# ENERGY EFFICIENCY ALONG THE BUILDING LIFE-CYCLE: A CONCEPTUAL MODEL FOR KNOWLEDGE AND INFORMATION EXCHANGE AMONG AEC PROFESSIONALS

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## ABSTRACT

Building Life-Cycle Assessment (LCA) promotes principles of careful treatment of the environment, preservation of the natural resources and economy in the construction and energy consumption of buildings. Recently, several information systems were developed or upgraded to support LCA. Such systems, however, do not effectively support knowledge exchange among the AEC professionals. In order to address this problem, the possibility to develop an open knowledge base supporting LCA is investigated in this study. Use cases from industry and legislation were collected and analysed. Then a conceptual model is developed by using the Web Ontology Language (OWL). Based on the model an initial knowledge base is populated with instances of new approaches, materials and methodologies related to LCA. This corresponds to key requirements from industry and demonstrates that the approach has the potential to facilitate greater knowledge exchange among AEC professionals in all LCA phases.

**Keywords:** Energy-efficient buildings, Sustainable buildings, Open knowledge base, Architecture.

## 1. INTRODUCTION

Today, in many developed countries there is a priority to reduce the emissions in the environment and at least the unnecessary energy consumption. Recent studies show that buildings consume 40% of the total final energy in the EU, which contributes to approximately 40% of total $CO_2$ emissions in the environment (Eurostat 2006). This situation is similar in many other developed countries, such as the USA. Moreover, it has been calculated that that the cost-effective energy savings potential in buildings in the EU is 28%.

In the area of AEC the term sustainable buildings has been introduced in order to promote principles of careful treatment of the environment, preservation of the natural resources and economy in their construction and use as well as cost-effective energy use. In construction practice, sustainable buildings are most often characterized as energy efficient buildings with very low energy consumption, which is covered mostly by renewable energy sources. Life Cycle Assessment (LCA) methodologies could be a viable approach towards sustainable buildings. However, it is necessary to transfer theoretical solutions to practice as well as to establish a feed-back loop to improve theoretical knowledge based on results of actual construction and refurbishment projects. It is a common observation that a number of factors hinder the wider acceptance of LCA methodologies, which are as follows:

1. The level of sharing of factual data and knowledge among the various AEC professionals is still very low. It is necessary to develop an information system that will support professionals in all LCA phases, which would make it possible to store, distil, discover i.e. share know-how and knowledge related to sustainable buildings.
2. The number of new materials, techniques, and approaches is expected to increase in the upcoming years. However, existing information systems supporting knowledge exchange among AEC professionals are not so flexible and do not facilitate seamless integration of these new approaches.

3. The dominance of the use phase naturally drew focus on the energy consumption of the operating building so far. Today, there are emerging needs to consider other factors, such as the use of renewable energy sources, ecologically friendly materials, and similar (Lenz et al. 2011). An information system is needed which would allow to assess a number of qualitative factor along with the traditional quantitative factors.

4. LCA takes into account environmental factors, such as emissions into the air, water and soil, resource consumption, as well as land use impact. That is, sustainable buildings should be healthy and user friendly as well as functional and socially acceptable. An information system supporting LCA should make it possible to classify the environmental impacts according to their potential effects and conceptualize them in a comprehensible manner.

5. There is a plethora of LCA methodologies and a lack of evidence about their usefulness from implementation (e.g. actual construction projects, refurbishment). Two LCA methodologies applied to a single building may produce significantly different final results, both in qualitative and quantitative terms. Therefore, an open information system is needed to gather data that will help to assess and compare LCA oriented methodologies.

6. Legislation, e.g. the EPBD in the EU (Šijanec Zavrl and Potočar 2011) as well as related software tools, data and techniques should be widely available and understood by the widest public. This includes minimum energy requirements for buildings, calculation methodologies for the determination of energy indicators of buildings and the mandatory energy performance certificates for all buildings. This goal can only be achieved by designing an information system, which is open towards the public as well as the AEC professionals.

In order to support the implementation of LCA methodologies, several new software tools have been introduced recently. Some of these tools are oriented towards the calculation of various building parameters (PHPP, BLAST, EnergyPlus, eQUEST, TRACE, DOE2, ECOTECT, GaBi), other incorporate knowledge about building materials and end products (EIE BUDI, CA EPBD II and EPA ED) and similar. These tools, unfortunately, do not allow for open sharing of know-how and knowledge related to sustainable buildings.

