the use of the Web Ontology Language (OWL) [2] for conceptual modelling. Recently, the OWL has been used in various studies related to building sustainability and energy efficiency [3; 4; 5; 6; 7; 8].

A variety of existing technologies can be used for storing and querying RDF Schema (RDFS) metadata including, for example, Jena API, Sesame2, KAON2, Kowari Metastore and similar. These systems rely on traditional relational database capabilities and enable rich, highly detailed application programming interfaces for manipulating and accessing RDF data, as well as queries using different languages, including the SPARQL query language. Although the aforementioned approaches provide robust storage and query of RDFS data, there are a number of open issues related to security concerns, access control to metadata, transaction, replication, evolution of metadata, the strategy for the propagation of changes, and similar, which currently receive minimal attention. W3C’s SPARQL Protocol is a very simple interface for Web services, which can be used to query RDF-databases. Although this technology has been intensively developed and tested, existing industrial applications do not fully exploit its capabilities for metadata management.

Recent Linked Data technologies [1; 8] promise an important shift in this domain. Most importantly, they allow for great flexibility and extensibility of the initial conceptual model of the knowledge base and for variety of intuitive browsing mechanisms. Based on an analysis of the end-user, application and system requirements, the OntoWiki technology [1] was selected for this study.

3 Building Energy Efficiency

According to some estimates 40% of the total final energy in the European Union (EU) is consumed by buildings [9]. This contributes to 40% of total CO$_2$ emissions in the environment in Europe. Because this situation is similar in many other developed countries, it is a common goal to renovate and refurbish existing buildings in order to reduce the emissions in the environment and at least the unnecessary energy consumption. The EU has set up ambitious goals defined in a package of measures on climate-energy policy, labeled 20-20-20. The goals are to reduce Green House Gas (GHG) emissions by 20% (to the level of year 1990), to reduce primary energy use by increasing energy efficiency by 20%, and to increase the renewable sources in the primary energy balance by 20%, all until the year 2020 [10]. The Energy Performance of Buildings Directive (2002/91/EC, recast 2010/31/EU) (EPBD) prescribes stringent requirements for energy efficiency of new buildings and major renovations and a mandatory energy performance certificate for all buildings [10].

According to current estimates the cost-effective energy savings potential in buildings in the EU is 28%. The EPDB directive aims to ensure that after the year 2018 (an interim target is set by year 2015) all new public buildings have nearly zero energy consumption and by 2020 all new buildings have close to zero energy consumption. In several countries, such as Slovenia, these measures have taken up the form of action plans on energy efficient and renewable energy sources, which emphasise and require a sustainable and energy efficient construction and renovation of buildings [11; 12].

Hence, in the area of architecture, engineering and construction there is a strong need for a properly structured information knowledge base on energy in buildings, which would contain a large number of relevant information, and be accessible to the various stakeholders. An open knowledge base would allow for a proper assessment of the for low-energy new construction and renovation of buildings and disseminate knowledge for different user profiles (e.g., building owners, energy inspectors, equipment and technology providers, designers, manufacturers of energy certificates).

As part of the study, various information sources related to buildings were analysed. These included:

- information sources related to the building stock; and
- materials, products and services offered on the market.

Criteria for environmental, economic and social sustainability and energy efficiency of build-
ings are currently based on qualitative (check-
lists) and quantitative (Life-Cycle Assessment) approaches [13]. The European projects EIE BUDI, CA EPBD II and EPA ED proposed methodologies for quantitative estimation of the energy efficiency indicators of buildings based on structural and mechanical properties of the buildings. The idea of these emerging databases is to link them to the databases of the building stock and to obtain assessment of the energy performance for all buildings in Europe.

It is also necessary to use environment friendly construction materials with low embodied energy and low emission of pollutants, according to Environmental Product Declarations (EPD). Such energy efficiency indicators are expressed in quantitative terms and in the future will be publicly available as part of national databases of the building stock. Such databases will be upgraded by qualitative data on the various aspects, including environmental information. Some databases are currently under construction as a part of the implementation of the EPBD in Portugal and Ireland (EIE BUDI, CA EPBD II).

