# Information Modelling for Sustainable Buildings

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## ABSTRACT

Achieving sustainability has become an important goal in the construction, refurbishment, operation and management of buildings. To this end, we need to achieve greater information exchange, especially, about practices and solutions for Energy Efficiency (EE) and the use of Renewable Energy Sources (RES) in buildings. However, in the building life-cycle, complex and disparate information sources are used by various stakeholders, thus understanding, integrating, managing and providing means for sharing such information is a challenging task. In this paper, we analyze the possibilities to capture, distill and disseminate expert know-how related to sustainable buildings, addressing the needs of the various stakeholders. A Sustainable Building Profile ($SBP$) is presented, which is a novel conceptual model designed to integrate information on EE and RES aspects of buildings. The $SBP$ makes it possible to analyse the transformation of a particular building over time. Different stakeholders can use it to study various engineering, operation and maintenance problems in buildings related to energy efficiency.

## Categories and Subject Descriptors

H.4.0 [**Information Systems Applications**]: General

## General Terms

Design,Management

## Keywords

energy efficiency, ontology, knowledge base, sustainable building profile

## 1. INTRODUCTION

Currently, information, knowledge and data related to various aspects of building sustainability, especially Energy Efficiency (EE) and Renewable Energy Sources (RES) aspects of buildings, are fragmented among various stakeholders. Examples of key stakeholders are producers of various RES, engineering companies that offer building materials, techniques, products and services on the market, architects that contribute to the design of sustainable buildings, manufactures that contribute to the design of less energy consuming machines installed in buildings, governmental organisations that are involved in passing new regulations. These stakeholders pose several key questions in addresssing energy efficiency in buildings:

i What needs to be done in order to convert an existing building to a building with optimal EE and RES profile?

ii How to improve the operation and maintenance of a building in order to reduce energy consumtion?

iii How understanding of existing sustainable buildings could facilitate the construction and operation of newly-created sustainable buildings?

To this end, we need to explore the possibility to develop a knowledge base that facilitates the sharing of such information among various stakeholders. Since the information is widely distributed, it is challenging to analyse and come up with a conceptual model that will support the capturing, distillation, management and sharing of such data, information and knowledge over time. This requires the analysis of diverse information sources that can be integrated in such a knowledge base and devises a novel conceptual information model as the core element of the knowledge base.

Our goal is to develop a conceptual model addressing EE and RES aspects of buildings for understanding, measuring and increasing the EE of buildings. This paper contributes (i) detailed analysis of requirements for integrated information about sustainable buildings, (ii) a novel conceptual model for sustainable building profiles (SBPs), and (iii) an ontology-based implementation for the SBP model. Our work can be considered as a first step towards the development of an open knowledge base of practices related to achieving sustainable buildings.

## 2. BACKGROUND AND RELATED WORK

The interim results of the ongoing EU project IntUBE [4] show a detailed analysis of the building life-cycle with relation to needed EE aspects at different stages. Our work complements the IntUBE development and is a step further, as our work aims to integrate the information needed in order to assist the stakeholders along the building life-cycle (i.e. starting from the building design up to its operational state) from a number of sources.

In order to physically store the structural and architectural information about buildings, the Industry Foundation Classes (IFC)[1] are

[1] `http://buildingsmart-tech.org/specifications/ifc-releases/summary`


*iiWAS2011* 5-7 December, 2011, Ho Chi Minh City, Vietnam.

based on the eXtensible Markup Language (XML) and are used by a number of software tool-suites. IFC has been introduced as a standard by the International Alliance for Interoperability (IAI). The IFC represents the core of a Building Information Model (BIM) [3]. Current trends are to include EE and RES related data in such models. An example of such development is the Green Building XML schema, which does not contain concepts related to FM systems.

DIE-2[2] is widely used by experts for EE analysis of buildings mainly due to its sophisticated nature. Its detailed design is an advantage for expert users, however, it may not be easily used by facility managers, building owners and other stakeholders. Green Building Studio[3] is an application used in the design phase of a building and considers EE aspects of the building. An important goal of the proposed study is to cover the whole building life-cycle, not only the design phase. The goal of this study is to go beyond these developments in the area of AEC and to analyse the possibility of integration of other information sources, coming from other areas related to building sustainability and along the building life-cycle. These projects could make use of the high-level conceptual model of building sustainability developed under this study. Recent studies have also shown that it is possible to use ontology and an associate knowledge base of a building, to deal with quantitative data, such as acoustic properties of a building [7]. While they clearly demonstrate the advantages of using semantic web technologies, they do not cover rich information compared to our model and they do not apply to energy efficiency.