Hence, there is a great need to develop an adequate information technology support with the key goal to facilitate greater know-how, information and knowledge exchange among AEC professionals related to environmental, economic and social sustainability of buildings. Such an information system and knowledge base may be oriented towards qualitative (check-lists) and quantitative methods based on Life-Cycle Assessment (LCA) approaches (Bribian et al. 2009). Should such knowledge be widely available, it has the potential to contribute to improved building designs, better quality construction, more cost-efficient energy use in buildings, more ecological materials, and similar.

The hypothesis of the present study is that by conceptualizing this emerging domain in a formal way (by using Semantic Web technologies), and by developing an open knowledge base it may be possible to provide appropriate information support for all LCA phases. In this context, Semantic Web technologies could be used to conceptualize, aggregate, store, distil and disseminate knowledge related to all LCA phases.

Semantic Web technologies demonstrate a number of advantages over more traditional data base technologies (Ludwig 2010). An important advantage is gained by the use of expressive languages based on the XML standard, notably, the Web Ontology Language (OWL), as well as query languages such as SPARQL, a W3C standard (Broekstra et al. 2002). Recently, in the course of the InteliGrid, OntoGrid and DataMiningGrid projects these technologies have been used to develop so-called semantic grid test beds (Stankovski et al. 2005; Stankovski et al. 2008a; Stankovski et al. 2008b; Turk et al. 2005).

Therefore, the primary goal of this paper is to develop a conceptual model, and a prototype of an open knowledge base based on the conceptual model, that would support knowledge and information exchange among AEC professionals in all LCA phases. In the following Section 2, the detailed requirements in all LCA phases are presented. In Section 3, part of the developed conceptual model is presented and the architecture of the open knowledge base. Section 4 summarizes our findings.

## 2. KNOWLEDGE FLOW ALONG THE LIFE CYCLE

A number of use cases scenarios were defined based on a series of meetings scheduled with AEC professionals. These included architectural bureaus, engineering companies, major material producers, vendors of renewable energy sources, study of legislation related to building energy efficiency and similar. With the help of the defined scenarios, a number of tasks which may be performed on a building throughout its life cycle (such as planned maintenance, refurbishment and change of use) were modelled.

These include:

- The publication and discovery of relevant eco-materials, which are used to improve a building's energy efficiency for the case of refurbishment.
- The publication and discovery of procedures for the renovation of existing buildings based on sustainably defined requirements.
- The comparison of various materials, products and procedures based on collected data.
- The use of opinions of AEC professionals to feed-back professional know-how in the loop.
- The storing and retrieval of information related to energy efficiency of a building, based on available data/measurements and building energy certificates.
- The possibility to calculate the building's energy efficiency directly on the Internet, based on the existing situation.
- The access to exemplary data for various cases of new builds and refurbishments for educational purposes.

These scenarios can further be used to determine and quantify the requirements related to energy efficiency and renewable energy sources improvements, the aging process and the loss of value over the life of the building. Moreover, certain tasks may be co-related and may have joint implications on the sustainability of a building and care was taken to include such relationships in the developed conceptual model. Following is a presentation of our analysis along the building life-cycle phases.

**Life cycle phase 1: New build**

In the typical design approach, oriented towards new build, the objective is to create a new individual building, a product, involving the use of resources and the acceptance of by-products and wastes. The design of the construction process must be in harmony with the long-term, holistic requirements already defined for the building so that construction solution can be efficiently and sustainably built, maintained, repaired, inspected, deconstructed and replaced. In addition to the ordinary functional, formal and structural requirements, it is essential to investigate the effects of the new system limits. Effects on the local area or at specific points are the focus during the execution phase. Which technologies and auxiliary materials can be used to achieve the objective of this phase must be made clear. At this stage, the requirements must be set out in a sustainable procurement policy for components, services and operating equipment (König et al. 2010).

In this phase, it is very important to provide for information and knowledge flow among the various professionals and between professionals and investors in order to make the latest knowledge on sustainable building more accessible. For illustration, an example of an architect's query is shown in Table 1.

**Life cycle phase 2: Use**

The reduction of energy demand and expenditure on energy provision, as well as raising energy efficiency and minimising the pollution are most important to the use phase. It establishes the safety and availability requirements that the building equipment must achieve, defines the target values for the consumption of energy and other media. The main issues during the use phase of a building are the adherence to the maintenance cycles, achieving the optimum operation, continuous monitoring and benchmarking against the target values of the building. The development of the quality concept in environmental management indicates extensive integration with the many objectives of sustainable building (König et al. 2010).

