EEBuilding
Data Models

OCTOBER 2011

Proceedings of the
2nd Workshop organised by the
EEB Data Models Community
CIB Conference W078-W012, 26-28 October 2011
Sophia Antipolis - France
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Foreword
by the European Commission

Building use is the source of some 40% of the energy consumption in Europe. Throughout its lifecycle, a building is managed by different IT tools. At the design phase of a building, architects use CAD systems, which today are often enhanced with software that takes account of its energy consumption. Ideally, the building’s energy modelling data would be exported to building energy management systems that optimize energy consumption during its use phase. These systems could in turn obtain data from sensor clouds and energy meters, and be capable of issuing commands to white goods and HVAC systems. Plug and play principles would make such systems user friendly. If and when micro and mini energy renewable sources become commonplace in buildings, they will also need to be integrated into the building energy management systems. If consumers are to have the possibility to sell energy back to the grid, semantics will be needed to enable this to work independently of the energy provider.

The requirements of interoperability between all these IT tools are therefore high. And with many low level protocols competing for the Home Area Network, discussions are often confused. If ICT is to be successful in this domain, standardisation will have to come in to play. For interoperability to become a reality, the first condition to be met is to agree on the high level data models, where standardisation can be more easily proposed and achieved.

Standardisation and interoperability are both priorities in the European Commission's Digital Agenda for Europe and several actions have been set out to promote EU-wide standards to ensure interoperability.

The Commission is exploring how standards can help to bridge the gap between research and marketable products and services, we are exploring the role of ICT standards developed by fora and consortia, we are promoting appropriate rules for essential intellectual property rights and licensing conditions in standard-setting, we are promoting interoperability between public administrations, and we are promoting open access to interoperability information in devices and applications.

The Commission welcomes this 2nd Workshop on Energy Efficient Data Models, a workshop that will promote the harmonization of approaches across research in this area, as an important milestone towards standards that can be agreed by industry, market players and public authorities and boost the interoperability of the applications and tools that support energy efficiency.

Colette MALONEY
Head of Unit,
EUROPEAN COMMISSION
Keynote message
by EEBA

In the whole context of Energy Efficient Buildings the creation of shared and agreed methodologies, models and standards is becoming a relevant issue to foster the adoption of novel technologies really able to effectively tackle energy savings and GHG reduction. For this reason, from its very beginning E2B Association has been aware of the relevant aspects of integration and interoperability, and in the development of the “Energy-Efficient Buildings PPP Multi-Annual Roadmap and Long Term Strategy” a great importance has been devoted to these challenges, considering integration of technologies as an enabling step to create real and "market-ready" energy efficient solutions.

Moreover, it is worth noticing that in the future development of carbon-neutral districts and cities (supported by several initiatives as Covenant of Mayors, Green Digital Charter, Urban Europe and others), buildings really lie at the heart of most of the issues and future solutions, and have to interact with other key areas / sectors (lighting, smart grid, etc.), but a major difficulty is that all the energy-related elements in districts (buildings, dedicated nodes producing or storing energy, smart grids, ...) still lie with rather poorly defined interfaces between them.

Within this framework, ICT solutions for Energy Efficient building suffer even more of this lack of integration and interoperability. In fact a lot of energy-related models are under development or refinement, but few (if none) of them have been tangibly assessed in a practical way and over a long period in time, and all these models are developed without real coordination and keeping in mind generalization and interoperability issues. Consequently, as current models are not leading to any sort of standards and ICT solutions based on them are not developed following such standards, they are not enough disseminated and tangibly used in Europe and world-wide: standardization will allow the reuse and spread of current and future R&D results.

As a consequence, a huge focus on interoperability is required and there is a desperate need to address interoperability issues between building subsystems, building and other buildings, building and other sectors, particularly smart grids (not only electric but also water, waste, heat/cool, etc...) – relying on semantic technologies, typically ontology engineering and ontology matching for interoperability inside and between Buildings. It must be kept in mind as well that another major interoperability problem is linked to the fact that utility companies are advancing very fast and strongly in providing standards in their own way without considering deeply enough how buildings operate or what the interactions to consider with buildings are. They do not consider users’ comfort, safety, etc. but just focus on energy trade (consumption, price). This takes place while the building sector is far from being active enough in terms of development of common models and standards for energy efficiency. As a consequence, there is a strong urgency to come back with standards to
provide interoperability models and tools taking into consideration all levels of complexity in energy management and optimization.

Within this urgent framework, the completed REEB project and the ongoing ICT4E2B Forum project (both supported by DG INFSO – Unit H4) are achieving a coherent vision that need to be complemented in strengthening future interoperability standards and ICT solutions, while at the same time the REViSITE project is working on similar achievements at the crossing of 4 sectors (Building, Lighting, Smart Grid, Smart Manufacturing), also in the development of communities influencing interoperability of the interfaces between buildings and other sectors.

Within this very active and rich context, we strongly believe that EEB Data Model Workshop is to be a fundamental step to launch a long-term brainstorming around standard models for “energy interoperation” in buildings, between buildings, and beyond (over districts and cities) - also relying on current efforts by FP7 projects from Unit H4 of DG INFSO for moving toward standardisation of E2B models developed by the various RTD projects – as buildings and the way they operate are considered as key elements in optimisation of energy management in districts.

Mr. Luc Bordeau, CSTB
Secretary General
http://www.e2b-ei.eu/default.php
1. Session: Ontological Engineering
State of the Art

1.1. Paper: Essentials In Ontology Engineering:
Methodologies, Languages, And Tools

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Abstract

In the beginning of the 90s, ontology development was similar to an art: ontology developers did not
have clear guidelines on how to build ontologies but only some design criteria to be followed. Work on
principles, methods and methodologies, together with supporting technologies and languages, made
ontology development become an engineering discipline, the so-called Ontology Engineering.
Ontology Engineering refers to the set of activities that concern the ontology development process
and the ontology life cycle, the methods and methodologies for building ontologies, and the tool
suites and languages that support them. Thanks to the work done in the Ontology Engineering field,
the development of ontologies within and between teams has increased and improved, as well as the
possibility of reusing ontologies in other developments and in final applications. Currently, ontologies
are widely used in (a) Knowledge Engineering, Artificial Intelligence and Computer Science, (b)
applications related to knowledge management, natural language processing, e-commerce, intelligent
information integration, information retrieval, database design and integration, bio-informatics,
education, and (c) the Semantic Web, the Semantic Grid, and the Linked Data initiative. In this paper,
we provide an overview of Ontology Engineering, mentioning the most outstanding and used
methodologies, languages, and tools for building ontologies. In addition, we include some words on
how all these elements can be used in the Linked Data initiative.

Keywords: Ontology engineering, ontology development methodologies, ontology languages,
ontology tools.

1.1.1. Introduction

Ontologies play an important role for many knowledge-intensive applications, since they provide
formal models of domain knowledge that can be exploited in different ways. Currently, ontologies are
used in (a) Knowledge Engineering, Artificial Intelligence and Computer Science, (b) applications related to knowledge management, natural language processing, e-commerce, intelligent information integration, information retrieval, database design and integration, bio-informatics, education, and (c) the Semantic Web, the Semantic Grid, and the Linked Data initiative.

During the last two decades, increasing attention has been focused on ontologies and their development. Indeed, ontology development has become an engineering discipline, Ontology Engineering, which refers to the set of activities that concern the ontology development process and the ontology life cycle, the methods and methodologies for building ontologies, and the tool suites and languages that support them.

When ontologies are going to be built, several basic questions arise related to the methodologies, languages, and tools to be used in their development processes:

- Which methods and methodologies can be used for building ontologies? Which activities are performed when building ontologies with a particular methodology? Does any methodology support building ontologies cooperatively? Which is the life cycle of an ontology that is developed with a specific methodology?
- Which language(s) should be used to implement an ontology? What expressiveness has an ontology language? What are the inference mechanisms attached to an ontology language? Is the language chosen appropriate for exchanging information between different applications? Does the language ease the integration of the ontology in an application?
- Which tool(s) give/s support to the ontology development process? Does the tool have an inference engine? How can applications interoperate with ontology servers and/or use the ontologies that we have developed?

Along this paper, we present the basics about ontologies, and show what methodologies, languages, and tools are available to give support to different activities of the ontology development process. The content of this paper can help practitioners and researchers in this field to obtain answers to the some of the previous questions. In addition, we include some words on how these elements (methodologies, languages, and tools) can be used in the Linked Data initiative. First, in Section 2, we define the world ‘ontology’ and briefly describe its main components. After that, in Section 3, we enumerate methodologies commonly used for building ontologies. In Section 4, we summarize the most used ontology languages and in Section 5, we present some tools used in the ontology development process. In Section 6, we provide some guidelines on how to publish linked data. Finally, we present some conclusions.

1.1.2. Ontology definition and its main components

The word ontology was taken from Philosophy, where it means a systematic explanation of being. There are many definitions about what an ontology is and such definitions have changed and evolved over the years. However, Studer and colleagues (Studer et al., 1998) provide one of the most well known definitions: "An ontology is a formal, explicit specification of a shared conceptualization. Conceptualization refers to an abstract model of some phenomenon in the world by having identified the relevant concepts of that phenomenon. Explicit means that the type of concepts used, and the
constraints on their use are explicitly defined. Formal refers to the fact that the ontology should be machine-readable. Shared reflects the notion that an ontology captures consensual knowledge, that is, it is not private of some individual, but accepted by a group”.

Ontologies can be modelled with different knowledge modelling techniques and they can be implemented in various kinds of languages based on different knowledge representation formalisms. It is important to mention here that there are connections and implications between the knowledge modelling components (concepts, roles, etc.) used to build an ontology, the knowledge representation paradigms (frames, description logics, logic) used to represent formally such components, and the languages used to implement the ontologies under a given knowledge representation paradigm. However, they share the following minimal set of components:

- **Classes** represent concepts, which are taken in a broad sense. For instance, in the domain of Energy Efficiency at Buildings, concepts are *Building, Door, Window, Device, Sensor*, etc. Classes in the ontology are usually organized in taxonomies through which inheritance mechanisms can be applied. We can represent a taxonomy of sensors (*Scanning Sensor, Optical Sensor, Touch Trigger Sensor*, etc.) or different types of doors in buildings (*Inner Door, Outer Door, Sliding Door, Rotating Door, or Strongroom Door*).

- **Relations** represent a type of association between concepts of the domain. They are formally defined as any subset of a product of n sets, that is: \( R \subseteq C_1 \times C_2 \times \ldots \times C_n \). Ontologies usually contain binary relations. The first argument is known as the domain of the relation, and the second argument is the range. For instance, the binary relation *locatedIn* has the concept *Building* as its domain and the concept *Location* as its range; in addition, this relation can have the concept *Device* as domain. Binary relations are sometimes used to express concept attributes (aka slots). Attributes are usually distinguished from relations because their range is a datatype, such as string, number, etc., while the range of relations is a concept.

- **Formal axioms**, according to (Gruber, 1993), serve to model sentences that are always true. They are normally used to represent knowledge that cannot be formally defined by the other components. In addition, formal axioms are used to verify the consistency of the ontology itself or the consistency of the knowledge stored in a knowledgebase. Formal axioms are very useful to infer new knowledge. An axiom in the Energy Efficiency at Buildings domain could be that it is not possible to build a public building without a fire door (based on legal issues).

- **Instances** are used to represent elements or individuals in an ontology.

**1.1.3. Foremost methodologies for building ontologies**

METHONTOLOGY, On-To-Knowledge, and DILIGENT were up to 2009 the most referred methodologies for building ontologies. These methodologies mainly include guidelines for single ontology construction ranging from ontology specification to ontology implementation and they are mainly targeted to ontology researchers. In contrast to the aforementioned approaches, a new methodology, called the NeOn Methodology, suggests pathways and activities for a variety of scenarios, instead of prescribing a rigid workflow.
In this section, we summarize the four abovementioned methodologies, describing in more detailed the current trend in ontology building presented in the NeOn Methodology.

**The NeOn Methodology** (Suárez-Figueroa, 2010) for building ontology networks is a scenario-based methodology that supports a knowledge reuse approach, as well as collaborative aspects of ontology development and dynamic evolution of ontology networks in distributed environments.

The key assets of the NeOn Methodology are:

- A set of nine scenarios for building ontologies and ontology networks, emphasizing the reuse of ontological and non-ontological resources, the reengineering and merging, and taking into account collaboration and dynamism.
- The NeOn Glossary of Processes and Activities, which identifies and defines the processes and activities carried out when ontology networks are collaboratively built by teams.
- Methodological guidelines for different processes and activities of the ontology network development process, such as the reuse and reengineering of ontological and non-ontological resources, the ontology requirements specification, the ontology localization, the scheduling, etc. All processes and activities are described with (a) a filling card, (b) a workflow, and (c) examples.

The set of nine scenarios for building ontologies and ontology networks can be summarized as follows:

- **Scenario 1: From specification to implementation.** The ontology network is developed from scratch (without reusing existing resources). Developers should specify ontology requirements (Suárez-Figueroa et al., 2009). After that, it is advisory to carry out a search for potential resources to be reused. Then, the scheduling activity (Suárez-Figueroa et al., 2010) must be performed, and developers should follow the plan to develop the ontology network.

- **Scenario 2: Reusing and re-engineering non-ontological resources (NORs).** Developers should carry out the NOR reuse process for deciding, according to the ontology requirements, which NORs can be reused to build the ontology network. Then, the selected NORs should be re-engineered into ontologies (Villazón-Terrazas et al., 2010).

- **Scenario 3: Reusing ontological resources.** Developers use ontological resources (ontologies as a whole, ontology modules, and/or ontology statements) to build ontology networks.

- **Scenario 4: Reusing and re-engineering ontological resources.** Ontology developers reuse and re-engineer ontological resources.

- **Scenario 5: Reusing and merging ontological resources.** This scenario arises when several ontological resources in the same domain are selected for reuse, and developers wish to create a new ontological resource with the selected resources.

- **Scenario 6: Reusing, merging and re-engineering ontological resources.** Ontology developers reuse, merge, and re-engineer ontological resources. This scenario is similar to Scenario 5, but here developers decide to re-engineer the set of merged resources.

- **Scenario 7: Reusing ontology design patterns (ODPs).** Ontology developers access repositories (e.g., http://ontologydesignpatterns.org/) to reuse ODPs.
Scenario 8: Restructuring ontological resources. Ontology developers restructure (e.g., modularize, prune, extend, and/or specialize) ontological resources to be integrated in the ontology network.

Scenario 9: Localizing ontological resources. Ontology developers adapt an ontology to other languages and culture communities, thus obtaining a multilingual ontology (Espinoza et al., 2009).

- **METHONTOLOGY** (Gómez-Pérez et al., 2003) enables the construction of ontologies at the knowledge level. It includes (a) the identification of the ontology development process (which tasks should be performed when building ontologies); (b) a life cycle based on evolving prototypes; and (c) some techniques to carry out management, development-oriented, and support activities. In addition, METHONTOLOGY includes a list of activities to be carried out during ontology reuse and re-engineering processes, but it does not provide detailed guidelines for such activities, nor does it consider different levels of granularity during the reuse of ontological resources (e.g., modules or statements). Moreover, METHONTOLOGY considers neither the reuse and re-engineering of non-ontological resources nor the reuse of ODPs.

- **The On-To-Knowledge methodology** (Staab et al., 2001) proposes to build ontologies taking into account how these are going to be used in knowledge management applications. The processes proposed by this methodology are the following: feasibility study, kickoff, where ontology requirements are identified, refinement, where a mature and application-oriented ontology is produced, evaluation, and maintenance. With respect to the reuse of knowledge resources, in the kickoff process it is mentioned that developers should look for potentially reusable ontologies. However, this methodology does not provide detailed guidelines for identifying such ontologies nor for reusing them. Besides, the methodology does not explicitly mention guidelines for the reuse and re-engineering of non-ontological resources, nor for the reuse of ontology design patterns.

- **The DILIGENT methodology** (Pinto et al., 2004) is intended to support domain experts in a distributed setting in order to engineer and evolve ontologies. This methodology is focused on collaborative and distributed ontology engineering. Its ontology development process includes the following five activities: building, local adaptation, analysis, revision, and local update. With regard to the reuse of knowledge resources, the methodology does not include guidelines for the reuse and re-engineering of existing knowledge resources.

### 1.1.4. Major ontology languages

Different ontology languages have different expressiveness and inference mechanisms, since the knowledge representation paradigms underlying all these languages are diverse. Therefore, one of the key decisions to take in the ontology development process is to select the language (or set of languages) in which the ontology will be implemented.

Next, we present an overview of the current specifications for ontology languages developed in the scope of the W3C Semantic Web Activity (http://www.w3.org/2001/sw/).
**RDF.** RDF (Klyne and Carroll, 2004) stands for Resource Description Framework. It was developed by the W3C to create metadata for describing web resources and its data model is equivalent to the semantic networks formalism, consisting of three object types: resources, properties and statements.

**RDF Schema.** The RDF data model does not have mechanisms for defining the relationships between properties and resources. This is the role of the RDF Vocabulary Description language (Brickley and Guha, 2004), also known as RDF Schema. RDF(S) is the term commonly used to refer to the combination of RDF and RDFS. Thus, RDF(S) combines semantic networks with frames but it does not provide all the primitives that are usually found in frame-based knowledge representation systems.

**OWL.** OWL (Dean and Schreiber, 2004) is the result of the work of the W3C Web Ontology Working Group. This language derived from DAML+OIL (van Harmelen et al., 2001) and, as the previous languages, is intended for publishing and sharing ontologies in the Web. OWL is built upon RDF(S), has a layered structure and is divided into three sublanguages: OWL Lite, OWL DL and OWL Full. OWL is grounded on Description Logics (Baader et al., 2002) and its semantics is described in two different ways: as an extension of the RDF(S) model theory and as a direct model-theoretic semantics of OWL. Both of them have the same semantic consequences on OWL ontologies.

**OWL 2.** OWL 2 (Motik et al., 2009) is an extension and revision of OWL that adds new functionality with respect to OWL; some of the new features are syntactic sugar (e.g., disjoint union of classes) while others offer new expressivity. OWL 2 includes three different profiles (i.e., sublanguages) that offer important advantages in particular application scenarios, each trading off different aspects of OWL’s expressive power in return for different computational and/or implementational benefits. These profiles are:

- OWL 2 EL that is particularly suitable for applications where very large ontologies are needed, and where expressive power can be traded for performance guarantees.
- OWL 2 QL that is particularly suitable for applications where relatively lightweight ontologies are used to organize large numbers of individuals and where it is useful or necessary to access the data directly via relational queries (e.g., SQL).
- OWL 2 RL that is particularly suitable for applications where relatively lightweight ontologies are used to organize large numbers of individuals and where it is useful or necessary to operate directly on data in the form of RDF triples.

OWL 2 provides two alternative ways of assigning meaning to OWL 2 ontologies: the Direct Semantics that assigns meaning directly to ontology structures and the RDF-Based Semantics that assigns meaning directly to RDF graphs.

**SPARQL.** Even if it is not an ontology language, we mention SPARQL (Prud’hommeaux and Seaborne, 2008) here because it supports querying the previous languages. SPARQL allows performing queries over RDF data and, since both RDF-S and OWL are based in RDF, also over RDF-S and OWL ontologies. SPARQL can be used to express queries across diverse data sources and its syntax is similar to SQL to facilitate its adoption.
1.1.5. Leading ontology tools

The landscape of tools that manage and exploit ontologies is broad and covers from the creation of these ontologies to their storage or visualization.

Next, we describe the different dimensions in which semantic technologies can be classified according to their functionalities (see Figure 1); these dimensions are based in the Semantic Web Framework (García-Castro et al., 2008). Each dimension description contains the names of some relevant tools.

![Semantic technology dimensions diagram](image)

**Figure 1:** Semantic technology dimensions (adapted from García-Castro et al., 2008)

- **Ontology management.** This dimension includes components that manage ontology-related information.
  - The **Ontology repository** stores and accesses ontologies and ontology instances (e.g., 3Store, AllegroGraph, Corese, Hawk, Jena, Kowari, OWLIM, Sesame, Virtuoso Universal Server, 4store).
  - The **Alignment repository** stores and accesses alignments (e.g., Alignment Server, COMA++).
  - The **Ontology metadata registry** stores and accesses ontology metadata information (e.g., Oyster, SchemaWeb). This metadata information can be described using OMV (http://mayor2.dia.fi.upm.es/oeg-upm/index.php/en/downloads/75-omv), the Ontology Metadata Vocabulary.
  - The **Ontology management programming interfaces** provide programming interfaces for managing ontologies and ontology instances (e.g., OWL API, RDF2Go, SemWeb.NET, Pubby, Elda).

- **Querying and reasoning.** This dimension includes components that generate and process queries.
The **Ontology reasoner** takes care of reasoning over ontologies and ontology instances (e.g., CEL, Cerebra Engine, FaCT ++, fuzzyDL, HermiT, KAON2, MSPASS, Pellet, QuOnto, RacerPro, SHER, SoftFacts, TrOWL).

The **Semantic search** component takes care of the user interface for editing queries and of their corresponding processing (e.g., ARQ, Ginseng, K-Search, NLP-Reduce, Ontogator, PowerAqua, SemSearch).

The **Ontology discovery and ranking** component finds appropriate views, versions or subsets of ontologies, and then ranks them according to some criterion (e.g., Swoogle, Watson, Sindice).

- **Ontology engineering.** This dimension includes components that provide functionalities to develop and manage ontologies.
  
  The **Ontology editor** allows creating and modifying ontologies, ontology elements, and ontology documentation. These functionalities include a single element edition or a more advanced edition such as ontology pruning, extension or specialization (e.g., DODDLE, graphl, GrOWL, ICOM, IsaViz, NeOn Toolkit, Ontotrack, Powl, Protégé, SemanticWorks, SemTalk, SWOOP, TopBraid Composer).

  The **Ontology browser** allows to visually browse an ontology (e.g., Brownsauce, BrowseRDF, Disco, facet, Fenfire, Jambalaya, Longwell, mSpace, OINK, Ontosphere 3D, Ontoviz, OWLViz, RDF Gravity, Tabulator, TGVizTab, Welkin).