# 3. MODELING INFORMATION

## 3.1 Conceptualizing Building Profiles

The first step in our work is to define a *Sustainable Building Profile* (SBP) for characterizing EE buildings which at the same time employ RES. An $SBP$ basically includes high-level information representing sustainability indicators (quantitative or qualitative) associated with a building and consisting of information that can be used to determine these indicators. Information in an $SBP$ is valid in a certain time. An $SBP$ conceptualizes the following main types of information: (i) building structure and MEP (Mechanical, Electrical and Plumbing) elements, (ii) sensor-based measurements about energy consumption, GHG emission, quality and conformity, and (iii) operational costs, together with associated sustainability indicators, such as whether an HVAC is energy-efficient. These types of information are extracted from multiple sources, such as building information systems (BIM), building sensor systems, and facility management systems. Figure 1 depicts an $SBP$ and its information sources. An $SBP$ can be described as $SBP(bses, bmeps, measurements, costs, rating, time)$ where $bses$, $bmeps$, $measurements$, $costs$, $rating$ and $time$ describe building structure elements, building MEP systems, measurements, operational costs, overall rating, and valid time, respectively.

### *3.1.1 Building Structure and MEP Systems*

An $SBP$ will include main, well-defined concepts for building structure elements and building MEP systems. Examples of building structure elements are building floors, spaces, and zones, while building MEP systems include chiller, electricity sources, HVAC, to name just a few. These concepts are well-defined in AEC as well as facility management. The reason for including them into an $SBP$ is that their characteristics and operational status have a strong influence on how energy-efficient a building is. They mostly are provided from AEC phases. In order to integrate them, we utilize existing concepts defined IFC and/or COBIE [5]. Note that for building structure elements and building MEP systems, sustainability indicators can be how they support EE or RES (e.g., in case of materials), measurements and operational costs, e.g., energy consumption of a HVAC. With respect to information related to EE and RES, the following information will be included:

- Use of RES, e.g. include solar thermal systems, buildings' integrated photovoltaic elements, hybrid systems, biomass, and heat pumps.
- Use of EE appliances and compact fluorescent lighting, Light-Emitting Diode (LED) technology etc. In the context of the transfer of measures that contribute to efficient energy use in public and residential buildings.

In the following subsections we will discuss measurements and operational costs associated with building structure elements and building MEP systems.

### *3.1.2 Measurements*

Using intelligent energy management, i.e. advanced sensors, energy control (zone heating and cooling) and monitoring systems, we can provide several types of information characterizing the operation and behaviors of buildings and their elements. Therefore, $SBP$ will include different sustainability measurements associated with building structure elements and building MEP systems. Typically, such measurements will be provided by facility management systems, such as the Galaxy Platform [2]. In our SBP a measurement is described as $measurement\ (name, value, time)$. A measurement can be associated with any building structure element or building MEP system/component. Since the number of building structure elements and MEP systems is possibly large, they are also organized into a hierarchical view (e.g. building structure elements) it may be necessary to organise measurements only at higher hierarchical levels. An $SBP$ will also include operational costs, such as electricity, maintenance and fuel costs. In our $SBP$, we represent $cost(category, value)$.

## 3.2 Gathering Information for SPB

Information in sustainable building profiles can be provided by different stakeholders, such as architects, construction engineers, machine engineers, producers of a variety of ecological and RES products, facility operators and regulators via different phases in the life-cycle of buildings. The information gathering can be performed via automatic processes, such as for sensor-based measurements, or manual processes, e.g., for operational costs. It can be based on processes to extract information from other systems, e..g, from building management systems and building information systems. However, so far, each stakeholder manages her/his own data and there is a lack of integrated processes for obtaining different types of data. Therefore, there is the need to integrate the processes to be able to capture, distill, analyze and disseminate data (e.g. energy indicators) of public, commercial and residential buildings. Without such data it is very difficult to identify the optimality of the proposed measures, best practices and possibilities of alternative building designs. Moreover, the integration of information could lead to a number of other benefits, e.g. investors could use such information as part of the planning processes and as well as a comprehensive information system designed to improve EE with improved comfort and other performance criteria. However, such integrated processes are complex and out of scope of the present paper.

