# Using Semantic Technologies for Energy-efficient Building Planning

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***Abstract*—The Directive 2002/91/EC of the European Parliament requires member states to calculate the energy performance of buildings with the overall goal of reducing their energy consumption. Existing tools for the calculation of building energy efficiency provide good results in calculating the energy level of a given building but fail to support the user in the subsequent step - the identification of strategies on how to improve the building's energy efficiency. The manual identification of the optimal building configuration is not only tedious but very costly for the user and, therefore, exacerbate improving building energy efficiency.**

**This paper gives an overview of a new decision support system called SEMERGY that enables stakeholders to efficiently identify potential building configurations with regard to (i) environmental impact, (ii) energy consumption for operating the building, (iii) energy used for the production and distribution of building components, (iv) financial constraints, (v) building component compatibility, and (vi) legal requirements. The provision of computational support for the buildings' design phase benefits the AEC (Architecture, Engineering, and Construction) stakeholders in view of cost reduction, energy efficiency, and occupants' comfort and productivity and, thus, facilitates the design of energy efficient buildings.**

## I. Introduction

Buildings account for around one third of the world's total energy consumption and a similar percentage of the world's greenhouse gas emissions. Statistics of the EU state that 40 percent of energy consumption and 36 percent of CO2 emissions are generated directly or indirectly by buildings [1]. The U.S. Department of Energy [2] reports that buildings account for 39 percent of energy use, 38 percent of carbon dioxide emissions, 65 percent waste and 71 percent of electricity consumption. As climate change negatively affects the quality of life around the globe, the European Union (amongst other industrial countries) agreed in the 1997 Kyoto protocol, to decrease its CO2 emissions by 8% until 2012 (based on CO2 emissions in 1990). To implement the Kyoto protocol the European parliament and European council passed the Directive 2002/91/EG (EPBD 2002) that introduced the Energy Performance Certificate (EPC) in December 2002 with the aim to assess and improve the energy performance of buildings. As a consequence the software industry developed tools to calculate buildings' energy performance based on their geometry, materials, windows, doors and heating/cooling configurations.

While the difficulties in collecting and processing critical information necessary for the calculation and improvement of building energy performance is generally known, effective solutions have not been found yet. Partial progress has been made in the area of building representation by the development of IFCs (industry-foundation classes), IFDs, and the building smart efforts. Existing tools provide good results in calculating the energy level of a given building. What these tools are not capable of is to give the users advice on the measures necessary to improve the energy efficiency of the buildings. The EU Energy Performance of Buildings Directive 2010 (the EPBD recast directive) improves the implementation by demanding the EPC to include (i) the assessment of the buildings energy performance, (ii) recommendations for the cost-optimal or cost-effective improvement of the buildings energy performance and (iii) an indication as to where the owner or tenant can receive more detailed information.

SEMERGY fulfills these requirements by providing a valuable extension to existing energy performance calculation tools. SEMERGY is a software solution that supports the user in the identification of strategies on how to improve the building's energy efficiency (considering financial, legal, technical and individual requirements and constraints).

It supports the stakeholder in the identification and selection of appropriate products (materials, components) from an almost endless pool of options. The product selection is a multidimensional problem that must consider the following product characteristics (cf. Figure 1):

- Environmental impact of building materials through the building's life-cycle (e.g., disposal of insulation material).
- Energy consumption caused by the operation of the building.
- Energy used in production and distribution of building components and materials. This energy amounts for 15 to 20 percent of total energy consumption over a 50 year period.
- Financial aspects that constrain the overall building configuration.
- Compatibility among building components (e.g., a certain window type can only be combined with a specific wall type).
- Legal requirements (e.g., required insulation quality).