  The **Ontology learner** acquires knowledge and generates ontologies of a given domain through some kind of (semi) automatic process (e.g., KEA, OntoGen, OntoLearn, Text2Onto, TERMINAE).

  The **Ontology versioner** maintains, stores and manages different versions of an ontology (e.g., SemVersion).

- **Ontology processing.** This dimension includes components that process ontologies.

  The **Ontology matcher** matches two ontologies and outputs some alignments. We can distinguish two types of such systems: those that generate alignments and those that use alignments for other tasks, such as merging or mediating (e.g., AgreeMaker, AMW, AROMA, ASMOV, AUTOMS, CMS, CODI, COMA, Ef2Match, Falcon-AO, Gerome, HMatch, Lily, MapOnto, Mapso, OLA, OntoBuilder, PROMPT, RiMOM, S-Match, SAMBO).

  The **Ontology localization and profiling** component adapts an ontology according to some language, context or user profile (e.g., LabelTranslator, lemon editor).

  The **Ontology evaluator** evaluates ontologies, either their formal model or their content, in the different phases of their life cycle (e.g., CleOn, ConsVISor, Eyeball, VRP).

- **Instance generation.** This dimension includes components that generate ontology instances.

  The **Instance editor** allows manually creating and modifying instances of concepts and of relations between them in existing ontologies (e.g., GATE, OCAT).

  The **Manual annotation** component is in charge of manual and semi-automatic annotation of digital content documents (e.g. web pages) with concepts in the ontology. This annotation process may be assisted or guided by a machine (semi-automatic annotation) (e.g., GATE, OCAT, OntoMat, Magpie, M-OntoMat, PhotoStuff).
The Automatic annotation component automatically annotates digital content (e.g., web pages) with concepts in the ontology (e.g., KIM, GATE-ML).

The Ontology populator automatically generates new instances in a given ontology from a data source (e.g., CLIE, NOR2O, R2O & ODEMapster, geometry2rdf).

The Instance matcher automatically is in charge of manual and semi-automatic matching of instances from different ontologies (e.g., SILK, LIMES).

Regarding the ontology engineering dimension, of special relevance are those software platforms that cover more than one of the aforementioned components and that support most of the activities in the ontology development process. In this paper, we focus on the new generation of ontology engineering environments, particularly, on NeOn Toolkit, Protégé, and TopBraid Composer. They have extensible, component-based architectures, where new modules can easily be added to provide more functionality to the environment.

- **The NeOn Toolkit** ([http://neon-toolkit.org/](http://neon-toolkit.org/)) is an ontology engineering environment that supports the complete life cycle of large-scale ontology networks. In order to support such a broad ontology modelling functionality, it has an open and modular architecture, which the NeOn Toolkit inherits from its underlying platform, Eclipse. Eclipse is a very rich development environment, which is widely adopted in the programming world and which perfectly fits to the modelling paradigm for ontologies. It provides developers with a framework to easily create, publish and integrate new features into the NeOn Toolkit. A substantial number of so-called plug-ins has been developed within and outside the NeOn consortium and are available at NeOn Toolkit homepage.

The NeOn Toolkit is available as an installable core version with the basic ontology functionality such as editing, browsing, ontology and project management. Currently, the following versions are available:

- The basic NeOn Toolkit provides the core functionality for handling OWL 2 ontologies.
- The NeOn Toolkit extended configuration includes advanced functionality for managing rule based models and ontology mapping facilities based on commercial extensions.

- **Protégé** ([http://protege.stanford.edu/](http://protege.stanford.edu/)) is an open platform for ontology modelling and knowledge acquisition. It is an open source, standalone application with an extensible architecture. The core of this environment is the ontology editor, and it holds a library of modules that can be plugged, called plug-ins, to add more functions to the environment. The main Protégé functions are to: load and save OWL and RDF ontologies; edit and visualize classes, properties, and SWRL rules; define logical class characteristics as OWL expressions; execute reasoners such as description logic classifiers; and edit OWL individuals for Semantic Web markup. Protégé is available in different versions, each including different plug-ins, whose main difference is the ontology language that they support:
  - Protégé version 3 supports OWL 1.0, RDF(S) and Frames.
  - Protégé version 4 supports OWL 2.0.

- **TopBraid Composer** ([http://www.topquadrant.com/products/TB_Composer.html](http://www.topquadrant.com/products/TB_Composer.html)) is a modelling environment for developing Semantic Web ontologies and building semantic applications. It is
fully compliant with W3C standards and offers support for developing, managing and testing configurations of knowledge models and their instance knowledge bases. It is implemented as an Eclipse plug-in.

TopBraid Composer incorporates a flexible and extensible framework with a published API for developing semantic client/server or browser-based solutions that can integrate disparate applications and data sources.


1.1.6. Ontology Engineering in Linked Data: How to publish data

Publishing Linked Data is a process that involves a high number of steps, design decisions as well as a wide range of technologies. Although some initial guidelines have been already provided by Linked Data publishers, these are still far from covering all the steps that are necessary (from data source selection to its publication) or giving enough details about all the steps. In this section, we summarize a set of methodological guidelines for the activities involved in the Linked Data publishing process. These guidelines consist of the following activities: (1) identification of the data sources; (2) vocabulary modelling; (3) generation of the RDF data; (4) publication of the RDF data; and (5) linking the RDF data with other datasets in the cloud.

1. Identification of the data sources. Within this activity, we identify and select the datasets that we want to publish. This is normally a costly and tedious activity that may require contacting the data owners, and government bodies. If lucky, we may have that data already available in a public data catalogue. A representative example of these catalogues in the Spanish context is the Aporta project (http://www.aporta.es) catalogue. Other possibility is to get an agreement with a particular government body to publish its datasets.

In the case of GeoLinkedData (http://geo.linkeddata.es) we have followed those two paths. In one hand, we have searched for open government information at the Spanish Statistical Institute (INE) open catalogue (http://www.ine.es). In the other hand, we have got an agreement with the Spanish Geographic Institute (IGN) for publishing its geospatial datasets.

2. Vocabulary modelling. After the identification and selection of the datasets we need to determine the ontologies to be used to model the data contained in those datasets. The most important recommendation in this context is to reuse as much as possible available ontologies that model the information needed. If we do not find any particular ontology suitable for our needs, we should create them, either from scratch or by reusing existing resources. This activity is well described in ontology engineering methodologies, for example the NeOn Methodology (Suárez-Figueroa, 2010), summarized in Section 3; and tools such as the NeOn Toolkit (presented in Section 5) can be used.

In the case of GeoLinkedData, our chosen datasets contain information such as time, administrative boundaries, unemployment, etc. For modelling the information contained in the datasets we have created an ontology network (Suárez-Figueroa, 2010). The vocabulary that models the information contained in the datasets has been developed by reusing the following available vocabularies or
ontologies: Statistical Core Vocabulary (SCOVO), FAO Geopolitical Ontology, hydrOntology, WSG84 Vocabulary, and Time Ontology.

3. **Generation of the RDF data.** The preliminary guidelines proposed in this chapter consider only the transformation of the whole data source content into RDF, i.e., following an Extract, Transform, and Load ETL-like process, by using a set of RDF-izers, i.e. ontology population tools. The guidelines are based on the method proposed in (Villazón-Terrazas et al., 2010) that provides guide for transforming the content of a given resource into RDF instances. The requirements of the transformation are (1) full conversion, this implies that all queries that are possible on the original source should also be possible on the RDF version; and (2) the RDF instances generated should reflect the target ontology structure as closely as possible, in other words, the RDF instances must conform to the already existing ontology schema.

In GeoLinkedData, given the different formats in which the selected datasets were available, we used three different RDF-izers for the conversion of data into RDF. We have used NOR2O for transforming the spreadsheets, R2O & ODEMapster for the databases, and geometry2rdf for the geospatial information.

4. **Publication of the RDF data.** The preliminary guidelines proposed here consider that we will serve RDF data from a particular ontology repository. Ideally, every RDF triple store software would provide a Linked Data interface. Using this interface, the administrator of the store would configure which part of the store's content should be made accessible as Linked Data on the Web.

In GeoLinkedData, for the publication of the RDF data we relied on Virtuoso Universal Server. On top of it, Pubby (http://www4.wiwiss.fu-berlin.de/pubby/) was used for the visualization and navigation of the raw RDF data. On top of these two systems, we have developed a web based application, map4rdf34, to enhance the visualization of the aggregated information. This interface combines the faceted browsing paradigm with map-based visualization using the Google Maps API.

5. **Linking the RDF data.** Following the fourth Linked Data Principle ("Include links to other URIs, so that they can discover more things"), the next activity is to create links between our RDF data set and external datasets. This activity involves the discovery of relationships between data items. We can create these links manually, which is a time consuming activity, or we can rely on automatic or supervised tools, such as SILK (http://www4.wiwiss.fu-berlin.de/bizer/silk/) or LIMES (http://aksw.org/Projects/LIMES). The activity consists in the following tasks: (a) to identify data sets that may be suitable as linking targets, (b) to discover relationships between data items of our data set and the items of the identified data sets in the previous task, and (c) to validate the relationships that have been discovered.

In the context of GeoLinkedData, we have identified as initial data sets to link with DBpedia (http://dbpedia.org) and Geonames (http://geonames.org), because these data sets include similar topics.
Conclusions

At the beginning of the 90’s, ontology development was similar to an art: ontology developers did not have guidelines on how to build ontologies. Work on principles, methods and methodologies, together with supporting technologies and languages, made ontology development become an engineering discipline, the so-called Ontology Engineering.

In this paper, we have provided a general summary on this discipline, focusing on ontology definition and ontology components (classes, relations, axioms, and instances), and methodologies for building ontologies as well as languages and tools for ontology building.

At this moment, ontology engineers and practitioners have at their disposal different methodologies for ontology development. The classical ones (METHONTOLOGY, On-To-Knowledge, and DILIGENT) that provides a rigid workflow for building ontologies, and the new one, the NeOn Methodology that conducts developers along different scenarios and activities for which prescriptive guidelines are provided.

With respect to languages, the decision of which one(s) to use for implementing the ontology should be based on the needs in terms of expressiveness and reasoning. In this paper, we provide the list of the most commonly used languages with their key features.

Finally, ontology engineers and practitioners needs tools that help them carry out different activities of the ontology development process (such as, implementation, evaluation, ontology search). In the last years, the number of ontology tools has greatly increased and they can be grouped into seven different dimensions (data and metadata management, querying and reasoning, ontology engineering, ontology customisation, ontology evolution, ontology instance generation, semantic web services). In this paper, we provide a brief description of three ontology development environment (the NeOn Toolkit, Protégé, and TopBraid Composer) that can be included in the ontology engineering dimension.

To put together methodologies, languages, and tools and the Linked Data initiative, we have also presented some guidelines on how datasets should be published in the Web of Data.

References


1.2. Paper: Semantic technologies and ontology matching for interoperability inside and across buildings

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Abstract

There are many experiments with buildings that communicate information to and react to instructions from inhabiting systems. Fortunately, the life of people does not stop at the door of those buildings. It is thus very important that from one building to another, from a building to its outside, and from a building considered as a whole to specific rooms, continuity in the perceived information and potential actions be ensured. One way to achieve this would be by standardising representation vocabularies that any initiative should follow. But, at such an early stage, this would be an obstacle to innovation, because experimenters do not know yet what is needed in their context. We advocate that semantic technologies, in addition to be already recognised as a key component in communicating building platforms, are adequate tools for ensuring interoperability between building settings. For that purpose, we first present how these technologies (RDF, OWL, SPARQL, Alignment) can be used within ambient intelligent applications. Then, we review several solutions for ensuring interoperability between heterogeneous building settings, in particular through online embedded matching, alignment servers or collaborative matching. We describe the state of the art in ontology matching and how it can be used for providing interoperability between semantic descriptions.

Keywords: Ontology matching, Ontology alignment, Alignment server, Context-based matching, Content-based matching, Context representation, Query mediation.

1.2.1. Introduction

Building information systems may be useful to architects, building owners and managers. However, ultimately, they have to be useful to inhabitants. A building cannot become energy-efficient or a data hub against those who live in it. Hence, a key element of such systems is adaptability to people. This involves understanding at some level the context in which people evolve and taking appropriate actions to support them. This applies naturally to energy-efficient buildings and thus efficiency must be supported by the whole building information infrastructure. Adapting to seasonal change, weather or energy prices is only a small part of the task. The most challenging part is adaptation to building inhabitants in the context of particular weather or season.
This entails anticipating: raising the heat before people arrive and lowering it before they leave; supporting them while they are here and cleaning up after they leave. An application for dealing with energy efficiency in buildings has to rely on many different sources:

- a local building information system about the building characteristics;
- the web for information such as weather forecast or energy prices;
- the electrical networks for consumption information;
- sensors (light, noise, movement, energy consumption) for monitoring activities;
- user personal information (agenda through phone or web) for planning future move.

This means that this future is not the goal of a single device: PC, TV, set-top box, smartphone, car or building. It has to be taken into account by all of them. Hence these devices need to interoperate. Nowadays, all these devices are particularly heterogeneous. They concentrate on a particular function and do not bother to communicate with other devices. It is typical that an experimental setting, provided for a particular building does not work with the next building. However, if we mostly live in a few buildings, we visit many of them during our daily life and it is not acceptable to be equipped differently for each of those.

So we would like to address here two types of heterogeneity: the heterogeneity between devices available in the building environment and the heterogeneity across buildings. Dealing with this heterogeneity is of utmost importance to ensure the continuity of users experience.

One common way to solve such interoperability problems is to define in advance required information and the way to exchange it. However, the task is already daunting given the quantity of heterogeneous devices. There is a multiplication of devices and efforts with divergent goals: reducing construction costs, long term energy efficiency, constant connectivity, radio-emission reduction, Gemütlichkeit, etc. Moreover, standardising at that stage of research is premature and would hamper the development of technology.

Hence, the solution is in the use of standard but general purpose technologies, i.e., technologies which have not been developed for a particular purpose. Web technologies have these characteristics and semantic web technologies are particularly adapted to the exchange of knowledge and data across a variety of platforms and protocols. Moreover, the benefit of using semantic technologies, and, in particular, ontologies, are already acknowledged in ambient computing and smart buildings, so this does not necessarily introduce new constraints.

However, these technology alone do not solve the ultimate interoperability problem: different devices and information system will use different ontologies. Again, this is perfectly natural and should be handled with the adequate tools. Semantic technologies, and, in particular, ontology matching, allow for overcoming heterogeneity.

In this paper, we show how semantic technologies, developed in the context of the semantic web, are particularly suited for representing information that is embedded, produced and consumed by building information systems. The next section thus presents semantic web technologies in the context of building information systems and more generally ambient computing. Then, we propose a framework, largely inspired from (Euzenat et. al. 2008), for dealing with heterogeneous ontologies. Finally, we review ontology matching as a key component of this interoperability.
1.2.2. Semantic technologies for building information systems

In (Euzenat et. al. 2008), we have considered context information management frameworks should be:

• Open, so that new devices and applications can be involved in the environment. It must thus rely on well accepted standards for expressing information which guarantees that components will be able to interoperate.

• Dynamic, so that these devices and applications can be taken into account dynamically. This requires that it can represent new types of information and that it can match these representations so that old parties take advantage of new ones and vice versa.

• Minimal, so that the framework does not put a non realistic burden on application and device developers. This requires to keep minimal the computing resources and specific interfaces needed for using this framework.

To some extent, the same constraints are considered for building information systems in systems such as CSTBox (Zarli et. al. 2010). However, we take here into account the need to achieve interoperability down to the level of data representation.

Because we want to focus on buildings and their inhabitants as they are, most of the information to store in building information systems is indeed context information. Hence, we present below the framework that was proposed for representing context information in pervasive computing (Euzenat et. al. 2008).

We provide example of the use of semantic web technologies for developing an application which needs to assess the temperature in a room and if there is light. This may be for deducing that there is no activity and for cutting heating or indicating that the room is free and suitable for some activities. The important point is that the application may be defined relatively independently from the building model and yet works.

So we first present how information can be modelled in OWL and expressed in RDF. Then we explain how OWL ontologies may be extended for expressing more precise information and how SPARQL queries may be used for obtaining information expressed in these extended ontologies without knowing them. Finally, we present the use of ontology alignments in order to work with heterogeneous ontologies. We only provide an informal presentation of semantic technologies; further details may be found in (Hitzler et. al. 2009).

OWL ontologies for characterising objects

OWL ontologies are used in order to characterise the objects that can be found within the environment. There are general purpose ontologies such as SUM [http://reliant.teknowledge.com/DAML/SUMO.owl], Cyc [http://www.cyc.com/2003/04/01/cyc] or DOLCE [http://www.loa-cnr.it/ontologies/DLP_397.owl] that can be used. The essential point is to have ontologies sufficiently generic to cover the various concepts involved in applications: resources, actors, places, dates, activities, permissions, etc. There are several ontologies of this type that have
been designed for pervasive computing purposes (Chen et. al. 2004a, 2004b, Wang et. al. 2004, Flury et. al. 2004).

These ontologies are in general not very sophisticated because they were designed to make the machinery of pervasive computing applications work. For each domain, it is necessary to develop a more precise description of exploitable information. (Flury et. al. 2004) proposed a semantic description of four different models (semantical, geometrical, graph theory based, and set theory based models) to represent indoor location information. To cover outdoor location, (Fu et. al. 2005) proposed a geographical ontology which gathers several geographical datasets. (Gandon and Sadeh 2004) presents a semantic description of rules to selectively control who can access to contextual information and under which conditions. A spatio-temporal approach is developed in (Ngoc et. al. 2005) to describe, with a dedicated ontology, user preferences in ubiquitous computing environments and their behavior routine. To describe users and their social relations, the FOAF [http://xmlns.com/foaf/spec/] ontology is appropriate, as well as the GUMO [http://www.ubisworld.org/] ontology described in (Heckmann et. al. 2007).

More specific representations for buildings are necessary, for instance to take into account building information models (plans, material, lifecycle), equipment (location, provider, characteristics) or energy (cost, capacity, efficiency) (Bourdeau and Laresgoiti 2011).

![Figure 1: Sample of general purpose ontology concepts (classes are in rounded corner rectangles, properties are related by dotted arrows and plain arrows between classes denote sub-class relationships). The ontology provides classes for devices and locations as well as properties such as “locatedIn”. Ontologies, such as those of Figure 1, can be used by applications to characterize information which is necessary for them. Usually, devices will use the most precise refinements of these models to be exploited by applications.](image)

**RDF graphs for modelling information**

Information can be represented as RDF graphs (Klyne and Carroll 2004). An RDF graph is simply made of a set of triples relating entities (classes, instances, literal values) through properties (see Figure 2). The benefit of using a general purpose language like RDF is that a common general
interface can be defined for components that exchange RDF triples. Interoperability is then trivially guaranteed by considering that they are consumers and producers of RDF. This attitude has been adopted worldwide from linked data to mobile phones.

Figure 2: Part of the information concerning a private room in a building can be represented by the following set of triples (classes are still in rounded corner rectangles, instances are in rectangular boxes, data is in blue rectangles; instances are related to their classes through rdf:type properties). It presents two sensors providing information about physical properties of the room (one of these properties is illuminance).

Figure 2 illustrates that information may not be expressed with regard to the general purpose ontologies as presented in Figure 1. In order for applications to know which devices to query, devices must publish the query types to which they can answer. This can be achieved by publishing the classes of objects and properties on which the component can answer. Ontologies are the natural way to achieve this and OWL is particularly suited for designing shared ontologies.

Matching information needs to actual information

Devices can be added at any time (which occurs when new people enter a room for instance). There is no reason, a priori, that added devices as well as new applications are really compatible. Indeed, each newly introduced sensor will provide more precision or information which has not been considered at application design time. In the same way, the applications cannot know all kinds of available sensors. Ontology description languages can help solving this problem. Fortunately, knowledge representation techniques in the OWL language always permit to specify a concept or a property without questioning those which existed originally.
Figure 3: In a particular environment, general purpose ontologies (Figure 1) are refined into more specific ontologies. They introduce new concepts (Heater, TempServ) and new constraints on existing concepts (the “informs” value of a TempServ is a Temperature). Here, instances of the building model are presented (clim station, LightViewer and private room: instances are denoted by grey rectangles and linked to their classes by thin arrows).

Let assume that an application wishes to know the temperature in the room and if there is light. A high level ontology enables to characterize its needs: the temperature and the illuminance are physical properties of the room. For that purpose, a query language like SPARQL (Prud’hommeaux and Seaborne 2006) may be useful for querying or subscribing to sources. The requested information (query) may be expressed by the graph pattern depicted in Figure 4 which corresponds to a set of RDF triples.

Graph patterns, such as presented in Figure 4, are the main components of SPARQL queries. However, it is not necessary to require devices to answer SPARQL queries. The ability to traverse RDF graphs is most of the time sufficient. Another benefit of using RDF and SPARQL is that services do not necessarily need to tell in advance to which query they are able to answer: applications can ask query that were not anticipated.
Figure 4: A query graph pattern (question marks instead of instance names introduce free variables). It can correspond to the information that an application requires from the environment (here the temperature and illuminance of a room). This information is expressed in function of the general ontologies of Figure 1.

In the sample application, the important issue is that the class of the sensors are temperature and light sensors. That these properties can be obtained by a ThermServer sensor, like a thermometer, located in the same room is not the relevant to the application. On the other hand, if the goal of the application is to reduce the climate when the outside temperature is low, it is important to know that this is not only a sensor. Using ontologies to express information permits a new equipment whose capabilities have not been known at application design time to enter and new applications to benefit from these possibilities.

Similarly, the application does not need to know that a room is a private room for artist to dress up or a public room that is left to the children to practice music instruments if the application only needs to know if someone is active in this room and what is its temperature. But nothing prevents the building model from declaring it like this. This will characterize the room precisely. Figure 3 shows how the ontologies of Figure 1 can be extended for the purposes of using sensors in room #1345.