In this phase is very important to increase the level of awareness of owners and building managers to contribute to sustainability. The conceptual model we want to make information accessible as well to non-professionals. Here we are aiming primarily at reducing energy consumption and pollution.

| Materials, equipment | Processes | Services |
|---|---|---|
| **Phase I: New Build** | | |
| • Material<br>• Insulation material<br>• Ecological material<br>• Windows, doors<br>• Heating system<br>• Cooling system<br>• Ventilation system<br>• Renewable Energy Sources | • Which insulation material is most appropriate<br>• Why choose ecological material<br>• How is made<br>• Energy efficient doors and windows<br>• Energy conservation and efficiency of materials<br>• Energy conservation and efficiency of systems<br>• Durability of materials<br>• Durability of systems<br>• Which system is more efficient? | • Nearest supplier<br>• How to build in such material<br>• Thermal characteristics of these buildings elements<br>• Nearest installation company<br>• Maintenance services<br>• Availability of services<br>• Cost of services<br>• Quality of services |
| **Phase II: Use** | | |
| • Ventilation systems<br>• Windows, doors<br>• Heating system<br>• Cooling system<br>• Energy efficient appliances | • Measures to reduce energy consumption<br>• Measures of shading<br>• Use of energy efficient appliances<br>• Measures of shading<br>• Measures for the improvement of the indoor comfort conditions in parallel with minimization of the energy requirements | • Smart house services<br>• Maintenance of ventilation and other systems<br>• Availability of services<br>• Cost of services<br>• Quality of services |
| **Phase III: Refurbishment** | | |
| • Ventilation systems<br>• Windows, doors<br>• Heating system<br>• Cooling system<br>• Building envelope system<br>• Renewable Energy Sources | • Measures to improve energy efficiency of heating, cooling, ventilation systems<br>• Measures for the improvement of the building's envelope<br>• Measures to reduce net energy dependence<br>• Measures for the improvement of the indoor comfort conditions in parallel with minimization of the energy requirements | • Availability of services<br>• Cost of services<br>• Quality of services |
| **Phase IV: Deconstruction** | | |
| • Deconstruction equipment<br>• Insulation material<br>• Material<br>• Building elements<br>• Building installations | • How to appropriately disassemble, separate and recycle the building materials<br>• Chemical characteristics of waste material<br>• Ecological material characteristics<br>• Most appropriate and sustainable solution in our region | • Is recycling service available in the neighbourhood<br>• Availability of services<br>• Cost of services<br>• Quality of services |

Table 1: Example queries in an open LCA oriented knowledge base.

**Life cycle phase 3: Refurbishment**

There are several basic strategies available for the maintenance of buildings. They may be focused on the whole building or its components. In general terms there are four main conservation strategies for buildings: value conservation strategy (reference strategy), value increase strategy (also referred to as refurbishment strategy or transformation strategy), low-level maintenance strategy and decay strategy (dereliction strategy). In a refurbishment project, the creative input of the designer is a combination of diagnosis and estimation of the long-term potential of a building (König et al. 2010).

In this section is required considerable emphasis on sustainability. Renovation of the building requires disassembly, separation and recycling of disposed materials and the selection of new materials for the installation. It is important that both experts and lay people access to the latest knowledge and services available in the market. Example queries when a client or an architect wants to gain knowledge and information on services is shown in Table 1.

**Life cycle phase 4: Deconstruction**

The strategic objective of every deconstruction is to ensure the highest possible level of subsequent reuse for all components, the minimisation of losses during deconstruction, transport and reinstallation and to control the risks of the whole demolition process by the exercise of design, technical and organisational measures (Schultmann 2001).

The preparation of a deconstruction project requires careful planning normally achieved by cooperation between the client, designer, specialist demolition contractors and any parties interested in the subsequent use of building components or materials. A design incorporating an integrated disassembly and recycling plan can result in higher quality secondary building materials. The plan should seek to ensure coordination between disassembly and material processing. A key factor is the coupling of the outward transfer of foreign materials and pollutants with the downstream building material processing as part of the building disassembly plan (König et al. 2010).