## II. The SEMERGY methodology

According to estimations the total emissions arising from the building sector will reach 11.7 GtCO2e in 2020. The Smart


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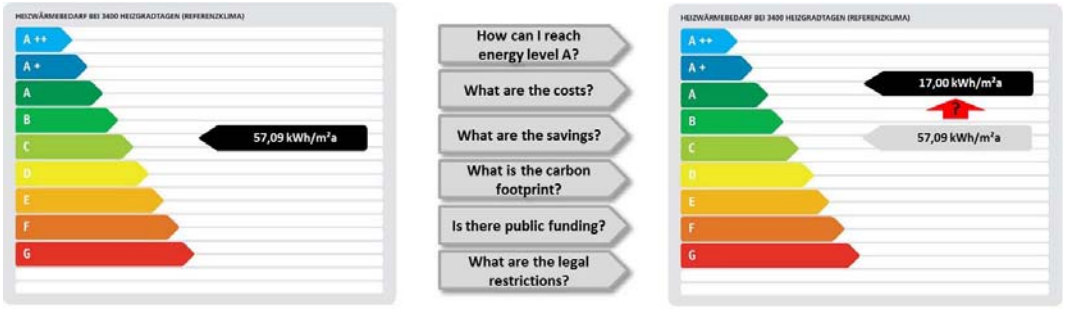



Fig. 1. The homeowner's challenges in improving energy efficiency

2020 Report states that improved building design and the use of automation technology could save 1.68 GtCO2e globally [3]. Other sources expect that greenhouse gas emissions in the the building sector can be reduced by 30-35 percent by 2050, in spite of growing numbers of buildings, by tapping the full potential of today's technology [4]. Basically there are two types of ICT-based building design improvement options: The first option is to equip new buildings with modern building management systems. The systems are already integrated in design phase, which makes optimization easier in comparison to integrating such systems in existing building, which is the second type of improvement. To reach the amount of emissions saving that is needed to successfully address the climate problem, both types of improved building design have to be realized. Equipping existing buildings with modern technologies globally is a large-scale project, but the energy saving potential is large. The retrofitting of existing buildings is a major part of the possibility supplied by ICT to reduce the carbon footprint of the building sector [5], since 80 percent of the existing building stock is more than 30 years old.

SEMERGY takes both scenarios into consideration and supports the optimization of new buildings and the retrofitting of existing buildings. In both cases the user can use existing CAD and BIM files as a basis for energy efficiency calculations. From a technological point of view, SEMERGY provides three layers including data acquisition, semantic enrichment, and decision making to support AEC stakeholders and individual homeowners in identifying energy-efficient building configurations.

### A. Data Acquisition

Structured and unstructured information resources are processed to generate potential building configurations. Structured resources include product libraries that are stored in databases, CSV, or XML files (dependent on the product vendor), and AEC domain specific resources, such as building plans and already existing building configurations (e.g., proprietary building configuration stored by an energy performance calculator). Unstructured information resources include natural language texts, such as standard, codes, or funding guidelines. As these structured and unstructured information resources lack semantic descriptions, SEMERGY provides interfaces, parsers, connectors, and concept/attribute identification methods. These methods extract the actual information from the sources and provide it to the semantic transformation module.

Besides structured resources, such as product databases, information from unstructured resources, such as standards, legislation, and funding guidelines, is crucial at identifying potential building configurations. To integrate unstructured resources into the AEC and legislation ontologies, SEMERGY uses parsers that support the extraction of concepts and defined attributes from unstructured resources, such as natural language text. Document-specific parsing profiles ensure that information is efficiently extracted, e.g., finding the regulations towards minimum glazing in inhabited rooms from a building code text. Additionally, external modules, such as existing energy performance calculation tools, contain valuable information regarding a specific building project (e.g., basic building configuration).

### B. Semantic Enrichment

The main goal of the semantic enrichment layer is to semantically enrich data coming from the data acquisition layer and provide it via ontologies to the decision making layer. Currently, energy-relevant building construction data (e.g., window and insulation data) is not semantically structured and stored in distributed data sources. As a result, data acquisition is cumbersome, time-consuming, costly, and error-prone, leading to energetically sub-optimal building design, renovation, and operation decisions. As previous studies have shown, the planning of energy-efficient buildings suffers from the sub-optimal retrieval and utilization of energy-critical information. Although the trend towards BIM-solutions experiences a rise in interest in recent years, there is currently no ontology-based solution that provides the required level of complexity. SEMERGY defines reference AEC ontologies (cf. [6]) that are used to provide interoperability between heterogeneous AEC resources, such as online catalogues, product databases, standards, and tool services. The ontologies will structure the necessary knowledge in a formalized and standardized way (the W3C Web Ontology Language OWL will be used to build the ontologies). Since no adequate AEC and legislation ontologies for supporting the building planning process are available, this research provides the first ontology-based solution for BIM.