The information required to answer the query can be found in the RDF graph of Figure 2, but it needs the content of the given ontology to do so. Indeed, the query pattern asks for a “Temperature”, but nothing is qualified as such in the RDF graph. However, the information provided by the temperature server have to be a “Temperature” according to the ontology of Figure 3, hence there is a temperature available. On the other side, the output of the LightSensor is not related to the room by “characterizes”. However, the ontology tells us that this is the inverse of “isCharacterizedBy” so we can use it as a valid answer for the query. Hence, the temperature of 22°C and the illuminance of 3lm/m² can be extracted from the graph by the query with the help of the ontologies.

This example shows the benefit of using semantic web technologies for dealing with this information: ontologies disseminated on the web provide the background knowledge necessary to interpret raw information.

The information is described by the device more precisely than in the query: the query does only wants to identify the temperature and illuminance for the room. The applications must be as general as possible when describing their needed information (the room temperature, the activity) whereas the information management systems must be as precise as possible on what they produce. That will permit the most specialized applications to take advantage of them.
Alignments

The proposed information management system makes it possible to introduce new devices in the environment by extending the ontology in such a way that existing applications can make the best use of them. However, this view holds if all parties share the same ontology. This is not always the case. Indeed, two sensor manufacturers will probably use two different ontologies to describe their products. Moreover, applications will probably rely on domain ontologies related to their scope. For instance, Figure 6 shows on the left-hand side an ontology in which areas are classified with respect to their function while on the right-hand side, access is considered instead. Reconciling these heterogeneous ontologies may be achieved through the use of ontology alignments. An alignment is as set of correspondences between ontology entities. Figure 6 presents such an alignment which expresses relations between the function ontology and the access ontology. It is visible that the latter is more general than the former: Backstage, Dressing and GreenRoom are more specific than Private Room and Parking is more specific than Outdoor location.

![Figure 5: Two ontologies (left: functional, right: access) and an alignment. Each correspondence, i.e., blue arrow, relates entities of each ontology with a relation (≡ for equivalence and ≤ for less general). Room #1345 being a Dressing, it is necessarily a Room in the access ontology because Backstage is more specific than PrivateRoom.]

The application is able to use the alignment for translating queries before sending them to devices or applications, and eventually translating the answer back. Indeed, if the room #1345 is a dressing in the functional ontology, it will still be an answer to the query of Figure 4 with the help of the alignment (the query asks for a Room which is more general than PrivateRoom, which is more general than Backstage, which is more general than Dressing).
Alignments may be more precise than the one of Figure 6 by providing confidence about the given correspondences and relating other entities such as properties or compound expressions (David et. al. 2011).

1.2.3. Ontology matching

As we have seen, interoperability can be achieved through alignments between the ontologies used by different parties. Ontology matching consists of generating an alignment from two ontologies, that can be used for various purposes such as merging ontologies, transforming data or querying. Ontology matching is actively researched and many algorithms have been provided for finding correspondences (Euzenat and Shvaiko 2007). Different features of ontologies are usually used for performing matching. Beside the classification provided in (Euzenat and Shvaiko 2007), we now consider that there are two broad categories of matchers: content-based matchers and context-based matchers.

**Content-based matchers**

Content-based matchers are those matchers using the content of the ontologies in order to match them.

- **terminological techniques** are based on the text found within ontologies for identifying ontology entities (labels), documenting them (comments) or other surrounding textual sources (related element labels). These techniques come from natural language processing and information retrieval. They can use the string structure themselves, e.g., string distances, or the ontology as corpus, e.g., statistical measures based on the frequency of occurrence of a term.
- **structural techniques** are based on the relations between ontology entities. These can be relations between entities and their attributes, including constraints on their values, or relations with other entities. These techniques take advantage of type comparison techniques or more elaborate graph techniques, e.g., tree distances, path matching, graph matching.
- **extensional techniques** compare the extension of entities. These extensions can be made of other entities, e.g., instances.
- **semantic techniques** are based on the semantic definition of ontologies. They use extra formalised knowledge and theorem provers for finding consequences of a particular alignment. This can be used for expanding the alignment or, on the contrary, for detecting conflicting correspondences.

Of course, most of the systems combine several techniques in order to improve their results. The techniques can be combined by aggregating distance results (van Hage et al. 2005), by using selection functions for choosing which one to use in the present case (Jian et al. 2005, Tang et al. 2006), or by deeply involving them all in global distance computation (Euzenat and Valtchev 2004, Melnik et al. 2002).

In the present case, all these techniques may be used for online matching but extensional techniques. Indeed, it is unlikely that devices will have much instances to offer at the moment of matching.
Context-based matchers

Context-based matchers take advantage of the connections ontologies have with a broader context in order to assess the correspondences between their components. These connection may come from different sources:

- Existing alignments with other ontologies, hence, having two ontologies already matched to a third one may be easier to match. There may be different approaches depending on the type of ontology selected: this may be a top-level ontology, a reference ontology for a particular domain or even all the ontologies of the web.
- Specific resources: These may be dictionaries defining words used in the ontology labels, multilingual lexicon providing the translation between several languages or encyclopedia such as wikipedia or dbpedia [http://dbpedia.org], its semantic web counterpart.
- Annotated resources: two ontologies used to annotate the same type of resources, e.g., web pages, pictures, products in a catalogue, offer the same possibility as extensional techniques. The larger the annotated resources, the easier it is to use statistical or data analysis techniques. The approaches differ depending on whether the two ontologies share resources, e.g., they index the same set of documents, or not (in which case a similarity between the extensions may be established).

Usually, context-based matchers are slower than content-based matchers for two reasons: they usually rely on large datasets and they involve combinatoric searches (to potential resources, potential matches and reconciliation).

1.2.4. Ensuring interoperability

In the context of building information systems, agreeing on standard universal and self-contained ontologies is not a reasonable assumption. Furthermore, such an approach will probably hamper the development of ontologies and technology. Hence, we have to rely on alignments. Defining a priori all alignments between all the possibly encountered ontologies suffers from the same problems as standardising ontologies. Not all the work on ontology matching is relevant to building information systems. In order to choose matching techniques for a particular applications, it is necessary to consider its characteristics. Indeed, the characteristics of matching in such systems requires that it be:

- automatic: it is not possible to rely on the user to directly help matching, and indirect help cannot postulated because there will not always be users;
- fast: when a process needs an alignment it cannot wait for hours to have the results, hence, either matching should be processed online or precomputed alignments must have been stored;
- correct: it is rather important the provided alignments be correct even if some level of fault-tolerance is possible; it is less important that it be complete.

We identify three possible approaches to obtain such alignments that we consider below: online embedded matching, ontology alignment service or collaborative alignment.
Online embedded matching

Online embedded matching consists, for each application willing to communicate with the environment, and this applies to building information systems as well, to be able to match ontologies on the fly. This does not seem to be a reasonable option due to the important resource consumption that may be involved in this matching task. Usually matchers have to compromise speed for correctness: some matchers are very fast and provide good results, but not fully accurate results. Given the requirements here, online embedding matching does not seem reasonable.

In addition, this may lead the application to rely only on matchers it embeds instead of taking advantage of the many new matchers available each year. An alternative solution is still to perform online matching but to rely on an external Alignment server able to perform matching on the fly. In this case, the server may provide many matchers and update them.

Ontology alignment service

Alignment servers (Euzenat 2005) help agents (information managers and applications in this case) to find an alignment between different ontologies they face. They provide mechanisms for:

- Archiving (and retrieving) past alignments;
- Dynamically matching two ontologies;
- Translating queries and answers to queries between information managers that use different ontologies;
- Finding out an ontology close to a specific ontology (this can be useful for finding intermediate ontologies which will facilitate matching).

An Alignment server uses a functional interface that allows the explicit handling of ontologies alignments that have been developed in the framework of the semantic web [http://alignapi.gforge.inria.fr/]. It could be invoked as a web service or through specific communication interfaces. Such a server could even directly embedded in centralised mechanisms such as the CSTBox (Zarli et. al. 2010) to be made available to various applications and devices.

One important feature of alignment servers in this context is their ability to store well identified and certified alignments that may be shared across applications. Indeed, the necessary alignments will often be the same, across different applications and different device providers, hence it will be convenient to share them across matchers.

Collaborative matching

Finally, Alignment servers may also be used for supporting collaborative matching in which application and devices only use parts of alignments, e.g., the correspondences needed to transform queries, and report when these correspondences are useful or when they lead to errors. This helps the server to rank correspondences and alignments and to improve its answers over time.

These three approaches are not incompatible and might even be used concurrently. For example, parties could agree on sharing common high level ontologies and leaving more specific ontology
evolve freely and independently. This is a strategy enabling a close account for a fast evolving domain.

Conclusion

We have considered the problem of deploying building information systems that can fruitfully interoperate with their environment (inhabiting devices, surrounding buildings, or larger infrastructure) and yet deal with expressive information. We showed how semantic technologies, as developed for the semantic web, may be used for that purpose: RDF for expressing data, OWL for defining the vocabularies, SPARQL for asking queries and alignments for bridging ontologies. We provided a quick survey of ontology matching and described how alignments may be provided to applications and devices.

Acknowledgments

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References


2. Session: Green Building Information Modelling

2.1. Paper: A Framework Approach for EEBIM and Heterogeneous EEAnalysis Data Models

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Abstract

A central goal for the advisement of sustainable optimization of energy performance and emissions reduction in building stocks and production plants is the integrated consideration of the whole life cycle of the building through an interoperable, yet distributed ICT system supporting concurrent engineering. The life-cycle should include the very preliminary design and cover in particular the operation and the retrofitting phases. Therefore our research goals cover data, information, model and ICT system interoperability. Based on this an information framework for an energy-information enhanced Building Information Model (eeBIM) with special emphasis on the data model for energetic building analysis is investigated. It is complemented by a SOA-based ICT system which is designed as an Integrated Virtual Energy Laboratory (IVEL) which can be beneficially applied in all life-cycle phases of a building for design decisions, control purposes, system identification and prognosis. The paper describes beside the requirements of the eeBIM the first stages of IVEL development including the definition of actors and usage scenarios, the specification of data exchange and interoperability requirements, the identification and generalisation of the major software components and the developed software architecture of the IVEL platform up to a first partial prototype realization.

Key words: eeBIM, energy-efficient building, energetic building analysis, virtual laboratory.

2.1.1. Objectives and Use Cases

The goal is to close the gaps between existing building data and software tools so that complex life cycle analyses and simulations can be easily done in all relevant phases where energy saving potentials exist. Case applications are preferably on public private partnership (PPP) construction projects where the greatest ICT-related challenges and potential benefits exist due to a stricter life cycle considerations. The research objective is to develop an Integrated Virtual Energy Laboratory
(IVEL) and energy information enhanced Building Information Model (eeBIM) enabling comprehensive studies of design and retrofitting alternatives concerning energy performance and total costs approaching true concurrent engineering in construction. The energy performance of a building depends on multiple factors ranging from the climatic conditions and the building materials used to the capabilities of the installed building automation systems and the actual activities of the occupants. In order to determine and control energy performance properly, a number of different information sources have to be taken into account and a number of different methods have to be applied starting already in early design. In Figure 1 the envisaged “TO-BE” process for true life-cycle engineering as envisaged in particular in PPP projects [8] is shown. It highlights (1) the phases in which beneficially application of an IVEL can be identified, and (2) the eeBIM that should be taken into account to achieve the “TO-BE” process. At the time being simulation is only partially applied in the design phase and sensor data are often only of limited benefit, mainly due to the missing of powerful and easy to apply system identification methods. There the simulation based system identification method is a promising candidate.

Figure 1: ICT impact (highlighted phases) on the “TO-BE” business live cycle process

The expected ICT impact in the different life cycle phases, which defines also the relevant use case for further studies, is:

The **Design Phase** has a key role in energy optimisation. The application of simulations in order to study already in the early decision phase various alternative for the energetic layout of the building the combination of building services equipment, energy supply, energy buffer and energy distribution systems is essential. More transparency providing tools for the multi model situation have to be provided that the client can check his ideas and requirements, the designers can verify the key design parameters, and the facility management can simulate the investment and consumption behaviour and costs (Use Case 1).

The **Commissioning Phase** is very difficult because rapidly. Here the automation of sequences with continuous monitoring, fast response to malfunctions and adjustment of the building automation system (BAS) is in the foreground. Primary roles in the process have the client, the building operator and the facility manager (Use Case 2).

In the **Operational Phase** all measured data can be much better evaluated by the operator on daily and/or weekly basis with a tool like an IVEL, i.e. errors can be better located and corrected faster. Additionally, end user behaviour can be better assessed and included in subsequent analyses and simulations (Use Case 3).

In the **Retrofitting and Refurbishment Phase** an IVEL enables early analysis of change, studies of alternatives and providing a pronounced decision making for the investment costs, change of use or
reduction of energy consumption and environmental impact. This phase is similar in nature to the
design phase, but it is also more complex due to the involvement of all actors and the need to
compare measured and simulation data and to adjust simulation models accordingly (Use Case 4).

2.1.2. State of the Art of ICT Application in Life Cycle Building
Energy Management

The effective planning, modelling and monitoring of buildings over the whole life cycle is a fairly new
approach in the construction industry, leading to complex multi-model data management and
numerical simulations of multiple variants. The new building information modelling paradigm (BIM)
defines via the standardised IFC project model [1] a good common data basis for life cycle
management bringing together all involved actors (architects, building services engineers, operators,
facility managers) besides architectural objectives. However, to calculate and predict energy
consumption appropriate simulation models are additionally needed. To serve all users adequately,
such models should be reusable and interoperable in a distributed heterogeneous environment. The
simulations themselves must be flexible and hence should be provided as services. The integration of
such services in a service oriented architecture (SOA) warranting the efficient collaboration of the
involved users and their applications is seen as the most promising approach today [2, 3].

In [3] a standard set of interfaces based on SOA and defining extensible and reusable segments is
described. There are services for energy simulation, maintenance, monitoring, sensors and actuators
and the BIM. The core of the system is a data warehouse which uses data from different sources on
three layers: a network layer which senses and communicates performance data, a data layer which
stores the data and a tool layer which involves end-user tools and graphical user interfaces. However,
the whole life cycle and the interaction designers involved in refurbishment cases are not sufficiently
addressed.

In recently suggested distributed environments the simulation process itself is provided as a service
which can be accessed globally or locally. This allows for exchangeability of simulation tools and/or
the GUI itself. In such approaches the GUI is provided as a client frontend whereas the simulation
process is realised as backend [4].

In [5] an approach to combine multiple instances of BIMs in a central data repository over the whole
building life cycle is suggested. A new BIM instance is produced for each major design change. The
model gets more detailed in every phase of the building life cycle. However, a web-based multi-user
environment is not envisioned. The focus lies on the metric of the system and the performance
history of the project.

In [6] a coherent strategy for combined use of multiple simulation models and solvers is suggested,
but the approach is limited to energy analyses and simulations and does not consider other related
life cycle aspects, nor the integration of CAD and FM systems.

However, much research work on IVEL approaches for life cycle building energy management has not
yet been done, although valuable work for concurrent engineering is available [7].
2.1.3. BIM Enhancement Approach

The support of the various phases of the live cycle by ICT demands either one large homogeneous data model or several lean interoperable ones. The IFC data model [1] has become the most prominent BIM model. However, it does not yet cover the information which is necessary for the energy analysis of buildings. The IFC data model is structured in several domain data models formalized in EXPRESS [9] and an interoperability layer [1].

The overall approach is to design an open SOA platform based on BIM, BIM-CAD and BIM-FM, extended by services for intelligent access to BAS and advanced energy analysis tools, built upon a common conceptual modelling basis, the envisioned eeBIM. The main development steps comprise: (1) Specification of the eeBIM and inter-linking it with all other needed data into a coherent multi-model framework, (2) complementing the eeBIM-based multi-model framework with an ontology that would allow managing complex IVEL platform interactions, and (3) Extending existing applications so that they can seamlessly exchange the required data in both directions.

An essential prerequisite for a successful development of the IVEL platform is a concise definition and analysis of the users target group, which consists of architects, civil engineers, HVAC engineers, facility managers but also decision makers in terms of financial investors. Usually they already have well established software solutions in their special domains. As these actors are only working in their own domains, the advantages of improved interoperability as supported by BIM can just be communicated by providing a better functionality in each sub-domain. This means, the IVEL must offer an excellent customers service including rapid iterations over design alternatives and tailored methods to evaluate the numerical results. This is also true for property developers who take over a larger part of the value chain in the life cycle of buildings. Those actors need to be convinced by substantial advantages of the IVEL; otherwise they will find their own internal solutions apart from BIM.

![Diagram showing the three partially overlapping basis data model for energetic life-cycle consideration](image)

For an integrated consideration of the energetic life-cycle aspects and an integrated energy analysis two additional but complementing data models are needed [Fig. 2], namely the data model for the numerical energy analysis tools, e.g., for Multizonal Building Energy Solvers (MBES) and for Building Envelope Systems Solvers (BES) [13], the other data model for the Building Automation System (BAS) in order to integrate sensor data. There several standardized data models are in strong competition. The three most applied ones are BACnet (EN ISO 16484), KNX (EN 14908) and LON (ISO/IEC 14543-3, former CEN EN 13221-1), which are the leading ones in their particular subdomain. In order to integrate them in a flexible way a BAS ontology model will be developed [12].
2.1.4 Energy information enhancement Procedure

A sound description of the expected eeTools’ functionality is a prerequisite for the definition of heterogeneous interoperable eeAnalysis data models as envisaged in the eeBIM concept, hence the workflow must be subject of analysis.

![Diagram of the building process](image)

**Figure 3: Implementation of the knowledge transfer process in the context of the IVEL platform regarding the building process**

IVEL is an industry-driven approach with strong research components. For an efficient collaborative work flow between research and industry it is essential to implement a knowledge transfer process (research, transition and application layer) orthogonal to the building process as depicted in Figure 3. This knowledge transfer process supports a quality assurance of tools in each phase of the building process. By means of model-to-model transformation and a consecutive data base enhancement it can be guaranteed that the tools in the application layer are always up-to-date in terms of accurate physical implementation, robust and fast numerical solution algorithms, completeness and reliability of data bases as well as ergonomic and user friendly graphical interfaces.

The tools in the application layer are to be integrated in IVEL as a web services. Their data models will be designed to provide interoperability between CAD, BIM, FM via eeBIM. This interoperability implements a rapid iterative work flow to investigate in the design and refurbishment phases sufficient numbers of variants to arrive at optimized solutions. The roadmap from BIM to eeBIM will consist of following major steps:

1. Transformation of the building geometry information from BIM obtained through BIM-CAD via 1st level space boundaries to 2nd level space boundaries [23] during iterative working cycles. It is necessary to maintain all in the previous iteration defined zones, surfaces, sub-surfaces and
material IDs unaltered, i.e. provide proper version management. In later design phases, the same procedure applies to constructional detail solutions, like constructional particularities as thermal bridges at floor/internal wall to external wall connections and balconies, for example.

2. The enrichment of the BIM by adding information on user behaviour, building construction layering and materials, climate and HVAC systems. Version management is needed to re-establish the previous state of the eeBIM model, e.g. after re-import from CAD on demand. The user behaviour and the HVAC operation need to be described by intelligent schedules for a concise description of building performance.

3. Especially developed procedures are needed for selection and generation of proper climate data (extreme or average, corrected for elevation and city location). Since moisture-related issues become more and more important in building energy design, especially in rehabilitation of the building stock, the material data base must be able to deliver the respective hygrothermal data.

The eeAnalysis data models of the eeTools in the application layer of the IVEL concept need to be designed to support the workflow described in the aforementioned steps. The data models can only be properly defined by taking the eeTools’ functionality into account. A precise feature planning has to be provided which comprises a comprehensive description of the users’ expectations and interaction with the IVEL platform as undertaken in [8] for different use cases as shown in the next section.

2.1.5. Enhancement for Building energy analysis

It is important to differentiate energy performance indications at three categories: the net energy, the final energy and the primary energy category. A building energy balance calculation comprises all three energy categories (see Figure 4). Building data are to be delivered by eeBIM at three levels, the building component level, the building zone level and the whole building level.

In the net energy category, the energy balance summarizes all solar and internal energy gains as well as all transmission and ventilation losses generated by the actions of the inhabitants, the climate and the building construction. Generally, the building envelope construction can be seen as an interface between outdoor climate and indoor conditions provided to humans. Its description requires eeBIM data on the building element, the building and the building cladding zone levels. The user requirements on thermal comfort and health generate a net energy demand in terms of kWh/m²a. This is thermal and electric energy which is preferably delivered by using renewable energy resources or alternatively by conventional HVAC technologies.

The final energy category is used to describe the efficiency of HVAC systems. Transmission and distribution loss is always unavoidable. The coefficients of performance (CoP) are annual average numbers for the efficiency of each the heating, cooling and ventilation systems being analysed at zone and building levels. The CoP converts net energy demand into annual fuel consumption (natural gas, oil, coal, LPG, biogas, anthracite) and electricity demand which constitute the energy bills to be paid.
The primary energy category has been introduced to measure the environmental effort for generation and delivery of the final energy. The primary energy factors are specific multipliers to estimate the environmental cost of each kind of final energy and hence are dependent on the location, i.e. on the availability of natural resources. In Germany, the factors for gas and electricity are 1.1 and 2.6, respectively. 1 kWh of electricity is environmentally more expensive than 1 kWh of gas.

Figure 4: Building energy balances and their influencing factors

The output from building energy simulation tools should allow in-depth analysis of the aforementioned energy categories. Figure 5 shows an example for annual analysis of net and final energy. Also monthly, daily, hourly and sub-hourly analysis is often necessary. The graphics show net energy gains by lighting, computers, equipment, occupancy, windows (sun radiation) and sensible heating. Losses are caused by glazing, walls, ceilings, floors, roofs, doors, infiltration and ventilation. The final energy break down comprises room electricity, lighting, domestic hot water, heat generation and system miscellaneous which can be summarized as final electricity and gas demand. The simulation results as depicted below need to be available for whole building analysis. In addition, the net energy analysis needs be carried out also at zone level. Weak points of the current building design can just be detected if a zone break down is provided by the analysis tool. This requires a huge amount of output data to be processed by a variant navigator. The eeBIM architecture needs to take this fact into consideration.
Designing an ontology for eeBIM, we have to distinguish between the physical objects of the data model and the intangible objects like rooms, zones, activities, etc., which are structuring the basic, i.e. physical objects to systems, in our case engineering systems, like the structural system, the energy system, the building usage system. One exceptional system is the space system, because it is the baseline system for many other systems. In the context of eeBIM we are strictly distinguish between the basic object model and the various engineering system models, because we have to deal with at least three different systems (see Fig. 6) and the basic building element model.