Same as in the phase of the renovation is also in the phase of deconstruction where the most important aspect of the process is sustainability. Knowledge on properties of materials and suitability for recycling, incineration or deposit are crucial in phase of deconstruction. Information on the availability and quality of these services can be queried in the conceptual model as shown in Table 1.

## 3. A CONCEPTUAL MODEL FOR LIFE-CYCLE ASSESSMENT

The detailed analysis of planned use cases and end-user requirements leads to the definition of a complex conceptual model. This is a first necessary step that defines the structure of the planned open knowledge base, which is designed to support the implementation of sustainable buildings.

The conceptual model is designed in order to take into account all stages of the life cycle of a building, the materials used, implementation techniques and technologies, as well as European and Slovenian Law and guidelines, all with the goal of facilitating greater knowledge exchange among AEC professionals, related to sustainable buildings (see Figure 1).

In order to develop the conceptual model, a number of Semantic Web tools could be used (Staab et al. 2004). For the purpose of the present application Protégé was used, which is an ontology editor and an API frequently cited in the literature. Protégé 4.0 includes support for OWL and is a scalable platform with graphical components, such as graphs and tables. It supports multimedia content such as audio, video and multi-format storage of metadata. Protégé API allows other applications to use, access and display data from the developed knowledge base.

The development of the conceptual model i.e. the ontology was a systematic process that took all phases of the building life-cycle and all end user requirements, which play the most important role in the development of the conceptual model. Moreover, the possibilities for querying (e.g. by means of SPARQL) the developed OWL graph were also taken into account (see Table 1). Care was taken that the ontology allows for seamless integration of domain ontologies, e.g. an engineering ontology, ecology ontology, safety ontology, etc., which can be used to further describe the materials, methods and techniques for construction and renovation, impose restrictions on their use etc.

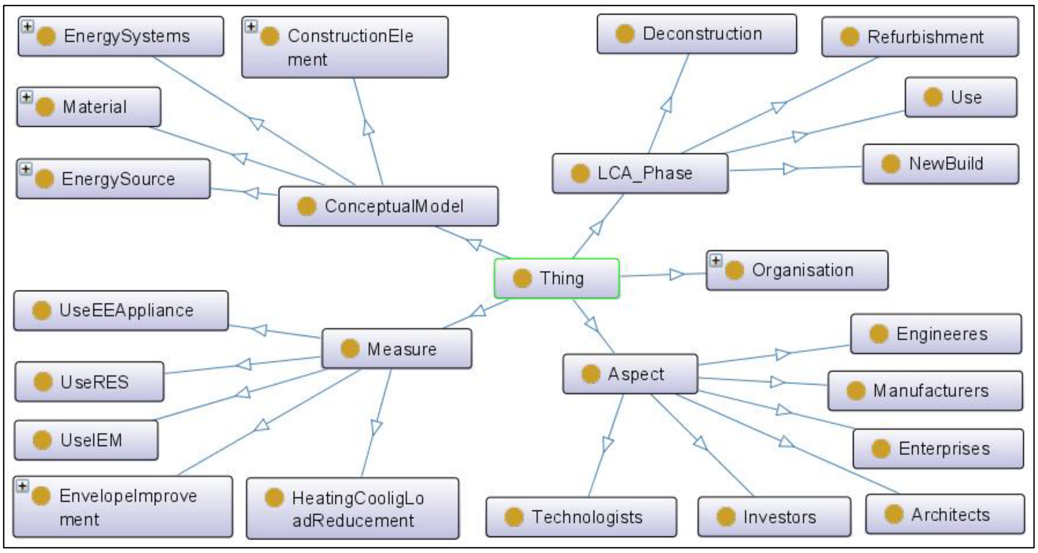

Figure 1: An ontology for sustainability of buildings LCA.

As it can be seen from Figure 1 the developed ontological concepts could be used to describe specific information, 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.

## 4. ARCHITECTURAL CONSIDERATIONS FOR AN OPEN KNOWLEDGE BASE

In the past decade a number of Knowledge Base management systems and APIs have been developed (Missier et al. 2007). Most useful are those that store and query RDF Schema (RDFS) metadata. Semantic technologies and systems that can work with RDFS are, for example: Jena API, Sesame2, KAON2, Kowari Metastore and similar. Those mentioned are best known and most widely used. These systems rely on traditional relational database capabilities, enabling a rich, highly detailed application programming interfaces for manipulating and accessing RDF data, as well as queries using different languages, including the query language SPARQL. SPARQL is a very simple interface for web services, which can be used to query RDF-databases. Figure 2 shows the architectural layers of the planned knowledge base. It provides interfaces for addition of existing knowledge as well as two search/browsing mechanisms. Some of the key functions of the high-level services are also depicted in Figure 2.