[2]http://www.doe2.com
[3]http://gbs.autodesk.com

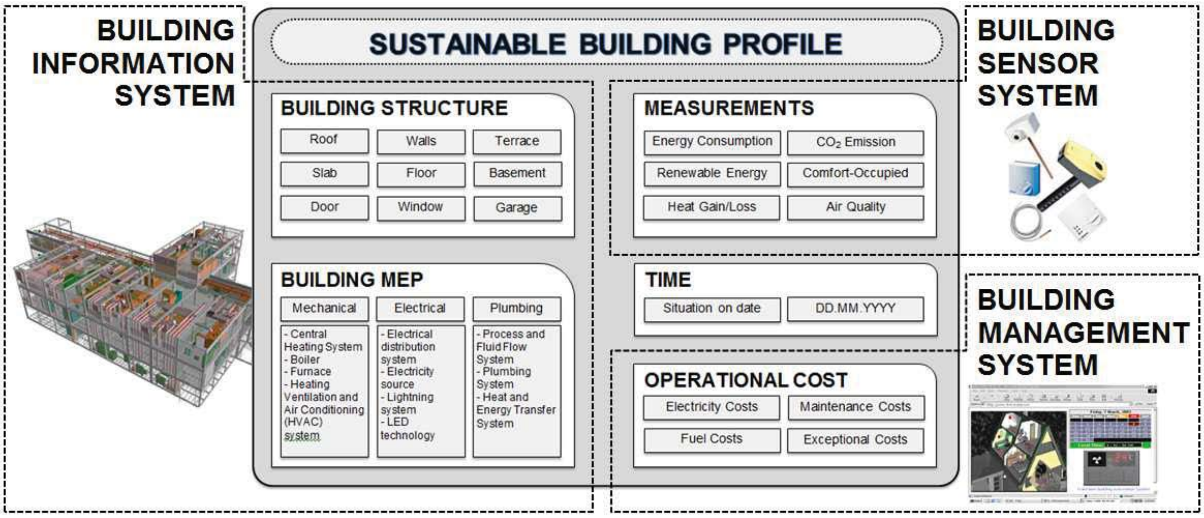


**Figure 1: A high-level overview of the sustainable building profile and related information sources**

### 3.3 Change Management for Building Profiles

An $SBP$ can be used to store an instance of building information in a period of time. However, during the life-time of a building, several instances of $SBP$ for a single building should be managed. Therefore, an important requirement for this work is to be able to manage information about sustainability of a building over time.

Particular attention is given to be able to capture information related to the following activities frequently performed on buildings:

- Measures for the improvement of the building's envelope, including addition or improvement of thermal insulation, placement and shading of EE doors and windows, increase of thermal mass, optimum shape factor of the thermal envelope, etc.
- Measures for reducing the heating and cooling loads, including exploitation of bioclimatic architecture, passive design, and incorporation of passive heating and cooling techniques (i.e., cool coatings, control of solar gains, and electrochromic glazing).
- Measures for 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, EE systems of distribution, storing and heat emissions, EE boilers etc.

In doing so, we propose to use versioning techniques to manage profiles of sustainable buildings. Given a building, we can represent a sustainable building profile, *sbp*, as a set of building profiles $sbp = \{bp_1(t_1) \rightarrow bp_2(t_2) \cdots \rightarrow bp_n(t_n)\}$ whereas an $bp_i(t_i)$ describes an instance version $i$ at the period of time $t_i$.

### 3.4 Potential Applications

As $SBP$ integrates several information sources along a building lifetime, a number of applications can be built atop that can be used by the various stakeholders. In the following section we discuss some of the possible applications, however, the detail design of such applications is out of the scope of the present paper.

It is important to realise that understanding common knowledge about sustainable buildings and how to achieve energy efficient buildings is of high interest to most of the stakeholders, such as AEC engineers, owners and facility managers. Existing approaches do not sufficiently cover all aspects as they do not have the capacity to integrate factual data and information from a variety of sources in a completely open knowledge base. The current approach is that an AEC company stores its own data, FM store their own data and so on. In the information integration approach presented in this study, it is possible to analyse the collected data to provide factual data about the utility, EE and RES aspects of the various techniques used to achieve building sustainability. That is, once the sustainability building profile is established and information is collected, we can analyze those data by means of statistical methods and machine learning techniques.

## 4. PROTOTYPE AND EXPERIMENT

The developed conceptual model integrates data, information and knowledge from a variety of sources. In order to implement the model and the underlying knowledge base a variety of technologies can be used. Our approach is to use Semantic Web technologies since they demonstrate a number of advantages over data base technologies [6]. Moreover, semantic web standards are designed for the web as a whole, thus making it possible to integrate information contained in web sites (e.g. web sites of producers of RES) as well as of data contained in proprietary information systems today and in the future.

We implement $SBP$ by using the OWL language. The developed profile is organised according to types of near zero-energy constructed buildings, renovating/refurbishment techniques, and the knowledge of different profile users (stakeholders) i.e. building owners, material manufacturers, architects, mechanical engineers, electrical engineers, civil engineers, construction managers, interior designers, contractors, facility managers, environmental engineers. Figure 2 presents some important entities in our ontology-based $SBP$. 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, EE heating system, EE windows, properties of insulation materials, photovoltaic elements, process descriptions, measures and technologies etc. We explain some of main entities in the following.