![Figure 6: Basic BIM (left) and Space System Model (middle left), Envelope System Model (upper right) and Space Climatic Zone System Model (lower right)](image)
A verified approach for the structuring and data representation of the system models is already inherently provided in the IFC for the space system model, whereas for the other two system models the structural system model an already existing extension model of the IFC, developed by [13] will be used by us as a best practice template. The information management of these system models, their interrelationships and links and their functionality, i.e. their meaning will be formalized in an eeBIM ontology, which will on one side be based on the on-going development of a construction ontology and the related exchange format the information container developed in the course of the mefisto project [18] and on the other side on the ongoing development of the BAS ontology [12].

2.1.7. Architecture of IVEL

Using the Information Delivery Manual IDM methodology (ISO 29481) [19] and the defined “TO-BE” process (Figure 1) the software architecture of the IVEL was conceptually developed. It is based on the sound and verified concept of an early development of an intelligent service oriented SOA based engineering design workplace and virtual engineering laboratory [7].

The IVEL architecture applies the SOA concept, following a standard UML-based modular approach. It comprises several types of services and applications, bound together by an IVEL Core Module that acts as middleware providing for the required data and functional interoperability. Modularisation of the platform components is consistent with the identified actor roles and respective business cases. Consequently, the following modules are defined (Fig. 7) and first prototypes are developed:

- **Design Module or Modeller Module**, comprising a CAD system and related cost estimation tools serving architects, building services engineers etc.
- **Facility Management Module**, comprising a FM system and related FM and cost calculation tools. The main users are the facility managers.
- **nD-Navigator as Public Access Module**, providing a general-purpose interface, filter and intelligent post-processor enabling easy-to-do studies of the building performance with regard to energy, emissions and life cycle costs serving all actors involved.
- **Operation Monitoring Module**, providing services for monitoring and control of the BAS. The main users are the building operators and the facility managers.
- **Energy Computing Module**, providing the energy and related (like hygrothermal) computational services and tools. Main users are energy consultants.
- **Reporting Module**, providing analysis and reporting services for generating comprehensive studies about the energy and emissions over the whole building life cycle.

Each of these modules is principally exchangeable due to the developed standardised data models in the course of the eeBIM, information exchange specifications and APIs. With the exception of the IVEL Core Module and the Energy Computing Module which are strictly service-oriented and accessed via WSDL-based interfaces all other modules provide their own GUIs, tailored to the specific needs and views of the respective actors. The IVEL Core controls the binding to all other services and provides all workflows and model mappings to various data formats. The interoperability with non WSDL-based applications is provided by a IVEL-Connector which defines a homogeneous interface via SOAP technology. Within this modular approach, four types of software tools have to be considered:
- **Local applications**: Typically these are the legacy systems with own GUIs. They have to be upgraded with IVEL-Connector based plug-ins.
- **Web applications**: Similar to the above, these are legacy application with their own GUIs. However, the GUI is Web Browser based providing for direct connection to the core, like the nD-Navigator.
- **Batch applications or Local tools**: Such applications are most sophisticated energy solvers, such as EnergyPlus [17] or Delphin [6]. They may have an own GUI but their input is file-oriented and allows for easy application of plug-in technology.
- **Web Services**: These are software services defined via WSDL. In IVEL all components of the Core Module, the IVEL-Connector and a specialised Energy Solver front-end are in this category, like most modern future developments will be.

![Software Architecture of the IVEL](image)

The Platform Management of the IVEL core is essentially a service registry that controls user registration, data manipulation, calls to sensors and the workflow of all tools involved. It is responsible for various data manipulation tasks such as model mapping, model conversion, multi-model linking, filtering and model versioning, and can thus be generally seen as a data warehouse enhanced with explicit business logic to allow the adaptation and semi-automatic execution of user workflows.

The *interface* to the IVEL Core is provided by the *IVEL-Connector* and the *Intelligent Access Services* (IAS), which bind all external distributed services and can be bound from (web-) applications in a homogenous way. The IAS is also responsible for the interpretation of user queries to the underlying information models.
The User Registry (UR) stores and manages user data whereby each user is assigned a specific role and access rights. His/her profile influences the actual workflow and the user’s views on the system. The Communication Controller (CoCo) manages the communication between (web-) applications and web services and tests the status of requested web services. The Simulation Controller (SiCo) is responsible for the simulation workflow, the specific optimization of the individual simulations and their parallelization runs. The Model Generator (MoGe) uses the eeBIM and the user queries to create the right analysis model and data format as well as the appropriate filtering of the building model to provide the needed focus and improve the performance of the simulation. Consequently, it is possible to easily simulate energy requirements or performances for one building storey or only some rooms. It will control the preparation of results and enrich the eeBIM instances respectively. The Model Manipulator (MoMa) will check if the eeBIM fulfils the minimal requirements of an energy simulation. For instance, it will convert 1st level to 2nd level space boundaries [23]. The purpose of the Model Combiner (MoCo) is to bring together the involved multiple data models and link them on instance level according to references to the linked models of the Information Containers [14]. Finally, the Versioning component manages BIM versions based on the approach of [20].

2.1.8. Current Implementations and outlook

At the time being, IVEL is in a relatively early stage. However, a number of measurable results is already available including the developed user scenarios in BPMN, fully instantiated requirements templates and identified software components, defined principal model schemas for all types of data involved, a first running version of the multi-model management framework of the IVEL platform and a first version of the nD navigator [21]. Current work focuses on the realisation of a Java-based framework for filtering IFC model data based on the GMSD method [22] to enable the manipulation of a building model. We subdivide filtering functionality in generic, semantic and geometry filtering methods and build various user-oriented and utility functions upon these. Thus, it is possible to easily define methods for filtering very individually specified building storeys, rooms, walls, windows and other building elements semantically and geometrically. To visualise the results of the simulation process we use a Java-based publicly available open IFC viewer [16], which we upgraded to a web application. It will be combined with charts and other visualisation widgets to prepare appropriate results for the end user in accordance with the user profile. Screenshots and synopses of some of these implementation results can be seen via the HESMOS web site (http://hesmos.eu). There are several ICT challenges with regard to the envisaged IVEL platform that can be deduced from the “TO-BE” process. These include:

- The disruptive nature of the related processes, taking place over dozens of years but not in continuous manner and not with the same actors and tools
- The heterogeneous and distributed nature of the information resources (building design data, building automation data, climate data, material and equipment catalogues, usage statistics etc.)
• The multiple data models that have to be integrated and mapped to the requirements of the involved services and tools
• The heterogeneous and distributed nature of the software tools (CAD and FM systems, general simulation frameworks, specialised energy solvers, cost calculation tools)
• Technical issues related to the information availability, especially with regard to building automation systems (BAS)
• Various legal issues related to warranties, information access, security, and so on.

These challenges all play direct or indirect role in the specification of the eeBIM and the development of the software architecture of the IVEL. The users of the platform benefit in various ways. An architect can be supported to perform energy simulations already in the early design phases of a project and receive informed feedback to his design decisions from life cycle point of view. After construction, facility managers and operators can monitor and control energy performance and the associated operational costs and take informed operational and refurbishment decisions. Last but not least, owners, tenants and public bodies can be empowered to supervise overall performance and costs, and thereby help to find and remove malfunctions or improve functional conditions in timely manner.

![Figure 8: Modell range to be covered by an eeOntology](image)

The eeBIM framework is still in an early stage and only puzzle pieces of the overall framework are sketched, including its possible extension. In a more global consideration of the energy problem more than the three already mentioned domains (Fig. 2) have to be considered and integrated in an overarching ontology. These are for instance (Figure 8) city planning and grid energy management system, i.e. GIS and BEMS data models, further on the mechanical and electrical product developments i.e. STEP (ISO 10303) data model including Product Library (ISO 13584) and the supply chain and logistic data models.

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2.2. Paper: Requirements and Gap Analysis for Bim Extension to an Energy Enhanced Bim Framework

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Abstract

An essential goal of European research and development initiatives is the achievement of zero energy buildings until 2020. In this effort, a considerable role is assigned to construction IT. Taking that into account, the EU project HESMOS (2010-2013) develops an industry-driven holistic approach for sustainable improvement of energy performance in PPP projects through integrated design and simulation, while striving to increase the quality of the building and to decrease life cycle costs. A central issue of the HESMOS platform is the life cycle integration of services and tools based on a consistent model-based approach derived from thoroughly studied end user requirements and existing gaps on the one side, and a preset high-level multi-model concept on the other side. This paper describes the research conducted in the frames of HESMOS in that regard. It presents the main use cases in a building’s life cycle where energy performance can be considerably improved via application of an interoperable ICT approach, enumerates the major challenges a virtual energy laboratory has to deal with, details the suggested overall requirements gathering methodology and explains the overall concept of an energy enhanced BIM framework (eeBIM). The paper concludes with an example service workflow based on the eeBIM framework, a summary of the findings and recommendations for further research.

Keywords: Life cycle energy performance, Requirements gathering, PPP projects, BIM, IDM.

2.2.1. Introduction

Many advanced ICT applications for the design of energy efficient buildings already exist. However, while it is generally understood that decisions on energy efficient building design and operation have to be taken in all life cycle phases, current applications are mostly developed for the use by energy experts in detailed design, where most building parameters affecting energy performance are already determined and optimisation capabilities are limited. There is little energy-related ICT support both for early design, where vital strategic decisions have to be met, and for the later operational phase, where improvement decisions have to be taken. As a result, ICT integration is poor and the provided decision support is on limited level. With projects, however, where public-private contracts of 25-30
years of building operation are usual, there are excellent chances to develop a more efficient, holistic approach for the realisation of innovative services and tools for energy efficient and low carbon buildings, enabling better consideration of a large number of life cycle issues. Major prerequisites in that regard are: (1) the proper holistic elicitation of the overall multi-user requirements, (2) the development of a common multi-model based energy-efficient BIM framework (eeBIM), built upon a sound methodical approach, and (3) the coherent multi-service use of an eeBIM repository throughout the building life cycle.

The objectives of this research, carried out in the frames of the European FP7 project HESMOS (HESMOS 2010) are, on one hand, the provision of a methodology by which end user requirements can be consistently gathered and transformed into measurable modelling and software design goals, and on the other hand, the development of an adequate eeBIM framework derived from these requirements and enabling full multi-model, multi-service integration. In the paper, the developed overall methodology, the findings regarding ICT requirements and the concepts of extending standard BIM (ISO/PAS 2005) towards a multi-model based eeBIM framework are discussed, and conclusions and recommendations for further research work are drawn.

2.2.2. Energy Related Life Cycle Building Management – State of the Art, Current Gaps and Suggested “TO BE” Use Cases

In current research and practice, the complexity of buildings and surrounding exterior spaces on macro, medium and micro level, the variety of climatic scenarios and activity profiles that need to be considered and the exploited possibilities for ICT-based feedback and control of energy performance have led to the development and use of highly sophisticated and specialised tools for building energy analyses, targeting various engineering disciplines and lifecycle phases. However, most such tools lack a coherent, model-based approach enabling their interoperable use throughout the life cycle phases of a building, even if some can (directly or not) import certain BIM data based on IFC or gbXML on limited level, e.g. EnergyPlus via GreenBuildingStudio. Many efforts have been invested in the development of simulation methods, services and tools enabling more informed design decisions on architectural or building services level (Clarke 2006, Maile et al. 2007, Schlueter & Thesseling 2009). Such simulations provide reliable prediction of energy performance but the respective models are difficult to create and, more importantly, interoperability with other design tools is on low level. Use in further life cycle phases is nearly unavailable. Hence, consideration of important life cycle issues such as operational and maintenance costs or changes in the building use or in user behaviour are hardly taken into account.

Similarly, there are many successful developments in the area of building automation systems (BAS) enabling their efficient use for energy performance monitoring (Packham et al. 2008, Menzel & Cahill 2010). However, these systems are also focused on their specific domain and lack life cycle interoperability. Feedback to designers and decision-makers is limited and results are not incorporated in facility management models and systems. Efforts undertaken in recent research projects such as AutEG (Oezluek et al. 2009) show that BIM - BAS integration can be achieved, albeit such efforts have also been limited mainly to the operational life cycle phase.
Undertaken analyses of the current situation show that considerable gaps exist in the information flows and model interoperability between building automation data, FM data and BIM data (Maile et al. 2007, Bort et al. 2011). Such gaps are especially important in PPP projects where due to the lack of interoperability the greatest benefits and savings can be missed.

Figure 1 below shows schematically the energy related actions and the information resources and software tools used in the building life cycle phases. It emphasises the main gaps that exist in current practice, namely: (1) the lack of a common data repository based on a consistent building information model, (2) the lack of software interoperability due to the absence of integrated standards based platform solutions, and (3) the insufficient use of simulation (based on BIM) and monitoring (based on installed sensors in the BAS) during the whole life cycle.

Specifically, improvements can be suggested in four of the shown six generalised life cycle phases, leading to four principal “TO.BE” use cases to be considered: (1) Design, (2) Commissioning, (3) Operation and Maintenance, and (4) Retrofitting and Refurbishment.

The **Design Phase** has a key role in energy optimisation. The right choice and combination of building services equipment in that phase is essential to achieve substantial later reduction of life cycle costs. Currently, this phase is best covered by energy analysis and simulation software, compared to all other life cycle phases. However, available research and commercial tools still only weakly support advanced life cycle considerations. They are used with dedicated specialised models that are not linked with the BIM data from CAD. This limits considerably their practical acceptance and applicability. In the defined “TO-BE” process, the client should be able to check his ideas and requirements, the designers should be able to verify key design parameters, and the facility management should be able to simulate the investment and consumption behaviour and costs.

The **Commissioning Phase** is very difficult to manage mainly because the product must be rapidly commissioned. Here the automation of sequences with continuous monitoring, fast response to malfunctions and adjustment of the building automation system (BAS) must be in the foreground. The simulation data and tools are helpful in general but are overall of secondary importance. Primary roles in the process have the client, the building operator and the facility manager.

In the **Operational Phase**, all measured data can be evaluated. As a result, errors can be located and corrected faster. This can be typically done by the operator on daily and/or weekly basis. Additionally, end user behaviour can be better assessed and included in subsequent analyses and simulations. However, for that purpose integration of BAS and BIM data into a common eeBIM framework is needed. This is particularly important for the envisaged “TO-BE” process where active control of energy performance via feedback to BAS is an important goal.

The **Retrofitting and Refurbishment Phase** is included whenever change of use or reduction of energy consumption and costs through investment in new components and systems are planned. This phase is similar in nature to the design phase, but it is also more complex due to the involvement of all actors (owner, end users, designers, facility managers) and the need to compare measured and simulation data and adjust simulation models accordingly. Due to that additional complexity, in current practice energy related ICT services and tools are hardly used. However, as in design, informed decisions taken in that phase can have far-reaching consequences. Important is, again, the capability to include multiple information sources, use up-to-date data from a sustainable data
repository, facilitate fast specification and analysis of adequate simulation models and provide for feedback of analysis results to the designers’ BIM.

Figure 1: Comparison of the current and envisaged life cycle of a building regarding energy efficiency

2.2.3. ICT Challenges with regard to Energy-Efficient Building Information Modelling

There are several ICT challenges with regard to the envisaged BIM-based framework that can be deduced from the outlined overall “TO-BE” process. These include:

- The disruptive nature of the related processes, taking place over dozens of years but not in continuous manner and not with the same actors and tools
- The heterogeneous and distributed nature of the information resources (building design data, building automation data, climate data, material data, equipment and product catalogues, usage statistics etc.) that need to be maintained during the whole building life cycle
- The heterogeneous and distributed nature of the software tools (CAD and FM systems, general simulation frameworks, specialised energy solvers, cost calculation tools)
- The multiple data models that have to be integrated and mapped to the requirements of the involved services and tools
- Various legal issues related to warranties, information access, security, and so on.

By examining the above issues related to warranties, information access, security, and so on.

By examining the above issues, the importance of a common modelling framework becomes evident. This, in turn, requires:

- A coherent eeBIM modelling approach, taking into account all energy related data models and respective information resources
• Appropriate extension of BIM to include necessary energy relevant extension, but without overburdening the model with highly specialised narrow-domain concepts
• Integration of existing building automation models such as BacNet, LON or KNX into the eeBIM framework
• Bi-directional transformation methods enabling the modelling transitions BIM ⇔ eeBIM, BAS ⇔ eeBIM, eeBIM ⇔ Simulation Models, eeBIM ⇔ Life Cycle Cost Models.

These issues are addressed in the following sections.

2.2.4. Requirements Gathering Methodology

Development of an efficient eeBIM framework, reusable and adaptable for different practical configurations, entails:

- proper definition of the involved actors and the roles they play in the overall process,
- specification of typical use cases and user scenarios,
- determining the respective information exchange requirements, and on that basis,
- elaboration of the eeBIM concepts, schemas and supporting methods and services.

This complex sequence of tasks is typically handled in cooperation of end-users, modellers and software developers who all have different background and expertise. Therefore, a grounded development methodology that can bring together such multifaceted teams is necessary. We suggest an approach based on the Information Delivery Manual (IDM) developed within the BuildingSMART initiative for that purpose (Wix 2007). However, we also extend and adapt IDM for the specific objectives of life cycle modelling, the definition of a generalised multi-model framework based on, but not limited to, a single standardised BIM (currently IFC2x3), and the derivation of information and processing (workflow) requirements for the components of an integrated virtual energy laboratory (IVEL).

The idea of IDM is based on the notion that only things that are well understood can be automated. IDM sets out to replace intuitively captured data exchange requirements, agreed mainly in informal, paper-based manner, by a well-defined process, specifically targeting BIM-based information exchange. For end users the approach is simple to understand, provides process-centric guidance and enables specification of requirements in plain engineering language. For BIM solution providers it offers a straightforward way to describe the detailed breakdown of the process into functional parts and identify the IFC capabilities needed to be supported for each functional part in terms of the entities, attributes, property sets and properties required. The main concepts of the IDM approach are:

- **Process Map** (describes the flow of activities for a particular business process together with the actors involved and the information required, consumed and produced)
- **Exchange Requirement** (represents a set of information that needs to be exchanged to support a particular business requirement at a particular stage of the overall process; it provides a description of the information in non-technical terms)
• **Functional Part**  (represents a unit of information used by solution providers to support an exchange requirement; a functional part is thereby a complete schema in its own right as well as a subset of the full standard on which it is based)

• **Business Rules**  (represent constraints that may be applied to a set of data used within a particular process; such constraints can be useful to vary the result of using a model schema without having to change the schema itself, e.g. when applied to a specific building type or localizing the interpretation of the standard).

IDM provides a more comprehensive and better-structured approach than the IDEF0 activity models used in the ISO STEP arena as starting point for the development of product data models (Fowler 1995). However, in its current version, similar to STEP it also targets particular single usage scenarios. Therefore, for the purpose of life cycle energy management, adaptation and extension of IDM was deemed necessary.

Figure 2 below outlines on high level the individual steps of the suggested methodology. It begins with the definition of an overall “TO BE” process in semi-formal manner, using the studied “AS-IS” processes for comparison and gap identification. After that, the user scenarios and their scope within the overall life cycle are determined, which are typically a subset of the full business process. At this point, the modified IDM process is started for each specified user scenario. Its principal steps, shown on the left side of Figure 2 are more or less self-explanatory.

Figure 2: Schematic presentation of the suggested extended IDM-based development process
We use a core set of the BPMN notation (OMG 2011) to represent the agreed processes, define the actors, their roles and main tasks, and determine the needed interactions, specifically focusing on the energy-relevant issues (first dashed box on Figure 2). This is easier to discuss and agree upon with the end users instead of directly aiming at development of full-fledged BPMN diagram. In the next step, the information exchanges are located and their principal content is determined. To do that, the BPMN diagrams for each identified scenario are expanded with additional swim lanes, capturing specifically the exchange points. These swim lanes contain no tasks and events but only information items, inter-linking the processes of the separate actors (second dashed box on Figure 2). After these tasks are finished, the role of the end users in the process is largely fulfilled. In particular, it was not found especially useful to try identifying functional parts in team with the end users. This IDM concept appeared to be quite abstract and difficult to understand to non-modellers. Therefore, a direct synthesis of the exchange requirements based on the detailed user scenarios in BPMN was undertaken instead (third dashed box on Figure 2). The next Figure 3 gives an impression of the level of detail of BPMN elaboration, whereby task and information items have been additionally annotated in tabular format (not shown on the figure).

Figure 3: Example of the developed process maps, showing User Scenario 4 "Refurbishment"

The next step comprises the mapping of the exchange requirements to BIM concepts. This is first done in tabular form, identifying – in particular - the relevant IFC classes and the cardinality of the relation of an exchange requirement to IFC concepts, as shown schematically on the right hand side.
of the fourth dashed box on Figure 2. Finally, the identified IFC classes are detailed on attribute level and related to the actual IFC schema, as shown in the last box on Figure 2. At this point, IDM is concluded, and a basis for the development of respective IFC model views supporting the respectively required information exchanges is achieved. Such model views can be developed using the MVD approach from BuildingSMART (Hietanen 2006) as well as methods and tools from recent BIM research, as e.g. shown in (Katranuschkov et al. 2010).

This is sufficient for eventual MVD standardisation and for software implementations realised separately from the modelling process, using the developed model views as baseline. However, the presented methodology offers also a straightforward way to the development of a software architecture for the targeted integrated virtual laboratory platform. It involves one additional step, namely the association of the identified information items to processes on service / application level, which in turn enables:

Tracking model evolution within a value-add user process involving one or more specialised engineering ICT tools;

Fine-grained service orchestration for the ICT processes taken place between the actors;

Better understanding of the interoperability requirements on software component level;

Last but not least, identification of information requirements (input, output) for each service component not only with regard to BIM, but also all other model data used in the process.