Because new products and services emerge on the market every day, it is necessary to use extensible and flexible technologies for the integration of such information. In the following section several use cases are discussed.

4 Use Cases

Our study further concentrated on an analysis of the motivation for creation of an open knowledge base of services for achieving energy efficient and sustainable buildings. In the course of the study, a number of experts were consulted, which led to the definition of use cases, which are listed in the following.

Use case 1: Publishing and searching for relevant materials for a specific case of renovation or refurbishment. Propose of the knowledge base is to be able to incorporate information on specific materials, systems, products, articles. These may include, for example, insulating materials, high insulation materials, organic insulating materials and their characteristics, energy efficient windows and properties, photovoltaics, heat pumps, heat recuperators, etc. The idea is that architects, designers and engineers will be able to access all information on all available materials and products in one place.

Use case 2: Publishing and finding the most effective services for the renovation of existing buildings based on requirements. It will be possible to obtain knowledge and information about known options and recommendations for refurbishment of existing buildings to achieve energy efficiency in relation to their current characteristics (sample). It is understandable that not all methods of measure are appropriate for all existing buildings. This will enable prospective investors to choose between possible remedial measures for their building, according to his priorities (energy efficient, ecology, durability, economy, etc.).

Use case 3: Comparing the various products and services according to various sustainability criteria. The purpose of the knowledge base is to assist in analysis of the available alternatives of refurbishment according to the wishes and requirements of the investor, according to the certificate of the building. For example when one wants to renovate his building to become more efficient he has many possible approaches to choose.

5 Linked Data and Services - A Conceptual Model

When designing the knowledge base, in order to take care of the end-user perspective, a number of concepts were defined related to services and measures for:

- the improvement of the building’s envelope, including addition or improvement of thermal insulation, placement and shading of energy efficient doors and windows, increase of thermal mass, optimum shape factor of the thermal envelope, etc.

- the reduction of the heating and cooling loads, including exploitation of principles of bioclimatic architecture, passive design, incorporation of passive heating and cooling techniques, i.e. cool coatings, control of solar gains, electrochromic glazing etc.

- the use of renewable energy sources, e.g. include solar thermal systems, buildings’ integrated photovoltaic elements, hybrid systems, biomass, heat pumps etc.

- the use of intelligent energy management, i.e. advanced sensors, energy control (zone
heating and cooling) and monitoring systems;

- the improvement of the indoor comfort conditions in parallel with minimization of the energy requirements, i.e. optimization of the ventilation rate, use of mechanical ventilation with heat recovery, energy efficient systems of distribution, storing and heat emissions, energy efficient boilers, preparation of hot water, systems for cooling and air-conditioning, efficiency use of multifunctional equipment, i.e. integrated water heating with space cooling etc.

- the use of energy efficient appliances and compact fluorescent lighting etc. In the context of the transfer of measures that contribute to efficient energy use in public and residential buildings.

The developed ontology of the knowledge base is organised according to the types of services that may be offered by construction companies and renovation/refurbishment techniques. It includes possibilities for including comments from the building owners, energy inspectors, equipment and technology providers, designers, issuers of energy performance certificates and so on. Therefore, the developed ontology defines important entities related to energy efficient and renewable energy sources in buildings. On the basis of the developed ontological concepts, it is possible to describe very specific information: e.g. related to the selection of various ecological or energy-saving materials, process descriptions, measures and technologies, e.g. energy-efficient windows, properties of insulation materials, photovoltaic elements etc.

6 Architecture of the knowledge system and application

The identified requirements show the needs of the stakeholders for dynamic, well-structured and up-to-date access to complex information sources related to building sustainability. The key technology that was selected for the application development is the OntoWiki authoring and content-management system, an open-source product of the Lod2 project [14], which conforms fully with the Linked Data trend of the Semantic Web.