Additionally, this layer transforms parsed data gained in the

data acquisition layer to semantically meaningful information. Therefore, SEMERGY maps the output data of each data acquisition module to AEC and legislation ontology concepts. The ontology logic utilizes mapping schemas and a reasoner to create ontology individuals according to our ontology specifications. The reasoner ensures the ontologies' consistency after each insert and modification operation.

### C. Decision Making

On the decision making layer, the AEC reasoning and logic module extracts potential building component configurations from the ontologies. The reasoning engine ensures that these configurations meet legal, technical, financial, and individual user requirements. Potential configurations are passed to the decision support and selection module. The decision support tool (based on [7], [8]) generates potential building configurations and passes them to the user interface. At each category, such as initial costs and energy consumption, the user influences potential building configurations by restricting or relaxing the constraints.

The main challenge is to formally model and implement building component dependencies and corresponding legal requirements (e.g., each living room requires at least one window). Therefore, SEMERGY uses a novel generic configuration module with AEC/Legislation reasoning and logic capabilities. The module provides reasoning and general logic mechanisms to identify potential building configurations based on the user's requirements. Based on the user requirements it will automatically identify compliant, technically and legally sound building configurations. This should guarantee the usability of the system even for users without strong experience in building science, such as estate agents and private home builders. A possibility could be a default setting for this input-data, which follows general laws and local regulations for standard users, and an advanced mode, which can be used by experts, who want to make more complex queries (e.g., what happens if codes from other countries are used instead of the local ones).

Energy performance queries typically spread over a broad range in both content and intent. Since energy performance queries are based on a multitude of dimensions and components the query space may become very large, resulting in an unacceptable system performance if immediate output is needed. SEMERGY intends to solve the system performance issue in a two-fold way: (i) The use of ontologies in the decision making process provides a unique way to pre-select the relevant components and thresholds. For example, if the user aims for energy performance level A+, the system automatically ignores all components (and dependencies) that do not support this level. (ii) The use of meta-heuristics allows us to identify the vast majority of efficient solutions at a fraction of the runtime that is required, e.g., by complete enumeration. In the first step the system provides the user with the status quo, i.e., the actual energy performance level of his/her building and the corresponding initial costs, running costs and energy consumption. In the next step the user decides to opt for energy performance level B, moves interactively the indicator arrow and the systems provides him immediately with the corresponding changes regarding initial costs, running costs and energy consumption (and the list of measures necessary to reach the intended level). Finally, the user decides to further reduce running costs. The system shows the user that higher initial costs are necessary to reach the indented level of running costs.

## III. Conclusion

SEMERGY supports the implementation of EU Directives, such as the climate and energy package or the Energy Performance of Buildings Directive as well as the Kyoto goals. It provides a novel decision support systems for the energy- and cost-efficient construction and renovation of buildings. The decision support system enables users to efficiently identify potential building configurations with regard to:

- Legal constraints such as the required usage of insulation that consumes only a limited amount of energy at its production
- Technical and physical special cases such removing existing thermal bridges at the building renovation
- Economic aspects. Profit ratio of investments such as renovations and solar collectors. Available funding.
- Detailed environment- and usage data such as hourly weather data (temperature, solar radiation, etc.)
- Micro climatic effects such as urban heat island effects
- Heat storage effects
- Obstructions because of surrounding buildings and terrain

The prototype developed within this project supports AEC professionals but especially focuses on making energy performance improvement available to private persons. Therefore, the developed prototype encapsulates the complexity and provides the user with an intuitive solution that can be used without training.

## Acknowledgment

This project is funded under the FFG Research Studios Austria programme (grant No. 832012) by the Austrian Federal Ministry for Economy, Family and Youth (BMWFJ).

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