To achieve that, a unified tabular form for capturing the information requirements for each component is suggested. At first, the BPMN diagrams are expanded to include the involved services and tools as shown schematically on Figure 4 below. A table is then prepared for each service or tool comprising five columns: (1) Resource category, (2) Informal description, (3) Formal specification, as defined in the underlying data model, (4) Data type, and (5) Exchange format (if applicable). The resource types for the targeted eeBIM platform are preset as follows:

- BIM data,
- Climate data,
- Material data,
- BAS data.

![Figure 4: Expanding a BPMN task on the level of services to enable explicit capture of model evolution](image)
This final step is particularly helpful not only for the platform realisation but also for the development and better understanding of the overall multi-model eeBIM framework.

2.2.5. Concept of the EEBIM Framework

Using all above considerations, an overall concept for an eeBIM framework was developed. It is presented schematically on the following Figure 5, which shows the main eeBIM component models and the involved model transformations embedded in the building life cycle and the principal services used for energy relevant analyses and decision-making. This figure essentially provides an eeBIM-centred perspective of the overall life cycle process identified during the requirement gathering task and documented in BPMN. At the top, the major relevant tasks in the building life cycle are shown, i.e. the Architectural Space Program developed in the early design phase where fundamental energy related decision are taken, the BIM-based Architectural and HVAC design, where decisions on material and component level are taken, and the Monitoring and Control via BAS in the Operation and Maintenance phase. At the bottom, the main related analysis tasks are shown, i.e. Energy Simulation – to forecast or check energy performance, and Life Cycle Costs Calculation – to include energy costs in the total life cycle costs and check eventual redesign, retrofitting or refurbishment decisions against the related investment and operational costs, thereby enabling informed decision-making. In the centre, the eeBIM framework enabling the interoperability and integration of all other components into a consistent platform is shown.

Figure 5: Generalised view of the suggested eeBIM framework
There are several input sources to be dealt with. BIM data comes as partially instantiated model from the space program (mainly IfcSpaces with properties capturing space use and related client requirements) and is later completed via architectural and HVAC CAD, adding building elements (IfcWall, IfcSlab, IfcColumn etc.) and equipment elements (IfcSpaceHeater, IfcPump, IfcFan, IfcDamp etc.) to the building model. Climate data originate from weather stations and are provided in weakly standardised form, even though the data structures are not very complex. Material data are also largely in proprietary format, specifically tailored for their use for energy simulation. However, material type names can be used to inter-link BIM-CAD material data and energy-specific material databases. Finally, in a later stage, data from BAS, such as sensor properties, measured values and locations have to be integrated with BIM. Output that needs to be considered includes energy simulation results, cost results and synthetic energy performance indicators. All that information has to be pulled together into a coherent modelling framework.

Considering these multiple information sources, the main concept of the eeBIM framework is established. Its essence can be expressed as follows:

- Keep the BIM schema virtually unchanged, with only minimal needful extensions on the level of additional attributes to spaces, space boundaries and building elements
- Interlink BIM to all other information sources via a separate Link Model binding the distributed data sources together and describing the semantics of the established links via added meta data in similar was as RDFS or Dublin Core (Nilsson et al. 2008)
- Use the so assembled BIM-based multi-model for all subsequent model transformations required for achieving service/tool interoperability.

If BIM is to be preserved largely unchanged, thereby facilitating feedback to architectural design after energy and cost analyses are done, adequate links to the needed external data must be established. In fact, the multi-model concept strongly depends on the quality and convenience of defining such links. In our approach, we use as baseline the specification developed recently in the German lead project Mefisto (cf. Scherer & Schapke 2011). It provides a very efficient method to store and retrieve inter-linked multi-model data, but the creation of such links may vary considerably for different use cases, ranging from fully automated trivial procedures to heavy-duty computational algorithms. Fortunately, the basic targeted use cases regarding the eeBIM framework can be efficiently tackled with the help of the suggested Link Model. Thus, climate data can be automatically associated to the building’s façades, which can be relatively easily determined from the available BIM data. Energy related material properties are linked to respective building element materials in BIM using a mapping table for the material names and associating building element IDs with the primary keys (or IDs) in the material data model. In similar manner, sensor information is linked to spaces or building elements depending on the sensor types, whereby location information can be used to determine the association of each sensor to the appropriate IFC component. Finally, calculated costs can be also associated to the various building components in straightforward manner, which is sufficient for cost estimation, prediction and planning by architects and building owners.

Model transformations are inevitable because energy solvers or cost calculation tools normally maintain their own specific data structures and do not “speak” BIM.

On Figure 5, four principal bidirectional transformation types are shown. These are:
• BIM (CAD or FM) to eeBIM (1a)
Typically architectural or MEF CAD and FM systems provide BIM data that is lacking many energy relevant features. Except for the external sources mentioned (climate, material characteristics and so on) the exported BIM data generally does not include space boundaries or at most defines them on what is known as Level 1 representation (Weise & Liebich 2008). However, energy solvers require at least Level 2a or 2b, which in turn leads to complex geometry computations and subsequent restructuring of existing BIM data.
• BAS to eeBIM (1b)
As indicated above, BAS data can be easily linked to BIM on the basis of the provided locational and typological information. However, the difficulty is to first provide a suitable BAS description, containing the needed meta data in neutral format. This requires a BIM-BAS ontology that defines concepts generalizing the data from the various used BAS standards today (LON, KNX, BacNet, EnOcean etc.).
• eeBIM to Energy Simulation Models (2)
Energy simulation models essentially employ the same data as already contained in the eeBIM, but structured completely differently. Therefore here a typical mapping transformation as used e.g. in federated databases is required. Due to the large range of available solvers, each having its own dedicated data input model, two possible approaches can be envisaged: (1) customary one step mappings to each solver integrated in the eeBIM-based virtual laboratory platform, and (2) the more difficult but also more promising two step approach involving development of a harmonised simulation model and first mapping eeBIM to it, thereby achieving higher level of interoperability on medium term.
• eeBIM to Costs (3)
This transformation is in spirit the same as the described transformation of eeBIM to Energy Simulation Models above. However, the IFC model already contains definitions of various cost elements, which greatly facilitates the mapping process.

Based on these principal links and transformations, closing the eeBIM life cycle circle, detailed modelling issues can be further defined and partial model views can be specified as necessary. Moreover, support ICT services and their interfaces can be more easily and clearly identified, and workflows providing for efficient service/tool orchestration of various sub-processes in the overall life cycle business process can be worked out, such as the automated creation of single-zone energy simulation models from architectural BIM.

Conclusions

In the preceding section of this paper, we described the gaps regarding energy efficiency in the current building life cycle and outlined a vision of a future “TO-BE” process where energy performance can be substantially improved. A comprehensive methodology for requirements gathering was suggested that provides for better cooperation of end users, modellers and software developers, thereby enabling holistic consideration of various life cycle issues and faster and better understanding of the related ICT challenges. On that basis, an overall concept for an integrating
eeBIM framework was developed, based on the idea of a federation of multiple models, bound together through a dedicated link model specifying the anchors of all external data to the central integrating BIM. In this way, a step forward towards flexible energy efficient nD modelling aligned with the BuildingSMART initiative was made.

Despite these achievements, several open issues need yet to be solved. This includes most backward transformations from solvers and cost calculation tools to eeBIM and adequate and reliable feedback from eeBIM to CAD, FM and BAS, improved tabular templates for capturing end user requirements, finding ways for more fluent transition from business processes to service orchestration workflows, tackling of various mapping issues and so on. This is on-going work expected to yield results within the next couple of years.

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References

   http://dublincore.org/documents/2008/01/14/dc-rdf/


2.3. Paper: Ontology models and design patterns for building automation

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Abstract

Building Automation Systems (BAS) monitor and control the energy consumers in a building and play a key-role in ensuring energy-efficient building operation and comfort to the user. To ensure this goal, the building automation system needs to be designed in a holistic manner with the buildings’ energy-efficiency in mind. As building automation systems can contain several hundreds to thousands of devices, the system engineering not only needs to be efficient itself, it also has to consider problems such as the interoperability of devices and their fitness for a desired function.

The paper introduces a novel design approach that permits a semi-automated design of building automation systems under consideration of the building’s energy-efficiency. The approach develops the design over different user-interactive abstraction levels. First, the requirements of the system are specified by requirement engineering. Then an abstract design is generated representing the functional system structure with a generative programming approach. Multiple semantically interoperable device combinations are created using evolutionary optimisation that fulfil the abstract design. The approach utilizes ontology-based design patterns and semantic device descriptions that allow for an ontology-based mapping of functional and non-functional requirements to the abstract design level and finally to specific devices. The device description model is a layered ontology architecture that provides technology spanning as well as vendor specific models for building automation devices. The application of semantic web technologies provides many benefits, from a reasoning based completion of device descriptions and their validation for consistency and correctness (device specification), over a generic, query based device interoperability evaluation, up to an automatic, rule-based instantiation of abstract design patterns (automatic design support). The approach is very effective for building automation systems as they can easily consist of several hundred devices and contain many repetitive design patterns such as rooms.

The paper illustrates the approach and the ontology description with a discussion of related standards and a practical example focussing on the engineering of building automation systems for energy-efficient buildings.

Keywords: Building Automation Systems, Ontology, System Engineering, Energy-efficient buildings.
Modern buildings are usually equipped with Building Automation Systems (BAS) that monitor and control most building system functionalities such as heating, cooling, air-conditioning (HVAC), as well as lighting, shading, and security. BAS are usually distributed control systems that consist of several hundreds to thousands of devices. In most cases the controls are realized locally (distributed) such that each room contains for example an individual local room temperature control consisting of a temperature sensor, a control unit, and an electronic valve. The devices communicate directly with each other using a shared communication media. Common communication technologies are for example BACnet, KNX, LON, or EnOcean, which is an emerging wireless technology (Kastner, et al. 2005). As BAS directly control most of the consumers in a building, e.g. the HVAC system, they can reduce the energy-consumption of buildings by up to 30 percent (Salsbury und Diamond 2000, Jagemar und Olsson 2007, VDMA 2008). This potential results in an increasing usage of BAS. Particularly as new wireless technologies such as EnOcean allow the simple integration of BAS in existing, older buildings.

To utilize this potential of energy savings, BAS need to be designed adequately. Building automation networks are designed during construction of the building including the placement of devices and their wiring. The usage of off-the-shelf units simplifies the design nowadays and reduces it to the composition of software function blocks. These function blocks encapsulate their implemented functionality and offer only input and output interfaces called datapoints. The system integrator connects these datapoints in a design tool by logical connections, which represent the data exchange of the distributed algorithms. Besides this functional design level, the system integrator defines also the topology and the addressing of the devices within these tools. The final logical system design is uploaded by the tools into the final network after its installation. The physical placement of wires and devices is planned separately with suitable CAD tools.

However, the classical network design has its pitfalls. The usage of prefabricated off-the-shelf devices divides the development of the system into two phases: The design of the devices and their function blocks by device developers and the devices selection, composition, and parameterization by system integrators to the full BAS.

This division does not only save time, it also creates new complications. Usually, the system integrator starts his design by selecting the devices he wants to integrate. This selection process is not easy at all, because the selected devices not only have to provide the purposed functionality but they also have to be interoperable, which means that devices of different manufacturers properly work together. This assumes that the system integrator first has to decompose the functionality to be realized in function blocks as well as to create a functional design in his mind, to compare his concept design with available device documentation or experience to select devices and evaluate their interoperability. Considering the number of several thousand different devices available at the market, it is basically impossible for a system integrator to identify the best fitting, cheapest, and most interoperable solution. Instead, 92 % of the system integrators report regular issues with interoperability and device selection (Dibowski, Ploennigs und Kabitzsch 2010). The main reason for these issues is that the designer lacks instruments to evaluate interoperability.
2.3.2. State of the Art

Interoperability in BAS

Different interoperability models exist such as syntactical and semantical interoperability (EC 2009), or conceptual interoperability (Turnitsa 2005). These concepts have in common that interoperability has a syntactical and semantical component and has different layers. We will use the layered interoperability model commonly used in building automation (Dietrich, Loy und Schweinzer 2001). To be interoperable, devices need to fulfil a set of conditions that are introduced in Figure 1 in the leftmost column.

<table>
<thead>
<tr>
<th>Compatibility Level</th>
<th>Standardization Level</th>
<th>LON</th>
<th>KNX</th>
<th>BACnet</th>
<th>EnOcean</th>
</tr>
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<tbody>
<tr>
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<td>ISO 14543</td>
<td>ISO 16484</td>
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<td>Interworkable</td>
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<td>SNVT</td>
<td>Data Point Types</td>
<td>BACnet objects</td>
<td>EPP</td>
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<td>Functionblocks</td>
<td>Functional Profiles</td>
<td>Application Models</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interchangeable</td>
<td>Behaviour</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 1: Compatibility standards in theory and praxis of BAS

The first condition is the *interconnectability* (technical interoperability in Turnitsa 2005) of devices, which is the ability of two devices to exchange messages with each other. Nowadays, this is usually not a big issue as only few communication technologies BACnet, LON, KNX, and EnOcean dominate the market. These technologies are all standardized apart from EnOcean, which provides interconnectability by the fact that only one company exists that produces nodes. ZigBee, as another example, illustrates the importance of interconnectability. Though ZigBee builds upon the standard IEEE 802.15.4, the standard allows that many variations, thus interconnectability often cannot be guaranteed. That is one of the reasons why ZigBee has problems to establish in the BAS market.

Interconnectability is therefore a problem in buildings, if devices from two different technologies should work together. This is not uncommon, as a BAS is usually integrated by different system integrators that specialized in specific industries (HVAC, shading, lighting, security) and each integrator uses his own technology such that the building contains different technologies in the end. Several gateway technologies address the vertical integration problem between the device and the management system. However, it gets problematic if devices should be integrated horizontally (e.g. if the occupancy sensor of the security system should be used for the HVAC system). Modern middleware technologies will provide new solutions to this such as the EU SCUBA project that develops a self-organisation system approach (SCUBA 2011).
Interworkability (syntactic and semantic interoperability in Turnitsa 2005) is the next condition for interoperability. It is given if two devices are able to understand their messages syntactically and semantically. All major technologies support interworkability by standardized datapoint types. These datapoint types define not only the syntax of the data exchanged (data type), but also its semantic (e.g. temperature -100 – 200 °C). These datapoint standards are widely accepted by the industry and also gateway mappings between technologies (LON/BACnet, KNX/BACnet, LON/EnOcean, etc.) exist, such that interworkability is usually quite well supported.

Interoperability (pragmatic interoperability in Turnitsa 2005) is the ability of two devices to operate together as one. This requires also a black-box understanding of what interfaces the other device provides and what the other device does with the information. For example, to create a room temperature control, the temperature sensor needs to send in regular intervals the temperature to a controller which then actuates the electric valve. For interoperability, the roles and the interfaces of the sensor, controller and actuator needs to be defined. LON, KNX, and BACnet also tried to address this aspect by standardizing function block profiles for common applications. These profiles define the interfaces datapoints and the basic role of a device. Unfortunately, these standards are not fully supported in industry (Dietrich, Bruckner, et al. 2010). The primary problem is that profiles are often too confined and, thus, allow manufacturers little freedom for developing innovative products. Or, they are too vague, regarding only a few common properties shared by all manufacturers and leaving to much space for manufacturer specific extensions, whose interoperability again causes problems. In result, BACnet stopped using its functional profiles.

Interchangeability (dynamic interoperability in Turnitsa 2005) is the dream of BAS operators as it allows exchanging broken devices even after years when the original devices are not available on the market anymore. However, it requires that two exchanged devices behave exactly identically. This means for example that two different room temperature controller devices have to implement exactly the same control algorithm. Interchangeability is hard to standardize, as the standardisation of behaviour restricts the device manufactures completely to produce device generics without innovation. Figure summarizes these compatibility levels and compares the situation for BAS. The lower level of compatibility (interconnectability) is usually strongly standardized in global organisations such as ISO. The higher levels (interworkability) are quasi-standards of user group organisations (BACnet Association, EnOcean Alliance, KNX Association, LonMark, etc.) to keep the flexibility for changes. The higher compatibility levels are usually less covered by standards, as here the diversity of the market develops.

Semantic Interoperability and Device Descriptions

The last section illustrated that the higher levels of interoperability are hard to standardize and that the existing standards have problems finding acceptance in practice (Dietrich, Bruckner, et al. 2010). This could be interpreted as bad will of the device manufacturers, but they mainly follow market rules and need to distinguish their products. This diversity of the market and the fact that the market is strongly dominated by small and midsize enterprises created a new situation where today several thousand different devices are available at the market. This large range also changes the need for
interoperability standards. The main issue regarding interoperability nowadays is not that none of the devices work together, but, to identify these devices that are interoperable and fulfil a desired functionality. Hence, it is rather a problem of describing the syntactical and semantical information of devices in an electronic readable format that allows searching and evaluating devices’ interoperability. These description formats should then be target of a standardisation.

In the different automation domains, several description formats for devices exist and are established in practice. EDDL (Electronic Device Description Language) (ANSI/ISA-61804 2007) and CANopen EDS (Electronic Datasheet) (EN 50325-4 2003) are two examples for device description languages that are commonly used by engineering tools to document the operation and parameterization of field devices from process and industry automation. Both are based on text files in ASCII format. GSDML (Generic Station Description Markup Language) and FDCML (Field Device Markup Language) (ISO 15745 2003) on the contrary are device description languages based on XML. GSDML fulfils similar purposes as EDDL and CANopen EDS. FDCML on the other hand is a meta-language for describing automation devices from different views, such as communication, functionality, diagnosis and mechanics. Its primary usage is to provide (human readable) product data sheets and to enable a tool based commissioning. FDCML is flexible for extensions such as manufacturer specific attributes, but which on the contrary inhibits the comparability of devices due to a non-uniform vocabulary.

The building automation domain also developed specific device descriptions, such as the ASCII based LonMark Device Interface (XIF) Files (LonMark 2005) or the binary EIB/KNX description files for the ETS engineering tool.

All device descriptions mentioned before are primarily specializing in device commissioning, configuration and testing. They are inadequate for a computer enabled retrieval of suitable devices and mostly do not facilitate comparability or automated interoperability evaluations. Additionally, the semantics of the applications (their functionality) are not formally defined, which is needed for a conceptual interoperability evaluation. Besides, there are no formal validation techniques available.

Contrary to that, classification systems like ETIM (ETIM 2011) for electric devices or the industry independent classifications eCl@ss (eCl@ss 2011) and PROLIST (PROLIST 2011) enable a description, categorization and comparability of devices for catalogues and biddings. Nevertheless, they do not cover commissioning, testing and interoperability evaluation or application semantics.

The smartphones and mobile devices domain again forced own specification approaches. They intend to describe the huge variety of different mobile devices for the sake of dynamic web content adaptation to the device specific features and hardware characteristics such as display resolution, color depth or supported graphic formats. The practical use case behind all approaches in this domain is to request relevant properties for a given mobile device from a centralized database to know how to dynamically adopt web contents. One of the early approaches in this field is the FIPA (Foundation for Intelligent Physical Agents) device ontology specification (FIPA 2001), which defines a common set of device properties in a proprietary frame-based representation.

More recently modern approaches like RDF and OWL have been used for the specification of mobile devices. RDF (Resource Description Framework) (W3C 2004) defines the data model of the Semantic Web, which denotes the vision of a World Wide Web, where the contents are not only understandable for humans, but also for machines. RDF is a graph based data model, which uses triples, consisting of
a subject, predicate and object, as elementary representation units. Several syntaxes are available, such as the XML-based syntaxes RDF/XML or abbreviated RDF/XML. The formal ontology language OWL (Web Ontology Language) (W3C 2009), which evolved to one of the most predominant ontology languages in recent years, is based on RDF and extends it with further constructs for a formal, semantic specification of knowledge. Ontologies emerged from artificial intelligence and convey the syntax and semantics of concepts and their relationships in a formal, declarative and computer-understandable way.

Conceptual Interoperability and Design Patterns

Interoperability requires more than simply correct defined syntactical and semantical interfaces as discussed in Section 0. It also consists of a black-box understanding of how the other device will act on the information. This is comparable to dynamic interoperability in the conceptual interoperability concept (Turnitsa 2005). The interesting idea in this concept is that the next and highest level is conceptual interoperability, which is reached if conceptual models can be created of the system enabling their interpretation and evaluation in terms of composability by engineers (Turnitsa 2005). This leads to another aspect commonly used in the design of building automation systems: design patterns.

Whereas installed BAS are mostly unique, this is different for building subdivisions like rooms, sections, and floors, that are usually equally equipped with devices. Here a number of recurrent design patterns exist, which cover primarily the functional design level. These design patterns are commonly utilized to accelerate BAS design.

Nowadays most design tools support copy-and-paste operations to duplicate design parts easily. The next development step is a pattern library, which was first introduced by the NL-220 tool. However, the disadvantage of these libraries is known as library-scaling-problem (Biggerstaff 1994). With time, the number of design patterns in the library grows, as each pattern needs some modifications in the next project. This results in multiple variants of similar patterns, which are difficult to distinguish. Particularly as NL-220 stores fixed device types in their patterns, its library scales badly with the flexible market and is usually bound to a single product line.

2.3.3. Ontology Concept

Overview

Ontology concepts for building automation systems should allow device specifications that permit interoperability evaluation without the issues of tight functional restrictions that failed in standards. To simplify the descriptions it should separate generic domain specific concepts from technology specific concepts for LON, EnOcean, etc. as well as from vendor and device specific concepts. It further should relate abstract design patterns to permit conceptual interoperability evaluation.