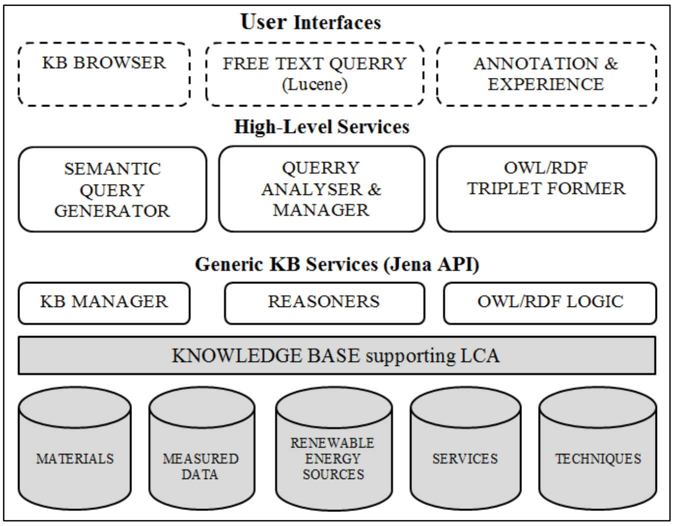

Figure 2: An architecture of an open knowledge base supporting LCA.

## 5. RELATED WORKS

Following a review of the state-of-the-art related to the use of Semantic Web technologies to achieve sustainable buildings it is possible to conclude that currently the most important research goal is to provide information and knowledge support in all LCA phases.

The interim results of the currently on-going project IntUBE - Intelligent Use of Buildings (Crosbie et al. 2011), are also of our interest. They show how to define a detailed life-cycle of a building and pin-point all parts where information on energy efficiency could be useful in order to achieve energy improvements. The developed conceptual model in this study complements and extents the efforts of the IntUBE project as it provides a formal modelling mechanism, which could be used to actually develop a knowledge base, as well as necessary services providing answers to complex queries of AEC professionals.

A number of multi-objective models, used to improve energy efficiency in buildings have also been recently developed (Diakaki 2010). They incorporate aspects, such as annual energy consumption, annual emissions of $CO_2$, initial investments needed, etc. As part of the models, there is a multi-dimensional function that can be used by the end users for optimization purposes. The conceptual model developed under this study does not include functions that may be used to perform calculations, but recent developments related to the OWL language may offer certain possibilities.

Specific tools have been developed by Erhorn et al. (2008), in order to provide guidelines for effective energy use for school facilities. This is a practical application, which, according to the given information about the size of schools, different rooms, windows, doors, etc., provides basic advice on the possible improvements in energy efficiency. In order to develop the system they used six years of experience in improving the energy efficiency of school facilities. The study of Erhorn et al. demonstrates the need for a knowledge base where experience could be collected for future use.

Pauwels et al. (2010) presented a model based on OWL that verifies the acoustic properties of buildings. This model does not apply to energy efficiency, but demonstrates clearly the advantages of semantic technologies and inference rules (in this study the N3Logic language is used) in solving specific problems related to buildings.

## 6. CONCLUSIONS

The results of present study showed that a number of Semantic Web technologies may be instrumental in the development of an open information system, which would incorporate knowledge and data related to all building life-cycle phases. Use cases scenarios and end-user requirements were investigated thoroughly as part of the present study. As a first step towards the development of an open knowledge base a formal conceptual model was developed, which is based on the OWL standard. It contains definitions of a number of important entities, which are related to the problems of building’s sustainability and cost-effective energy use, e.g. it can be used to annotate, publish, discover, and retrieve concrete specifications of materials, processes and techniques, which are stored in the knowledge base.

The conceptual model is designed having in mind the open-World assumption, that is, the Semantic Web itself, which allows for its future extensions with other ontologies. The advantage of this approach is that in the future, the conceptual model may gradually be extended to incorporate new knowledge as and when it becomes available. As it was shown in this study, the developed prototype demonstrates that Semantic Web technologies could facilitate greater knowledge exchange among AEC professionals related to sustainable buildings in all LCA phases.

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