The system uses the Virtuoso advanced RDF storage system [15]. The efficiency of the RDF storage and the sophisticated knowledge-base access interfaces provided by OntoWiki API may be further used by applying a variety of reasoning technologies. The developed information system has a layered architecture including:

- User Interfaces Layer;
- Context Object;
- Application Layer; and
- Persistence Layer.

In the following, the layers of the architecture are described briefly in a bottom up fashion.

The persistent storage is based on an RDF storage adapter provided by OntoWiki. It supports authoring, versioning, Access Control Lists (ACL) and other necessary low-level functionalities. Moreover, it fully organises and optimises the content of the knowledge base for performance. Instances contained in the knowledge base concern various products, services, best practices, user management and authoring hierarchies, etc.

The Application Layers main function is to contribute to a greater flexibility of the design of the end-user interfaces. A number of machine-accessible data interfaces, such as SPARQL [16] are supported, which makes the knowledge base suitable for future integration with other information systems in an open way. According to publication principles [17], OntoWiki makes all the resources accessible by their URI (provided that the resources URI is in the same namespace as is the OntoWiki instance). Furthermore, for all the resources used in the knowledge base additional triples can be fetched if the resource is dereferenceable. Another provided feature is that of a semantic pingback.

The User Interfaces Layer contains the exploration (end-user) interfaces for the knowledge base. They were developed by using the Cascading Style Sheets (CSS) Framework, the OntoWiki User Interfaces API and templates, and the RDF author. The exploration interfaces use the capabilities of the lower Application Layer of the knowledge base.

The knowledge base can be used to deliver various applications, for example, for the selection of best services for refurbishment of win-
dows. An example of such application is presented in Figure 1.

Several advanced features are implemented and may be used, such as faceted browsing, content-specific browsing, full-text search, a visual query builder and a provenance-tracking mechanism. The first three mechanisms are sufficient for browsing and editing all the information contained in the knowledge base in a generic way, while the second two approaches can be used by more information-technology savvy users. Additional interfaces are designed to provide the publication of new resources, various comparisons, an analysis of refurbishment scenarios, tagging, commenting and rating, and other capabilities.

The knowledge system allows for the exploration of its content by using various mechanisms. The Search mechanism is designed to allow a free-text search in the knowledge base and the Compare mechanism can be used to compare two or more items, for example, two windows, two heating systems, etc. The Select mechanism makes it possible to select a list of necessary, appropriate products and/or professional services that the end-user has found in the knowledge base. The Analyse scenario mechanism makes it possible to analyse the overall effect of the selected materials and products in terms of the presentation of various sustainability and economic parameters. This helps the user when analysing various refurbishment or building scenarios.

7 Discussion and Conclusions

The purpose of this work is to present a model of an information system that can be used for spreading information on the energy efficiency and sustainability of buildings. The ontology developed in OWL proved instrumental in capturing the essential properties of construction services. It defines all relevant entities which are important when solving problems of building energy efficiency. On the basis of the developed ontological concepts it is possible to describe the specific materials, services and techniques (e.g. energy efficient windows and their properties, especially effective insulating materials, photovoltaic elements etc.) The ontology and the underlying knowledge base are designed having in mind the open-World assumption, which allows for its future extensions with other relevant concepts as and when they become available. The ontology can be used to annotate concrete specifications of materials, processes and technique, which are stored in a knowledge base. The use of the OWL language makes it possible to gradually extend the conceptual model with new knowledge items as and when they becomes available (e.g. on new materials, techniques and processes).

In near future one can expect rapid research and development in the field of sustainable assessment of buildings, in a way that environmental evaluation (based mostly on energy use and emissions of the implemented construction materials and products) shall be upgraded with eco-
nomic and social sustainability of the building. One of the scientific challenges in this respect is the comprehensive organization of the services and approaches and their effects on the energy balance and/or the building energy performance certificates. The energy related data will represent the core building information in the next years, being aware of the fact that energy and CO$_2$ reduction in buildings are European priority.

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