These requirements result in the layered ontology architecture based on OWL as shown in Figure 2. This ontology layer architecture builds the ontological framework and unified vocabulary for the
ontology-based device descriptions (ODDs). During design time, considerations were made on whether to reuse existing upper ontologies such as DOLCE, SUMO, COSMO etc. Such ontologies often provide hundreds of concepts for multiple purposes. Unfortunately, only a marginal part of the vocabulary that is needed for specifying technical devices is covered by them. For this reason, it was decided to not use such an upper layer ontology and designing an efficient ontology from scratch without overhead in querying and reasoning architecture tailored for the needs of device descriptions in building automation.

The concept for the ontology-based device descriptions was first presented by Dibowski (2008). It separates the device descriptions into four layers. The main concern of these layers is to separate generic domain specific concepts from technology and vendor specific concepts. Layer 1 contains the ontologies that define the domain specific vocabulary, i.e. the common vocabulary for modeling devices of the automation domain. Layer 2 refines this vocabulary towards specific technological platforms, resulting in a vertical, platform specific partitioning for this and all subordinated layers. A further vertical partitioning occurs in Layer 3 where for each manufacturer a type definition ontology is added, if appropriate for the platform. Layer 4 finally bases upon the definitions of all superior ontologies and contains the individual device specific ODDs as such, which are platform and manufacturer specific.

On top of the model of ontology-based device descriptions a layer of functional concepts is defined that completes the ontology by conceptual interoperability. This layer defines functionalities, abstract function blocks and design patterns of how these function blocks interact to fulfill a specific functionality. It is basically an extension of the pattern ontology introduced by Ryssel (2009). These function blocks and design patterns are of a very abstract and generic nature. For example, a temperature control is described by a temperature sensor, a controller and actuator function block. These function blocks are technology and vendor independent and illustrate only the conceptual interaction of the functions that are generally known and accepted. They do not restrict the way they are implemented. The function blocks may be realized on one or multiple devices using different technologies and whatever datapoint number and type is seen appropriate by the vendor. This leaves maximum freedom to the vendors and does not restrict them as previous standardized profiles. The interoperability of devices is left to the semantics defined in the higher levels of device descriptions. Vendors are basically restricted to edit their data, i.e. their device descriptions, but cannot add or change the ontology vocabulary. This permits vendors to fully describe their devices, but they cannot change the underlying concepts. The technology specific vocabulary and data may be standardized by the user organizations of the specific technologies such as LonMark or EnOcean Alliance that develop technology specific standards anyway. The general domain specific vocabulary as well as domain specific concepts can be standardized in international standards to specify a common semantic concept for BAS. In the next sections, the layers are described in more detail.
Layer 0: Functional Concepts

Layer 0 of the ontology architecture specifies the functional concepts and semantics for the domain of BAS. The main concepts are described by four ontologies, as pictured in Figure 2, which are complemented by a set of other ontologies, not displayed in this Figure.

The abstract vocabulary ontology defines the general concepts and corresponding properties that are relevant to model abstract, platform independent function blocks used in the conceptual design patterns. These are the concepts fc:FunctionBlock, fc:Inport, fc:Outport. Specific function blocks are defined as instances of these concepts. For example, the functionality of an occupancy sensor is represented as instance fc:occupancy_sensor with a single outport.

The functionality of function blocks is specified by relating each of them with a specific function. All BAS functions used are defined in the functions ontology in a complex function taxonomy with the root concept comm:Function. This functions ontology plays a central role. Functions are not only used for describing the functionality of function blocks, they are also essential entities for describing functional requirements in the initial stage of requirement engineering (requirements ontology) and for describing the functionality of devices and their functional profiles (Layers 1 to 4). By using the same ontology vocabulary in all three cases, an unambiguously direct mapping of requirements to function blocks and to appropriate devices is possible during the design process of BAS and other applications.

The fourth ontology, the design patterns ontology, defines typical BAS design patterns of how these function blocks need to be combined to fulfill a specific functionality. The individual patterns are modeled in the ontology in a generative pattern that combines several related patterns in a generic representation. Using a Generative Programming concept the individual patterns can then be recreated depending on the requirements specified. Thus, not all possible solutions need to be stored in the library, but few generic construction plans. See Ryssel (2009) for more details.
Layer 1: Domain Specific Layer

Layer 1 of the ontology architecture is the top layer for the device description ontology. It defines the domain specific vocabulary for automation devices. It consists of four ontologies that are arranged in two sublayers. The upper vocabulary sublayer contains the general vocabulary ontology as the main component of Layer 1. Herein all general concepts and corresponding properties, annotations and constraints are defined that are relevant for a domain spanning device modeling. Examples are the general concepts ba:Device, ba:Manufacturer, ba:FunctionalProfile, ba:Antenna and so on, along with their describing datatype properties. Additionally, object properties are specified that relate the concepts with each other.

The lower data sublayer consists of three ontologies that add instance definitions for some of the general concepts from the vocabulary sublayer. The separation in two sublayers is done to separate concepts from individuals and to facilitate clarity and maintenance. In the manufacturers ontology for example all device manufacturers are defined. The hardware ontology specifies individuals for all solar cells, transmission mediums and energy storages, which are used in practice. Semantic types, used for a deep semantic specification of functional profile's semantics (Dibowski and Kabitzsch 2011), are predefined in the semantic typesontology. Device manufacturers reuse these specifications in their own ODDs by simply referencing them via object properties. This referencing simplifies the specification process, saves memory and avoids duplicate specifications and inconsistencies.

An important and powerful mechanism of ontologies is the principle of inheritance. A concept can be defined as subconcept of a given concept, which is then its superconcept. According to the semantics of OWL, each subconcept inherits the set of all datatype and object properties defined for all of its superconcepts. The inherited properties can be constrained via property restrictions for the subconcept, which specializes the subconcept with regard to its superconcepts. Another way of
specialization is the introduction of new datatype and object properties that are specific for a subconcept. From a set theoretical point of view a subconcept is thus a subset of the intersection of each of its superconcepts.

The principle of inheritance is applied for the ODDs to reuse existing vocabulary by extending and inheriting from existing concepts, which ensures a unified core vocabulary for all hierarchically related concepts. Inheritance is used in the schema ontologies of Layer 1 and Layer 2 (cf. Figure) to build up a concept hierarchy. Figure illustrates this in the Layer 1 ontology excerpt. Here the concept ba:Device is defined as the topmost superconcept of all other device concepts. It defines a set of datatype properties like the device name (String), the ingress protection (Integer), its mounting form (Enumeration) and operating voltage (Enumeration). Additionally, an object property is introduced that relates individuals of the concept with one individual of the concept ba:Manufacturer, stating that a device is produced by a specific manufacturer. Several subconcepts for ba:Device exist, such as ba:AutomationDevice or ba:WirelessAutomationDevice, which inherit all the properties of its superconcept. While ba:Device represents electrical devices in general, ba:AutomationDevice represents intelligent field and automation devices. Such devices are equipped with a transceiver (relation to ba:Transceiver) and come with one or more functional profiles (relation to ba:FunctionalProfile) which are the software applications that run on the device. The functional profiles are related to the subconcepts of the Layer 0 concept comm:Function they implement to permit conceptual interoperability evaluation and an unambiguous mapping to requirements and function blocks, which are also related to the comm:Function subconcepts. Finally, a ba:WirelessAutomationDevice is an automation device capable of wireless communication via an antenna.

Layer 2: Platform Specific Layer

Layer 2 of the ontology architecture refines the common vocabulary of Layer 1 towards specific technological platforms, such as the LON or EnOcean building automation technologies. As in Layer 1, there is a separation in a vocabulary sublayer and a data sublayer. The vocabulary sublayer consists of the platform vocabulary ontology that defines platform specific concepts and properties. It extends the general vocabulary ontology from Layer 1 by defining its concepts as subconcepts of the common concepts. This can be seen in the lower part of Figure. Here the LON specific schema ontology introduces amongst others the concept lon:LONDevice as subconcept of ba:AutomationDevice. Thereby each LON device is per definition also an instance of ba:AutomationDevice and ba:Device. As a consequence, LON devices can be specified by using the same vocabulary (datatype and object properties) as defined for ba:Device and ba:AutomationDevice, enhanced by some LON specific specializations, as explained in the following. On the one hand, the range of some datatype and object properties is restricted by property restrictions to LON specific values and concepts. On the other hand, further LON specific datatype and object properties are introduced, such as the datatype properties lon:deviceSPID and lon:deviceXIFFile, which define the device’s standard program ID and the name of its device interface file. The same is done for the EnOcean platform. The concept eno:EnOceanDevice is defined as subconcept of ba:WirelessAutomationDevice. EnOcean devices thus
extend the characteristics of automation devices with an antenna and EnOcean specific properties and constraints.

The data sublayer of Layer 2 contains ontologies that add instance definitions for some of the platform specific concepts from the vocabulary sublayer. Specific LON and EnOcean hardware ontologies define all existing LON respectively EnOcean transceivers. Standardized profiles, variable and parameter types are defined in the respective standardizations ontology. As with the data sublayer ontologies from Layer 1, device manufacturers reuse these specifications in their own ODDs, thus simplifying the specification process and saving memory and time.

**Layer 3: Manufacturer Specific Types**

While Layers 1 and 2 were still manufacturer independent, Layer 3 focuses on manufacturer specific type and profile definitions. In manufacturer specific type definition ontologies all variable, parameter and profile types of the corresponding manufacturer are predefined as individuals, one for each manufacturer and each with a manufacturer specific unique URI. Again the individuals defined here can be reused by the device manufacturers in their ODDs by referencing them, with the same benefits as on Layers 1 and 2. For some platforms such as EnOcean, Layer 3 may be omitted completely, as the platform does not support manufacturer specific type definitions.

**Layer 4: Manufacturer Specific Device Descriptions**

Layer 4 as the lowermost layer finally comprises the individual, platform and manufacturer specific ODDs as such. The ODDs employ the ontology definitions from the superior layers, as explained before, by importing and using them. Only the concepts of the Layer 1 and Layer 2 ontologies (e.g. lon:LONDevice, lon:FunctionalProfile, eno:EnOceanDevice) are instantiated here and assigned with property values, which have not been instantiated in the data sublayer ontologies of the subordinate layers. For all other concepts, the required individuals defined in the data sublayers of Layers 1, 2 and 3 are reused by referencing them. This specification with the same ontology vocabulary ensures a unified specification of all devices and facilitates a manufacturer-spanning comparability and retrieval of devices.

As appropriate partitioning, the assignment of one ontology file for each device seemed to be the best choice. This reflects the current state of the art practice in domain engineering and fits best into the practical demands. For each ODD a globally unique URI is used. It is composed from the manufacturer specific URI extended by a device specific identifier.

Altogether, the introduced device description approach provides a formal, extensible, manufacturer-independent and machine readable specification format, which is required for design automation. It enables a deep, unified specification of devices from different domains and platforms and thus ensures comparability of different devices. The ODDs are furthermore particularly suitable for a comprehensive specification of the hardware and software of devices, including also their functionality and characteristics necessary for an automated interoperability evaluation. For more detailed information about the semantic specification model the interested reader is referred to (Dibowski and
Furthermore the inheritance mechanisms of OWL can be applied to define new concepts by specializing existing concepts, what enables the reuse of existing vocabulary and a unification of the core vocabulary common for different platforms.

2.3.4. Enhanced Design Process

The ontology concept introduced in the last section can enhance the design and operation of BAS in multiple ways. This section will illustrate the application of the ontologies for the automated system design that was developed in the German AUTEG and AUDRAGA project. Other examples will be given in the conclusion.

![Diagram](image)

**Figure 4: Basic design approach**

Figure 4 introduces the design process. The design approach implements the process proposed by the German national standard VDI 3813. The design of the BAS starts with analyzing the building geometry to determine not only the size and quantities of the system, but also to identify the room usage types for the building, i.e. number of office rooms, laboratories, corridors, technical rooms, etc. These room usage types usually pre-define, which templates (patterns) will later be needed.

Then the functional requirements for each of these templates are defined, which generally specifies the functionality that should be installed for a template / room type (e.g. automatic temperature control). Based on these requirements an abstract design is created. This abstract design aims at creating a conceptual system specification that can be used for call for tenders. For this, it needs to be detailed enough that the basic system functionality and architecture is defined without restricting the technology or vendor for implementation. Thus, it should allow a conceptual interoperability evaluation.

In the next design step a system integrator can develop his final design based on this abstract design specification. This process is automated by an evolutionary optimisation algorithm.
**Geometry Import**

The design of a building automation system starts with analysing the existing geometry of a building. Building information models such as IFC (ISO 16739 2005) allow accessing this information and are supported by all major architecture CAD tools. Relevant data in the IFC files are for example the building structure such as number and size of buildings, floors, and rooms. In addition, specific objects such as windows or doors may be relevant to estimate the number of window contacts or light switches. This information can be extracted from the BIM to facilitate a fast analysis and assignment of templates and quantities.

**Requirements of Energy Efficient Buildings**

The first step in a new project is the definition of the system requirements, which is usually done together with the owner. A generic requirement engineering tool, which bases on the ontology Level 0, has been developed to provide support for this first design step. System requirements can be of functional and non-functional nature. Functional requirements determine the envisioned functionality of the installed system. This mainly is determined by the comfort that should be reached, the usage flexibility, and the desired energy efficiency of the building. Particularly the latter one is an important driver nowadays to invest in BAS as up to 30% of the energy consumption can be saved by optimal control.

However, defining requirements for a building automation system depending on the desired energy-efficiency class of the building is not easy. The EN 15232 (2007) simplifies this by defining four energy-efficiency classes for buildings from D to A. The EN 15232 (2007) further defines the basic requirements which have to be fulfilled by a building (automation) system for each class. Figure 5 shows an example for the heating system. The energy efficiency class is shown on the right side divided for residential and non-residential buildings. The functionality is given on the left side with different feature levels. In the example the emission control is shown. The lowest building Class D is reached if no or a centralized automatic control is installed in the building. For class C, which is currently standard, an individual room control is necessary. If the building should reach class A it needs an individual occupancy dependent room control.

<table>
<thead>
<tr>
<th>Definition of classes</th>
<th>Residential</th>
<th>Non-Res.</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCBADCBA</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Heating Control**

The control system is installed at emitter or room level, for case 1 one system can control several rooms

<table>
<thead>
<tr>
<th></th>
<th>Residential</th>
<th>Non-Res.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No automatic control</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Central automatic control</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Individual room automatic control by thermostatic valves or electronic controller</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Individual room control with communication 3 between controllers and to BACS</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Integrated individual room control including demand control (by occupancy, air quality, etc.)</td>
<td></td>
</tr>
</tbody>
</table>

Figure 5: Example from the EN 15232 (2007)
Abstract Design and Design Patterns

In the next step, abstract design templates can be generated from these functional requirements using the information stored in the Layer 0 ontologies. Abstract design templates are a technology and vendor independent function block representation of the intended functionality as defined by the VDI 3813 (2011). The generation bases on a generative programming approach as introduced in Ryssel (2009). The approach automatically creates for each requirement template the specific abstract design including segments. This automated process removes the need for drawing these abstract designs from the planner. Figure shows the abstract design (template) for an occupancy dependent room temperature control of the heating system that additionally turns off if the windows are opened. This template supports building energy efficiency class A of the EN 15232. Further mappings to individual functions in a building automation system including the function blocks and design patterns are defined in VDI 3813.

These templates are assigned to the building’s structure elements such as rooms that were previously exported from the BIM. Finally, the planner of the system has a complete documentation of his system as defined by the VDI 3813 including abstract designs, function lists, and the required quantities to prepare a call for tender.

Figure 6: Abstract design for an occupancy dependent room temperature control

Final Design

The next step is to create a detailed system design for the abstract design including selecting and composing devices to realize the functionality defined by the requirements and the abstract design. To improve the efficiency of system design and address the interoperability problem, the system integrator is supported by an automated design process that selects interoperable devices and composes the final system by connecting the devices’ datapoints. It implements a systematic engineering process that develops the final design over different user-interactive abstraction levels (Dibowski, Ploennigs und Kabitisch 2010).
Figure 7: Detailed design pattern for an occupancy dependent room temperature control

The device selection and composition bases on an Evolutionary Optimisation approach (Oezluek, Ploennigs und Kabitzsch 2010), which utilizes an ontology-based device repository for the retrieval of requirement compliant and interoperable devices. The multi-objective optimisation approach evolves several candidates in parallel and evaluates them by the compliance with the requirements, interoperability, and price. The compliance and interoperability of the devices is automatically evaluated by the device repository that applies expert knowledge specified as generic rules. The device selection and composition approach is non-trivial as usually no simple 1:1-mapping between abstract functions and devices exists, but several thousand combinations per design. For example, Figure 7 shows the best detailed design candidate for the abstract template in Figure . The nine abstract functions blocks (sensors, switches, and actuators are simplified to symbols) in Figure map onto three device profiles for the detailed design candidate in Figure 7, which are provided by three devices. Please refer to Dibowski (2008, 2011) for more details about the approach.

Conclusions

The ontology architecture introduced in this paper allows for modeling of semantical interoperability in building automation systems. Ontologies provide many benefits for such an approach. The hierarchical layered architecture separates domain generic aspects from technology and vendor specific parts. The vocabulary can be easily extended to support evolution of generic concepts as well as extension of specific ones. Formal validation techniques common to ontologies can further enhance the consistency and completeness of the data (Rieckhof, Dibowski und Kabitzsch 2011). These properties simplify not only the handling of the ontology specification, but also the standardization of the underlying concepts. This was demonstrated by relating relevant standards in the domain of building automation. Further standardization should not target the conformance of device functions in profiles, but the electronic description of interoperability. To facilitate this, the ontology-based device description was extended by a conceptual functional layer to support the evaluation of conceptual interoperability and the composable devices. This should reduce the common interoperability problem without restricting the development of new device generations.

The benefits of an ontology architecture that contains device semantics and conceptual interaction patterns are manifold. One example was provided with the introduction of an automated design approach for building automation systems that works for wired and wireless systems (Dibowski, Ploennigs, & Kabitzsch 2010, Ploennigs et al. 2011). Comparable concepts can also be used to develop self-organising approaches for the system commissioning and maintenance as well as new intuitive pattern based approaches for information retrieval from building automation systems. These
topics are currently investigated in the European projects SCUBA and HESMOS (SCUBA 2011, HESMOS 2011).

Acknowledgments

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References


3. Session: Energy and Behavioural Modelling and Simulation at Facility Management

3.1. Paper: Energy and Behavioural Modelling for managing energy resources in residential buildings

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Abstract

Current implementations of building information models (BIM) essentially store data on building physics (spaces, envelope, partition walls, equipments...), but not all data needed by applications during the building operation or facility management (FM) phase, as for instance energy management tools. However, it is important to agree on a common conceptual definition of building operation and FM data to make it sharable between all concerned stakeholders and make FM applications interoperate in a seamless way.

This paper presents an analysis of the various kinds of data needed to be collected and stored for the purpose of advanced building energy management systems (BEMS). These include: (a) building behavioural data about the actual building operation that can be acquired by means of embedded sensors, (b) user behaviour data (user activities...) that have proven to have a great influence on actual building energy performance, (c) energy prices evolution, and (d) weather forecasts. We also propose a global and conceptual model of these data that is consistent and linked with standard BIM representations like IFC or gbXML files, and that can be seen as a further extension of BIM that covers some FM issues. Finally we show through some examples how this model can be used to support advanced BEMS functions such as the anticipation of energy demand, the optimisation of building operation (energy demand, local generation and energy storage), and the improvement of user behaviour, in order to increase the overall energy efficiency of buildings. In particular, we illustrate the use of these data by energy simulation software like EnergyPlus.

This work is currently performed in the context of the FIEMSER EC-funded project that aims at developing an innovative energy management system for existing and new residential buildings (single-family houses, multi-dwelling building blocks).

Keywords: BIM, Data Modelling, Energy-Efficient Building, Intelligent Control, BEMS
3.1.1. Introduction

Building operation and maintenance (O&M) requires a lot of information for appropriate decision-making from building owners and facility managers: not only descriptive “static” data on the building (spatial layout, envelope, components, equipments, etc.), but also “dynamic” data on the building usage and operation, energy performance, and already performed maintenance activities. A link with the (evolving) regulatory context also allows to know in which legal conditions the building has been designed and maintained. Some research work, like the French SMARTIMMO project, is currently contributing to the definition of a reference model for small or medium tertiary buildings that should host all information needed to provide innovative services to facility managers or end-users (e.g. in terms of performance monitoring or security) during the building operation phase.

Building Information Models (BIMs) have the capabilities to store all information related to buildings during their lifecycle. Although the interest in using BIM data to support O&M is widely shared among building owners (Journal of Building Information Modelling, Spring 2011), the focus of BIM has been on the design and construction phase until now, and less work has addressed information modelling during the O&M phase (Meadati 2009).

In terms of energy, many ICT-based services can be envisaged to support building operation: monitoring of actual building energy performance, continuous commissioning (i.e. a continuous evaluation of the building performance in order to reach or maintain an energy-efficient operation), global energy management (through BEMS – Building Energy Management Systems), evaluation of energy-efficiency improvement in case of renovation, etc. However, it is important to agree on a common semantic definition of these data to make them sharable between all concerned stakeholders (building owners, facility managers, energy service providers, end-users, etc.), and make FM applications interoperate in a seamless way. This would allow fostering the deployment of energy-related applications, as well as energy benchmarking (e.g. comparison of performances of similar buildings).

This paper presents some results obtained in the context of the EU-funded project FIEMSER, in relation to the elaboration of a data model for building energy management. It also shows how this model can be used to support advanced BEMS functions such as the anticipation of energy demand, the optimisation of building operation (energy demand, local generation and energy storage), and the improvement of user behaviour, in order to increase the overall energy efficiency of buildings.