Each building will be characterized a *SustainableBuildingProfile*, which links to different stakeholders (specified by *Stakeholder* and its subclasses), to a snapshot of building profile, specified by

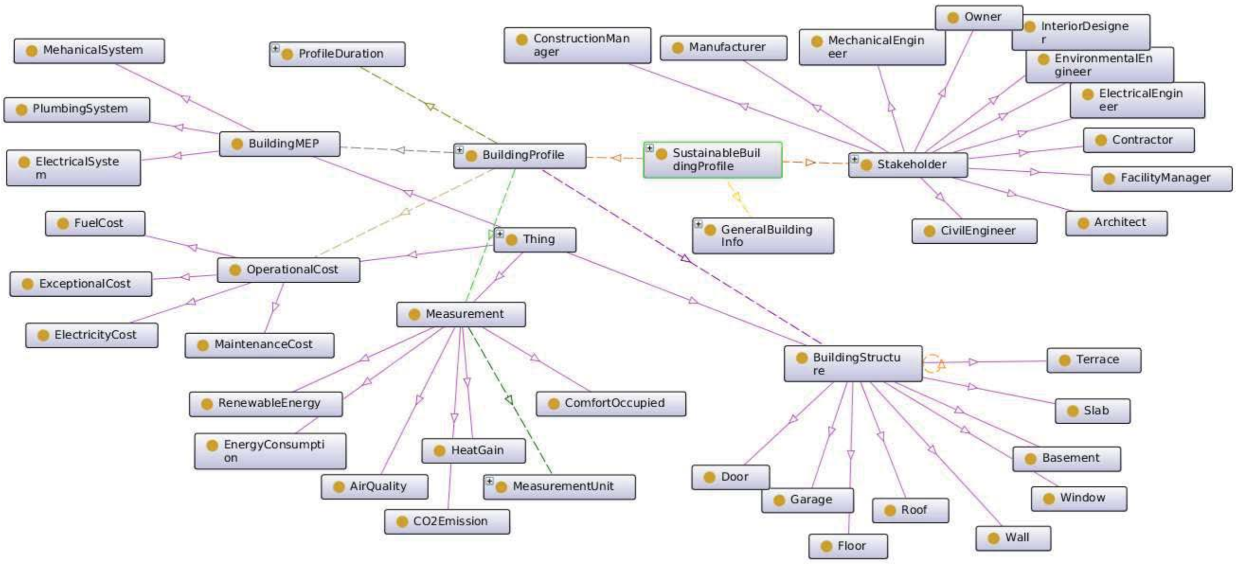


**Figure 2: An ontology implementation of a Sustainable Building Profile**

*BuildingProfile*, and to generic building information, specified by *GeneralBuildingInfo*. *BuildingProfile* is used to manage information about building MEP systems (specified by *BuildingMEP*), operational costs (specified by *OperationalCost*), measurements (specified by *Measurement*), and building structures (specified by *BuildingStructure*). Each building profile instance will be associated with a duration (specified by *ProfileDuration*) in which information in the profile is valid. In our implementation, *BuildingStructure* will consists other *BuildingStructure*, considered as sub elements.

In populating the information for *SubstainableBuildingProfile*, it is up to the user to decide the duration of a building profile. Furthermore, if a part of information in a profile in a duration does not change, e.g., building structures, it does not need to store such a part again in the profile in the next duration. Using linked profiles and durations, unchanged information can be detected.

## 5. CONCLUSIONS AND FUTURE WORK

The key outcome of this work is the SBP, which conceptualizes EE and RES aspects of buildings as needed by the various stakeholders beyond the area of AEC. A number of use case scenarios were analysed and it is shown that it is possible to integrate diverse information sources (from BIM, FM tools and similar) in an open knowledge base. The developed SBP makes it possible to describe specific materials, processes and techniques used throughout the building life-cycle, which is an advantage over single tools and solutions geared towards calculating certain aspects of EE in buildings.

The SBP is 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 SBP was implemented by using the OWL language, which makes it possible to gradually extend it with other relevant concepts (e.g. on new materials, techniques, processes) as soon as they become available. In our future work, we will continue to elaborate our ontology and build scalable knowledge systems for gathering information from multiple sources. Furthermore, we will focus on information extraction techniques to inteface our system to existing building structure and facility management systems.

## 6. ACKNOWLEDGEMENTS

The operation part of this research is financed by the European Union, European Social Fund, within the framework of the Operational Programme for Human Resources Development for the Period 2007-2013, Priority axis 1: Promoting entrepreneurship and adaptability, Main type of activity 1.1.: Experts and researchers for competitive enterprises. The work is also partial funded by the Pacific Controls Cloud Computing Research Lab.

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