3.1.2. Building energy management systems

A BEMS (Building Energy Management System) is a computer-based control system connected to the building’s mechanical and electrical equipments such as heating, cooling, ventilation, lighting, and even insulation and appliances. An advanced BEMS also has the ability to control the building’s energy production and storage systems (photovoltaic panels, combined heat and power generators, batteries, etc.) along with the possibility to retrieve energy-related information from the internet, like weather forecasts.
The main goal of BEMS is to control all energy components of the system in an optimized way to minimize the global primary energy consumption of the building while ensuring optimal indoor comfort (according to user needs and wishes) and safe operation of all controlled equipments, based on three main functions:

- Advanced monitoring (including maintenance supervision, failure detection, diagnostics)
- Optimized control of energy resources and loads of the building
- Real-time and consolidated reporting (including benchmarking features)

The FIEMSER system is an innovative BEMS for existing and new residential buildings, which pursues the increase of the efficiency of the energy used and the reduction of the global energy demand of the building, but without penalizing the user comfort level. In order to achieve this goal, two main strategies are followed:

- Minimize the energy demand from external resources through the reduction of the energy consumption in the building and the optimized management of local generation (heat and electricity) and energy storage equipment to satisfy the energy demand of the building, and even provide the capability to export energy to the utilities when needed. In case the energy price is not constant, and there is not enough local energy to satisfy all the loads, a second-level optimization strategy (after the first one has been fulfilled) would consist in scheduling those loads at the cheapest possible prices.
- Enhance the interaction with the building user in order to increase his consciousness about his energy consumption and CO2 emission, by providing hints to make punctual changes in his behaviour without major disruptions of his comfort conditions.

The FIEMSER system differentiates from current marketed BEMS on the following aspects:

- Control strategies: it provides holistic, predictive and optimized energy management strategy, which takes into account not only the current building operation conditions, but also its expected evolution that depends on planned user activities. Besides, it considers both thermal and electrical energy, passive and active components (Photovoltaic - PV, Combined Heat Power - CHP, windmills, windows, blinds, shutters, etc.).
- Control & monitoring network: the FIEMSER system deploys dependable and energy efficient wireless communication network. It has an IP-based infrastructure (6LowPan), and ensures interoperability with existing control communication systems on the market (KNX, LonWorks, ModBus...).
- User interfaces: the way the FIEMSER system will interact with end-users will depend on their role (occupants or facility manager); for occupants, the interactive digital TV will be privileged, thus moving the BEMS user interface to the most common and user-friendly system in homes, the TV.

BEMS are currently based on three main functional modules: interaction with the building, control logic and user interface. FIEMSER also follows this general approach, as shown in figure 1, but goes a
step forward in the functional requirements for each module. A detailed description of the functionality of each FIEMSER module is available in (Perez 2011).

Figure 1: FIEMSER functional modules

Hereafter, this paper focuses on the modelling of the data used by - and exchanged between – the different FIEMSER modules and relevant external services (e.g. weather forecast service).

In order to understand the basis of this data modelling work, a functional overview of the FIEMSER system is provided in the diagram below (figure 2). This diagram identifies the main system processes (blue boxes), corresponding to the main use cases (UC), and supported by specific modules of the FIEMSER system. Main input and output data (red boxes and lines) are mentioned for each process. It should be noted that some processes will be run in a cyclic mode, whereas some others will be started by the end-user or triggered as a post-condition of other processes (blue arrays). Those cyclic processes are identified with the icon  in the functional diagram.

The database plays a central role in this functional architecture. It contains all data collected from the sensors and external sources, and exchanged between the components. Storing all data in the same database guarantees their consistency and allows performing detailed performance analysis.
The main processes shown on the previous diagram can be mapped to the high-level requirements identified for the FIEMSER system:

1. **Minimizing the energy demand from external resources**, through the reduction of the energy consumption in the building and the correct management of local generation (heat and electricity) and energy storage equipment to satisfy the energy demand of the building. It will be achieved through:
   - Monitoring the actual building operation and usage via a sensor network (UC3)
   - Controlling the HVAC equipments, and other energy-related home devices and appliances, through an advanced Devices Control System (UC3)
   - Scheduling the management of local energy resources (solar panels, µ-CHP…), storage and loads in an optimal way by anticipating needs (linked to occupant behaviour), and taking into account weather forecast, evolution of energy prices, and possible shiftable loads (e.g. washing machine) (UC4)
   - Dynamically identifying significant deviations to resources scheduling, and taking appropriate measures (UC5)

2. **Interacting with the building user**, in such a way as to increase his awareness about energy consumption and CO2 emissions, and encourage his adoption of eco-behaviours, by:
   - Dynamically reacting to inefficient user actions, and providing suggestions for more energy-efficient operations (UC6)
   - Integrating building’s user preferences in terms of occupancy and activities, and user preferences (set-points, rules and strategies for managing energy devices) (UC2)
• Calculating and informing the occupant on actual building energy performance, comparing with past values, and suggesting ways of improvements (UC7 & UC8)

3. **Develop plug-and-play solution for adding new components or devices** to the FIEMSER system:
   • Adding new device (UC1)

### 3.1.2. Data modelling – Approach and methodology

The elaboration of a data model is often a complex task, not only when data are numerous and varied, but also because of the different views that can be chosen to analyse the role played by these data in the related business processes, and to structure them accordingly.

The methodology chosen to elaborate the so-called FIEMSER Data Model followed a bottom-up approach, starting from the description of specific parts (sub-models) and merging the produced sub-models into a holistic and consistent model.

More precisely, the methodology comprised three main steps, as shown in figure 3:

1. **Categorization of data:** several categories of data have been identified, starting from the description of use cases, each category corresponding more or less to a specific functional view of the system.

2. **Modelling of data in each category:** this was achieved by following the UML class diagram approach, complemented with a tabular template in order to describe classes, attributes and relationships.

3. **Merging produced sub-models into a global Data Model,** which implied identification of common concepts and possible inconsistencies.

This work was supported by a detailed analysis of the state-of-the-art, including the review of ongoing R&D projects on ICT for energy efficient buildings (EnPROVE, EnergyWarden, ENERsip, IntUBE, PEBBLE, SmartCoDe, BeyWatch, BeAware...), with a focus on data modelling, and a comparative analysis of relevant standards in the building domain, especially the IAI/IFC and gbXML standards.

![Figure 3: Methodology for data modelling](image)
3.1.4. Data categorization

The first step of the modelling methodology led to the identification of eight main data categories (see table 1), starting from the analysis of use cases and gathering data that contribute to the same functional role for the FIEMSER system.

It should be noted that these categories do not constitute disjoint sub-sets of data. Indeed the same data can belong to more than one functional view. Nevertheless, this bottom-up approach allows dividing the complex modelling work into more elementary tasks.

<table>
<thead>
<tr>
<th>Data Category</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental and contextual data</td>
<td>Location, climate zone, shadowing, building orientation, etc.</td>
</tr>
<tr>
<td></td>
<td>Weather data, energy prices, etc.</td>
</tr>
<tr>
<td>WSN-related data</td>
<td>Sensors &amp; actuators (location, characteristics, configuration data, etc.)</td>
</tr>
<tr>
<td></td>
<td>Data collected from sensors (equipments operation, building usage)</td>
</tr>
<tr>
<td></td>
<td>Log of activations (control orders sent to actuators)</td>
</tr>
<tr>
<td>User preferences</td>
<td>Usage profile, definition of scenes, including comfort set-points and use of appliances</td>
</tr>
<tr>
<td></td>
<td>Control rules and energy strategy</td>
</tr>
<tr>
<td>Resources scheduling data</td>
<td>Scheduling of resources</td>
</tr>
<tr>
<td>Advices</td>
<td>Orders, and associated advices, created as a result of an event, usually associated to an action of the user and some other actions suggested by the system</td>
</tr>
<tr>
<td>Energy performance indicators</td>
<td>Log of consumptions</td>
</tr>
<tr>
<td></td>
<td>Performance indicators</td>
</tr>
<tr>
<td>Energy-focused BIM (Building Information Model)</td>
<td>Space organisation / Envelope &amp; partition (characteristics)</td>
</tr>
<tr>
<td></td>
<td>Home equipments like appliances, generators, and storages (location, type, characteristics...)</td>
</tr>
<tr>
<td>User Access Rights</td>
<td>User rights regarding the access to FIEMSER functionalities</td>
</tr>
</tbody>
</table>

Table 1: Data categories
3.1.5. Energy and behavioural modelling

The second methodological step consisted in elaborating a UML sub-model for each data category. The achievement of the final set of sub-models resulted from an iterative process including intermediate milestones where produced sub-models were merged together to harmonize the definition of concepts and relations, and identify possible inconsistencies. Sub-models were then refined, merged again, and so on until the final production of a comprehensive and consistent global data model.

We hereafter show three examples of sub-models that are of special importance in the operation of the envisaged BEMS:

- The first one structures all the data handled by the wireless sensor network
- The second one models the user preferences
- The last one shows how our data model is linked to the information contained in a traditional BIM

In order to simplify the models and make the reading easier, the methods attached to objects are not represented in the following UML diagrams.

**Wireless Sensor Network**

The Wireless Sensor Network (WSN) model represents the interface to the building's sensing and acting infrastructure. This interface is handled by ControlDevices, i.e. the devices that can be controlled and monitored directly by the system. Each ControlDevice can be interfaced with a number of HardComponents (either sensors or actuators), and handles a number of software and network protocols (e.g. Zibgee, KNX, ModBus...). The sensed values are stored in the DataLog class. The system configures the sensing and acting infrastructure by sending configurations instruction to the device in charge of the specific sensors and actuators. Each instruction, as well as any event raised by the hardware, is logged (EventLog). Finally, this component maintains an estimate (CtrlDeviceEnergyConsumption) of the energy consumed by every ControlDevice.
User Preferences

The User Preferences diagram describes the data model used to represent the daily planning of the building usage by the end-users. It comprises the definition of daily usage profiles at level of building zones, each profile describing the sequence of scenes (e.g. dinner), the loads involved, and the comfort set-points (temperature, minimal luminosity...). In addition, the model also includes the user choice of the control rules associated to each device.

The main classes described in the diagram are:
• **HomeUsageProfile class**: This class allows defining different profiles for the daily usage of a BuildingPartition (in case of a multi-dwelling building this is either a dwelling or a common building area). It is composed of a set of ZoneUsageProfiles that detail the usage of each building zone.

• **Scene class**: This class allows defining usage scenarios, i.e. specific usages of the building, in terms of comfort set points and appliances usage.

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**Figure 5: Class Diagram for User Preferences (provisional version)**

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**Building physics - Interoperability with BIM**

Special attention was paid to the interoperability with architectural CAD tools and energy simulation tools. The two main standard data models in EEB (Energy Efficiency in Buildings), IFC and gbXML, were analyzed. Finally, the gbXML data model was selected as reference data model for the FIEMSER system development. gbXML, which results from a bottom-up approach, focuses on building thermal load properties. It is then simpler and easier to use and more efficient than IFC to integrate with thermal analysis software, thus allowing quicker implementations (Dong 2007). The XML basis (data model in XML Schema and data format in XML) provides flexibility and extensibility, and data can be
easily processed by XML parsers. Besides, gbXML is integrated with CAD, design and simulation tools like REVIT or SketchUp. The limited features in terms of geometry (compared to IFC) are not an obstacle as far as buildings with standard geometrical features are addressed.

The part of the model addressing the building physics is related to the building spaces organization, including the definition of homogeneous thermal zones. However, attributes about geometries are not included because it is assumed that this information will remain in the gbXML file. Consequently, the following diagram includes direct links with gbXML objects that are relevant for the energy simulations.

It should be mentioned that a second part of the model deals with the home equipments hierarchy, and describes the data about the resources used in the building.

Figure 6: Class Diagram for Energy-focused BIM - Organisation of Spaces (provisional version)

**Global data model**

The merging of the eight sub-models corresponding to the eight data categories constitutes the global conceptual FIEMSER data model.
It should be noted that, due to the chosen bottom-up approach, an important work of harmonization and disambiguation was needed to reach a consistent holistic model. Many objects are shared by different views, and the different authors of these views may not only choose different labels for the names of these objects and their attributes, but also (which is a much more difficult issue to solve) have different understanding of the underlying concept. Moreover, it is well known that several modelling choices can be made to express the same knowledge. To support the merging work, it was asked to provide a clear definition of each concept and each attribute included in each sub-model. This facilitated the identification of common concepts and attributes (which then received a unique labelling), and their structuring in a common model. The Open Source StarUML platform was chosen to support this modelling work.

A hundred of classes are defined in the current version of the data model.

3.1.6. Optimized management of energy resources

The previous data model has been elaborated with the objective to support functionalities of advanced BEMS like the FIEMSER system, which includes the optimization of the energy consumption and local generation through a dynamic scheduling of resources. In FIEMSER, the component in charge of this optimization is the Intelligent Control System (ICS – see figure 1). It optimizes the operation of the devices under its control in such a way that, the usage of resources minimizes the import of electricity from the grid, maximizes the use of its own energy generation, maintains the comfort within the desired limits and, in a second step, reduces the cost of the energy. An example of action that can be envisaged to minimize the energy bill is to shift the use of some appliances (like a washing machine) to a period when the energy price is the cheapest possible.

One of the main challenges is to estimate the expected energy demand of the building as accurately as possible, typically over the next 24 hours. This is achieved by taking into account not only the current building operation conditions but also its expected evolution, which depends on the weather forecast and the scheduled home usage profile, as introduced in figure 5.

More precisely, this “day ahead” forecasting needs to estimate the thermal and lighting energy demand of the building (by taking into account different alternative operations of the active components), as well as the non-controlled energy resources, which include the non-controlled electricity demand (e.g. from appliances) and the local energy generation by non-controllable generation units, such as solar collectors or PVs. Such estimation relies on the buildings physics and equipments, whose characteristics are imported from gbXML file (see figure 6), weather forecast, and planned user presence and activities over the next scheduling period, as modelled in figure 5.

Several energy simulation software are available to calculate the energy demand (TRNSYS, etc.). We chose EnergyPlus since it can be used with no-cost license, has been extensively tested, and can be easily interfaced with tool like Green Building Studio (GBS) where basic gbXML file, containing only architectural data, can be enriched with settings and installations information.
Conclusion and perspectives

The data model presented in this paper results from a bottom-up approach guided by practical needs to support the advanced functionalities of the BEMS system developed in the context of the EU-funded FIEMSER project. It interoperates with standard BIM representations like generic IFC or more energy-focused gbXML, and proposes a semantic extension of those models to deal with concepts specific to energy management systems.

Agreeing on a common definition and structuring of concepts between people with different skills and expertise in related domains like energy, ICT, or automatism, has required many exchanges and a proper methodology. A provisional version of the data model has been produced but the work has to be continued. Indeed, the data model, which is an important foundation to ensure the interoperability between the different functional modules of the system, needs to be completed and adapted in the light of the detailed specification of these modules, which is currently in progress.

Further steps will consist in developing these components, achieving the system integration, and validating the system in real life conditions in two testing facilities in Spain and Germany, with two different climatic conditions.

References

3.2. Paper: Energy and Behavioural Modelling and Simulation for ee-Buildings Design

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Abstract

Construction Products (and especially those of commercial use) constitute energy intensive systems through their whole life cycle, comprising energy demanding assets and facility operations, as well as occupants that are the driving operational force, performing everyday business processes and directly affecting overall energy consumption. Modelling and simulating the energy efficiency of buildings and various facilities semantics has now been established as an integral part of the design process and many simulation tools are commercially available as a common practice by engineers. This paper reviews current findings and research results on various aspects of energy and behavioural modelling and simulation. Specific topics include building and workplace design and simulation, industry technological solutions on energy management, user behaviour and occupancy modelling, enterprise business and component semantic modelling. In this respect, the paper presents the dominant Building Information Models and respective tools and products with respect to the main identified construction performance and behaviour aspects. Also a review of relevant activities at a pan-European and International level is conducted. On the other hand, the paper attempts to position current findings with respect to the traditional approaches that are known in the literature as Building Energy Management Systems, controlling their main energy producing and consuming sources. A thorough analysis is also presented about modelling energy consumption in enterprise buildings, where a major gap is identified on energy use or waste due to human behaviour driven by business related operations and processes in the spatio-temporal domain. This motivates a review of the basic algorithms in modelling and simulation systems with regard to occupancy presence and movement patterns and future trends in contributing to open business modelling repositories.

Keywords: Building Information Modelling (BIM), Business Process Modelling (BPM), Occupancy Simulation, Workplace Design and Simulation.

3.2.1. Introduction

Energy performance of construction products during operation heavily relies on three interrelated spatio-temporal groups of factors: construction assets and facilities, environmental conditions and occupant behaviour. Construction products constitute energy intensive systems through their whole life cycle, comprising energy demanding assets and facility operations, as well as occupants that are
the driving operational force, performing everyday business processes and directly affecting overall energy consumption. Energy efficiency (EE) concerns and respective solutions have been presented in the past addressing all phases of construction product life cycle from the design phase (early and detailed design and engineering), to the realisation phase (procurement and development), as well as the support phase (mostly focusing on operation and renovation). However, extensive industrial practice throughout the years and respective market studies verify that most crucial decisions concerning construction products occur in the early phases of the design process. Moreover, critical decisions that are made during the early design phase determine those factors that are responsible for the total energy consumption, despite the fact that building operation phase accounts for 80% of the total energy consumption. On the other hand, existing tools for assessing the energy consumption of buildings, only take into account certain critical factors, possibly ignoring the qualitative influence of other equally important factors. Therefore, it becomes apparent that architects, designers and engineers need tools that will assist them in creating better and more sustainable construction projects. The need for such tools is more urgent today due to global energy-related challenges, such as the global climate change and the efficient management of natural resources.

This paper presents a survey of the state of the art on energy and behavioural modelling and simulation tools for EE buildings design. Initially, the paper reviews energy management of building and workplace design and simulation tools providing a deep insight to the most common approaches and products that are available on the relevant market. Also, a number of current and past industry technological solutions, as well as research practices with the corresponding implementation projects are presented. Moreover, it becomes apparent that the enterprise business and component semantic modelling tools and practices that are used by existing Building Information Models, and Building Energy Management Systems rely on underpinning information and semantics representation technologies. After illustrating those factors that are related to the construction assets of buildings, our analysis focuses on those aspects of energy use or waste due to human behaviour driven by business related operations and processes. In this regard, occupancy modelling research efforts and results are presented. The assessment of the state of the art on energy and behavioural modelling and simulation tools for EE buildings design, reveals the new research challenges on this area that are discussed later on, in this paper.

3.2.2. Building Design, Modelling & Simulation

**Commercial Products for BIM Based Integrated Design & Simulation**

Significant effort has been made on the development of BIM based commercial tools, that have gradually moved the industry away from the "2D design" approach and towards a "Model Based" Integrated Virtual Design and Construction Process. Such vendors include Bentley Systems, Autodesk and Nemetschek Group. **Autodesk**’s ([www.autodesk.com](http://www.autodesk.com)) comprehensive building information modelling (BIM) solutions, including the Autodesk Revit family and Autodesk Navisworks, enable intelligent 3D workflows across the entire building lifecycle. The platform combines building information modelling (BIM) data with a
wide range of building simulation and energy analysis functionality through desktop and web service platforms to better simulate design performance and sustainability. Revit also uses the integrated IES tools for load calculations. AutoCAD MEP design and construction documentation software is built for mechanical, electrical, and plumbing engineers, designers, and drafters. The platform has software that can export to load calculations software such as TRACE and input results back to the software, based on the gbXML standard.

Bentley Solutions ([www.bentley.com](http://www.bentley.com)) provides software tools for the design, construction and operation of infrastructures. The company's software serves the building, plant, civil, and geospatial vertical markets in the areas of architecture, engineering, construction (AEC) and operations. Their software solutions are used to design, engineer, build and operate large constructed assets such as roadways, railways, bridges, buildings, industrial and power plants and utility networks. Bentley’s principal software solution is MicroStation, a desktop 2D/3D CAD platform upon which Bentley and third-party software companies build more specific solutions. Apart from desktop applications, Bentley also has a few server application.

Nemetschek Group, offers programs such as VectorWorks Fundamentals, which is an architectural building program that can plug into Graphisoft AutoCAD and CATIA, VectorWorks Landmark for site planning and VectorWorks Spotlight for lighting design. HVAC Building Services and 3D Viewer (plus Nemetschek’s Allplan ([www.allplan.co.uk](http://www.allplan.co.uk)) for architectural design and Modelling software).

In 2006 Oracle also launched a new collaborative building information management platform (CBIM) and is working with Graphisoft to fully integrate building modelling tools with design collaboration, visualization, life-cycle management, and other applications.

Furthermore, while BIM technology is maturing, significant parallel efforts are being made by several vendors (like for example Google SketchUp) in the development of software for model viewing, model checking, energy analysis and simulation, facilities management, etc., to support various use cases associated with building information (like cost analysis, scheduling, and conflict resolution between structural and mechanical components).

### Building Energy Simulation Models

The dominant Building Information Models and respective tools capture three core construction performance and behaviour aspects, that is a) **Thermal load calculation**: the thermal peak load analysis of buildings (heating, cooling) based on which HVAC optimization can be performed (Corgnati et al. 2008), b) **Computational fluid dynamics**: applying fluid dynamic models to simulate airflow on the interior and exterior building spaces (Zhai 2006) and c) **Interior lighting and acoustics simulation**: analyzing factors influencing the interior lighting and acoustic conditions of buildings towards predicting the interior lighting levels (e.g. daylight level) and acoustics (e.g. reverberation time) (Daniel et al. 2004; Kima and Kimb 2007).

Although recent market evidence reveals the continuously growing demand for integration of structural design and analysis programs into building information models, the actual business practice demonstrates limited BIM model tie-ins that can dynamically and seamlessly integrate HVAC-related design programs (such as load calculation programs, pipe and duct sizing programs, building energy
modelling/analysis programs such as Trace 700, DOE-2, EnergyPlus, Blast, etc.). Very few companies have fully integrated either facilities operations and management programs or daylighting and illumination simulation and design programs (such as Superlite, LUMEN, or Radiance, AutoLUX, Autodesk Lightscape, etc) into BIM models.

In general, existing energy performance modelling and simulation approaches focus on the structural behavior of buildings and its relation and response to specific environmental conditions, failing to capture the driving factor of energy consumption, that of the occupants. The available modelling methods and systems do not deal with activities performed by occupants or with the resulting utilization of space and movement through space. Due to the complexity of the problem with capturing user preferences and activities engineers and existing simulation and design tools tend to eliminate the influence of users as far as possible to optimize building performance (Zimmermann 2006) eventually leading to assumptions about average user preferences and behaviors. This does not only result in rough and imprecise architectural designs in terms of energy performance of constructions during future operation, but also in fully automated systems without interaction, poor performance and low end user acceptance.

**Building Information Modelling and Standardization Initiatives**

Past experience has proven that there is rarely one model appropriate for all practices. In fact, in most of the cases BIMs’ added value lies on the fact that it provides a core *composite information model* comprising multiple sub-models and respective information views addressing specific business needs and different aspects of the overall construction product life-cycle. Stakeholders involved in the process are often making limited use of intelligent models for portions of the project scope to assist them with many of their traditional activities. Furthermore, these stakeholders have different expertise and varying business requirements. As the BIM technology evolves, greater interoperability occurs between disparate software systems. Undoubtedly, most opportunities lie within the integration of D&E practices covering aspects of both the design and the construction practices, efficiently supported by appropriate BIMs addressing application specific needs.

Serious effort has already been devoted to the design of common data exchange standards in the building industry. Apart from certain proprietary standards developed by specific vendors, at present, the Industry Foundation Class (IFC) and Green Building XML (gbXML) are two prevalent models in the architecture, engineering and construction (AEC) industry.

The **Industry Foundation Classes (IFC)** is a neutral and open specification data model intended to describe building and construction industry data. It is an object-based file format with a data model developed by **buildingSMART** (International Alliance for Interoperability).

The **International Alliance for Interoperability (IAI)** ([www.iai-na.org](http://www.iai-na.org)) is international alliance established to improve communication, productivity, delivery time, cost, and quality throughout the whole building life cycle. IAI is a council of the National Institute of Building Sciences (NIBS) at [www.nibs.org](http://www.nibs.org). Its mission is to providing a universal basis for process improvement and information sharing in the construction and facilities management industries. It’s goal is to build on the collective knowledge of the global construction and facilities management industries to define programmable...
language XML data models for information transfer between disparate software packages (as an example, aecXML is a framework for using an eXtensible Markup Language standard specifically related to technology in architecture, engineering and construction). They also offer comprehensive, intelligent and universal data models through Industry Foundation Classes (IFCs) to IFC.XML2 ISO 10303-28, which incorporate HVAC schemas compatible with ifcXML - IFC2X3 code (ISO 10303-11), as well as data elements that represent entire portions of a building or system. These are used to assemble computer readable models of the facility that contain all of the information on the parts and their relationship (ISO/PAS 16739). The IFC model specification is open and available (http://www.nemetschek.net/news/pressreleases/2007/041807.php). It is registered by ISO as ISO/PAS 16739 and is currently in the process of becoming the official International Standard ISO 16739 with major implementation worldwide like BuildingSMART (Australia), SARA (Finland), CORENET (Singapore), Building Lifecycle Interoperable Cost (http://www.blis-project.org/index2.html), Simple Access to the Building Lifecycle Exchange (http://www.blis-project.org/~sable/).

The Green Building XML schema, referred to as "gbXML", was developed by Green Building Studio (formerly GeoPraxis) with the support of the California Energy Commission Public Interest Energy Research (PIER) Program, and the California Utilities (Pacific Gas and Electric Company, Southern California EDISON and Sempra Energy Utility) to facilitate the transfer of building information stored in CAD building information models, enabling integrated interoperability between building design models and a wide variety of engineering analysis tools and models available today. gbXML is developed based on the XML (Extensible Markup Language) format. XML provides a robust, non-proprietary, persistent, and verifiable file format for the storage and transmission of text and data both on and off the Web (W3C, 2006). Today, gbXML has the support and wide adoption by the leading CAD vendors, Autodesk, Graphisoft, and Bentley. With the development of export and import capabilities in several major engineering modeling tools, the standard allows several popular CAD software (e.g., Autodesk’s Revit, Architectural Desktop, and Graphisoft's ArchiCAD) and energy analysis applications (e.g., DOE-2. e-QUEST, HAP) to exchange data using this schema, through the Green Building Studio web service. It enables building design teams to truly collaborate and realized the potential benefits of Building Information Modeling. Based on XML, extensible markup language, gbXML has a global “language” format, with consistent syntax and can potentially represent any computational building model through translation using appropriate mapping engines. In June of 2000, the gbXML schema was submitted for inclusion in aecXML(TM), the industry-led initiative, launched by Bentley Systems with much excitement in the summer of 1999. Shortly thereafter, gbXML became the draft schema for the Building Performance & Analysis Working Group. The gbXML.org site was created in February of 2002 to host and further stimulate development of the schema.

Of particular interest is the work being done by the FIATECH (a non-profit consortium supported by NIST and established by the Construction Industry Institute) towards fully integrated and automated design and construction technologies. FIATECH is a consortium consisting of stakeholders from several domains and industries which due to their business operations are engaged in large scale construction. In addition, it includes the leading providers of engineering, design, and construction services as well as prominent technology providers of a wide range of industry, construction and...
building operation relevant solutions. Main mission of FIATECH is to make a step change improvement in the design, engineering, construction, and maintenance of large capital assets. Their Capital Projects Technology Roadmap (CPTR) (http://fiatech.org/tech-roadmap/roadmap-overview.html) is a cooperative effort of associations, consortia, government agencies, and industry, working together to accelerate the deployment of emerging and new technologies that will revolutionize the capabilities of the capital projects industry. The vision of the future for the capital projects industry is of a highly automated project and facility management environment integrated across all phases of the facility lifecycle. Information is available on demand, wherever and whenever it is needed to all interested stakeholders. This integrated environment will enable all project partners and project functions to instantly and securely "plug together" their operations and systems. Interconnected, automated systems, processes, and equipment will drastically reduce the time and cost of planning, design, and construction. Scenario-based planning systems and modeling tools will enable rapid, accurate evaluation of all options, resulting in the selection of the best balance of capability and cost-effectiveness. New materials and methods will reduce the time and cost of construction and greatly extend facility performance, functionality, aesthetics, affordability, sustainability, and responsiveness to changing business demands. The initiative is led by FIATECH and is open to all stakeholders who are committed to the future success of the capital projects industry.

Last but not least, is the ICT4E2B Forum initiative. The ICT4E2B Forum is a European Project that brings together ICT and Building stakeholders to identify needs, challenges and opportunities in further research and integration of ICT systems for Energy Efficiency in Buildings. ICT4E2B Forum fosters the cooperation between researchers, end-users/practitioners, building owners, technology-suppliers, and software developers as regards the use of ICT for an efficient use of energy at building and district level. In short, the ICT4E2B Forum has the following objectives: a) Bring together relevant stakeholders to identify and review the needs in terms of research and systems integration, b) Update the REEB research roadmap and c) Promote the use and further development of ICT for improved energy efficiency of buildings.

3.2.3. Occupancy Modelling

Energy consumption in enterprise buildings is a major source of carbon emissions and is highly dependent on human presence and behaviour in such environments (Liao and Barooah 2010; Kashif et al. 2011). As of today, various strategies and methods have been proposed to improve the energy efficiency of commercial and home buildings that consider various environmental factors including occupancy modelling (Dong and Andrews 2009; Bourgeois et al. 2004; Bourgeois, Reinhart, and Macdonald 2006; Hutchins, Ihler, and Smyth 2007; Mahdavi and Pröglhöf 2009). However, energy use or waste due to human behaviour in the spatio-temporal domain is not yet fully investigated in the literature.

In the past years, one basic algorithm for using in modelling & simulation systems with regard to occupant presence was the diversity profiles (Abushakra et al. 2001). These profiles represent the combined behaviour of all occupants. A diversity profile describes the presence of occupants and (for
instance) the corresponding energy loads stemming from utility demands. Diversity profiles however have failed to sufficiently capture dependencies of occupancy patterns with overall environmental conditions (Bourgeois et al. 2004) or temporal variations (Page 2007). Authors in (Bourgeois et al. 2004) presented a sub-hourly occupancy control model in order to propose a framework for whole-building energy simulation that can assess the impact of short term occupancy variations and other environmental factors. By using a suite of occupancy-based predictive models in ESP-r tool savings in energy requirements have been reliably predicted as well as monthly peak power demands on whole building have been remarkably enhanced. In a more recent study (Hutchins, Ihler, and Smyth 2007) on modelling the human presence, authors suggested a probabilistic model for estimating occupancy in buildings using networks of occupancy sensors. This approach as well as similar methodologies (Liao and Barooah 2010; Bourgeois, Reinhart, and Macdonald 2006; Mahdavi and Prögihöf 2009) overcome the limitations of simpler occupation estimation methods but do not directly examine the occupancy modelling in the spatio-temporal domain with correlation among data from different sensor networks that exist or could be integrated in the enterprise buildings. One other shortcoming of the existing technologies for occupancy modelling is the lack of generalized occupancy models (abstraction) that can be adapted not only to whole building occupancy estimation but also to zone level. In addition, due to dynamic nature of the occupancy in buildings, the construction of mathematical models that is appropriate on one hand for zone level occupancy estimation and on the other hand for real time occupancy predictions remains a challenging research problem.

As far as contemporary research or existing technological tools (Chen 2009; Crawley et al. 2008) is concerned there is no enterprise modelling (or simulation systems) which fully exploit/address the actual effect of occupants and their respective actions/behaviour in their working environments. For instance, in the field of occupancy behaviour, modelling research is mainly focused on control-oriented user behaviour, i.e. the interaction between the occupants and environmental controls, like windows, lights and heating systems (Zimmermann 2006; Mahdavi et al. 2008) not taking into account additional types of enterprise utilities. Furthermore, modelling is based on stochastic processes, such as Markov chains (Page 2007) or Poisson distributions (Wang, Federspiel, and Rubinstein 2005) dealing with occupancy as a random stochastic process not taking into account typical business episodes, constituent processes and respective events that directly affect and drive specific occupancy patterns.

3.2.4. Enterprise & Business Process Modelling & Simulation

**Enterprise Models**

As of today modelling technologies are a commodity and used in various areas such as process management, business modelling, software development, security, etc. Typically tools implementing the technology are bundled as tool suites implementing a certain method that consist of a specific procedure model, a modelling language and algorithms (e.g. acquisition, analysis, simulation, generation) supporting the application of the method. Models can be basically distinguished between
non-linguistic or iconic models that use signs and symbols that have an apparent similarity to the concepts of the real world and linguistic models that use basic primitives such as signs, characters or numbers. Nearly all models in computer science are of the latter linguistic type. Linguistic models can be further distinguished in being realized with textual and graphical / diagrammatic languages (Harel and Rumpe 2000).

Karagiannis (Karagiannis and Kühn 2002) adopted a layered model stack originally proposed by (Strahinger 1996). The lowest level in the stack represents the original – “the real world” that is used to craft the model situated on the second layer. Model created in the second layer is described using the metamodel from the third layer. Highest layer is the meta² model which describes the concepts for building the metamodels. In computer science models are seen as “representation of either reality or vision” (Whitten, Bentley, and Dittman 2004), representing the real world in an agreed syntax and semantics.

The modelling language proposed by (Karagiannis and Kühn 2002) is defined by syntax, semantics and notation that provide the necessary modelling primitives in order to build the model. Current existing modelling approaches can be classified in the dimensions domain, design and integration: a) Domain: data processing, knowledge representation, requirements engineering, information systems, business process- & workflow management, decision support, and business, b) Design: macro-level design (generates concrete meta models (layer 2) that act as templates or reference structure) and micro-level (concerned with the definition of the structure of data models or representation languages) design and c) Integration: bringing together different meta models

**Relevant Initiatives, Tools and Standards**

Meta modelling is widely applied in different scenarios:

- **Business Modelling**: depending on the targeted application area different tools exist, implementing methods on different abstraction levels such as BPMS, BPMN, BPEL, EPC and IBM’s LOVEM (List and Korherr 2006) provide an overview and evaluation on business related modelling tools currently available on the market.

- **Legal Modelling**: current approaches handle the legal frame by modelling business rules using standards as SWRL (Karagiannis et al. 2008) or RuleML (see HERA Project, http://www.alexandria.unisg.ch/Publikationen/54615 for prototypic implementation), as well as ontology based approaches (Bottazzi and Lehmann 2006).

- **IT Modelling**: on a management level highly abstract tools exist to handle aspects such as architecture and service management implementing methods and approaches such as ITIL and COBIT. On a technical level CASE tools support the MDA utilizing UML as a modelling language and providing functionality supporting software engineers. Advances in the area cover aspects such as integrating semantic technology and providing mechanisms for reasoning and traceability as done in the MOST project (http://www.most-project.eu/). Concerning the scope of objectives in the Adapt4EE, an emphasis in the IT modelling domain is on the Enterprise Architecture Management. This stems from objective to derive relevant data from areas such as Inventorying, IT Demand & Project Portfolio Management, Technology Management and Architecture Governance and Master Planning and based
on that data to be able to map the actual IT environment and usage toward the planned energy efficiency (e.g. based on the occupancy connected with used applications and infrastructure)

- **Semantic Modelling**: prominent candidates are ontology editors – still a research topic and resulting in different tools and frameworks developed by academic institutions as open source such as Protégé (protege.stanford.edu), NEON (www.neon-project.org/web-content/) or Top Braid Composer and similar tools. Beside semantic modelling tools based on formalisation standards, there are tools which are based on semi formal languages with the advantage to employ a more user oriented notation lowering the entry barriers of usage for domain experts. In the area of knowledge modelling tools and approaches such as PROMOTE (Karagiannidis and Telesko 2000) and KMDL are prominently employed.

From a technology perspective, tools follow a client server architecture implementing meta models on database level. More advanced tools build upon flexible meta-model definitions for modelling method development e.g. the ADOxx® Meta² Platform as a basis for the ADONIS® toolkit (http://www.bocal.com/jumpto.jsp?goto=ADONIS&lg=at).

### 3.2.5. Building Energy Management Systems (Bems)

#### BEMS Weaknesses

Simulation and Operation are tightly intertwined practices. Efficient Building Simulation taking into account all building operational parameters (including occupants) leads to realistic and accurate evaluation and optimization of alternative Building Designs and eventually to efficient Building Energy Management. Building Energy Management Systems (BEMS) are now a routine component of large and medium-sized buildings, controlling their main energy producing and consuming sources. However, despite their prevalence, the majority of BEMS platforms consist of automation/control systems with some monitoring capabilities and with relatively limited intelligence. BEMS platforms do provide considerable and valuable energy savings – for new and retrofitted spaces – but their performance seldom matches the full potential of addressed spaces. In fact, even for new buildings designed according the industry best practices, achieved efficiency systemically lags behind values predicted at design time (Demanuele, Tweddell, and Davies 2010). A number of reasons contribute to this performance gap:

- Buildings are rarely built as they are designed.
- Buildings are rarely used as assumed by the designers.
- Available monitoring/sensing information is not accurate and detailed enough to provide the fine-grained information advanced control algorithms would need to improve their performance.
- In general, and despite the large number of significant research and industrial advances (artificial intelligence, agent-based approaches, neural networks, fuzzy logic) (Packam et al. 2008) most BEMS control algorithms still struggle to dynamically adapt to the continuous changes in buildings and in the way they are occupied.
- And a number of systems (e.g. HVAC, lighting, co-generation etc) may simply not operate efficiently, due to non-consistent control strategies or malfunctioning components.
In this context, specific studies within projects REEB (Hannus et al. 2010) and intUBE (Vermesan et al. 2008), as well as other industry surveys (Paiho et al. 2008), have identified a number of present drawbacks and respective future challenges related with these circumstances.

It is essential that EBMS can seamlessly interoperate with other technical systems supporting different user groups (tenants, owners, network operators, etc.). In addition, there is a need for better automation and control solutions, consisting in methodologies, procedures and ICT systems that are able to manage energy production and usage in a building, according to information received from inside the building (user interfaces, sensors, appliances, energy devices – production, storage, consumption) and outside (Internet, ESCOs, district energy systems, weather, etc.). Moreover, there is also a generalized need for better monitoring/sensing frameworks, relying on “the instrumentation of the building with smart meters, other sensors, actuators, micro-chips, micro- and nano-embedded systems that allow collecting, filtering and producing information locally” (Hannus et al. 2010). This sensing framework must be easy and safe to deploy, which raises the need for secure wireless communications and proper standards and middleware for device discovery, integration and management. Last but not least, buildings monitoring systems should provide decision support functionalities through increased information granularity, while automation and control algorithms should also take user activities and building usage into account, for predictive (and not only reactive) control.

**Semantically Enhanced Device Management**

Delivering accurate simulation models requires detailed monitoring of enterprise & building operational parameters which in turn necessitates for semantically enhanced management of enterprise constituents (assets, occupants, processes, environmental parameters). As service-oriented architecture (SoA) has been becoming widely used for distributed software, many efforts have been done to adopt this architecture for middleware for embedded devices so that devices can be integrated easily into business applications. UPnP represents an early adoption of SoA for devices, which unfortunately with the development of web service standard, it became incompatible. European Union funded projects such as AMIGO (http://www.hitech-projects.com/euprojects/amigo/index.htm), SIRENA (http://www.sirena-itea.org/), and SOCRADES (http://www.socrades.eu/Home/default.html) have developed frameworks for devices adopting web services. They rely on Device Profile for Web Services (DPWS) technology which is becoming a standard web service for embedded system. DPWS addresses these problems: a) **Discovery** ensures that services offered by devices can announce themselves and be discovered by the consumers, b) **Eventing** ensures that interesting events are delivered to the interested application, c) **Metadata Exchange** describes what the service does and how services can be accessed. Thus it provides a better interoperability for heterogeneous platform, d) **Security** ensures that sensitive data is encrypted on the exchange process, e) **Addressing** describes how services can be addressed and f) **Policy** allows services to publish their policy on security, quality of service etc.

As the implementation of SOAP based web service standard like Apache Axis, WCF consumes too much resources to be run on top of resource constrained devices, many approaches implement web
services on top of intermediate gateways. The Hydra project (http://www.hydramiddleware.eu/) follows this approach ensuring the support of a wide range of heterogeneous devices and preserve compatibility to enterprise applications at the same time. Hydra has made significant contributions to the research into service-oriented architectures for networked embedded devices based on a semantic model-driven approach offering web service interfaces for controlling any type of physical device irrespective of its network technology. RUNES, SM4ALL, EMMA, Sofia, eDiana, and POBICOS are also examples of EU-funded projects that aim at middleware for pervasive environments in home, health care, and energy management domains. Furthermore, such technologies are further developed within the FP7 European Project SEEMPubS (http://seempubs.polito.it/) which focuses on reduction in energy usage in existing public buildings and project ebbits (http://www.ebbits-project.eu/news.php) which focuses on architectures, technologies and processes, which allow businesses to semantically integrate the Internet of Things (IoT) into mainstream enterprise systems and support interoperable end-to-end business applications.

Previous effort mainly address the operational phases of buildings or enterprises and has not yet focused on the development of robust and efficient modelling and simulation tools that will subsequently allow for energy performance evaluation and optimization at the early planning and design phases of both building constructions as well as enterprise business processes.

Conclusions & Future Challenges

Architects, Designers and engineers (D&E) lack the tools that will assist them in the complete evaluation of the energy performance of alternative design decisions towards producing better and more sustainable construction products, taking into account all aspects of building operation under real life conditions. From the Sustainability and Energy Efficiency viewpoint, the need is to have accurate and realistic (account the many variables at stake) as well as enhanced (with comprehensive enriched knowledge) analysis and simulation services in order to optimize the overall building design while considering the many competing dimensions under concern. Most specifically, during early design phase the focus on EE should be on realizing the most efficient design considering the many variables to be potentially taken into account (health and comfort performance, building costs, whole life costs, etc) also including one of the most important factors, that of occupants’ behavior.

Energy-intelligent constructions incorporating innovative ICT (self-organized integrated frameworks of sensors, actuators, meters etc) will present the ability to efficiently adapt to occupant needs and preferences, maximize energy performance while at the same time comply to overall business requirements. This can be further realized through the fusion of two (currently disjoint) worlds: a) Building Information Modelling (BIM) and b) Business Process Modelling (BPM), having occupants as the main catalyst. This fusion, among other obvious advantages, will also present the ability for enhanced diagnostic and renovation of existing constructions and also generate infrastructures and simulation environments to assess variants of environmental performance of buildings, tools for dynamic building evaluation at run-time, and allowing optimisation based on multi-dimensions / multi-criteria constraints.
In the current available building performance simulation programs the presence of occupants and their influence on a building are (at best) based on predefined activity/presence schedules. These schedules however, are often assumptions rather than based on measured observations and resulting descriptive and predicting models. Thus, the results of such simulation systems are tentative at best and may often be misleading. Therefore, future research should aim to deliver and validate holistic energy performance models that incorporate architectural metadata (BIM), critical business processes (BPM) and consequent occupant behavior patterns, enterprise assets as well as overall environmental conditions.

Finally, the delivery of such open and formal enterprise models will significantly contribute to the interoperability between building design and management subsystems throughout the whole building design, construction and operation life-cycle. Furthermore, holistic information models also supported by efficient visualization tools and visual analytics techniques, governing and managing all aspects of construction products (assets, occupants, processes, environment) and establishing a dynamic, enterprise-wide perspective on how well construction resources and occupant activities are aligned with business needs, allowing for a complete evaluation and optimization of overall building-enterprise energy performance. Furthermore, it is critical that building performance simulation should be made available at an early stage where the impact of design decisions is highest.

References


3.3. Paper: Knowledge Management for Integrated Energy Demand and Supply in Buildings, Campus and District

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Abstract

The aim of this research is to produce, from an energy management perspective, a detailed description of the University College Cork, (UCC), campus district heating network. Based on the detailed description of the Campus Network and gathered data, multiple simulations will be carried out to test behavior of three selected buildings with regard to the network's and buildings' performance. This paper introduce to the exercise of data collection of existing network. It also defines how to use simulation where some data is missing. Finally it proposes a general idea for knowledge management system that could compile all the information that is necessary to determine campus performance.

Keywords: District energy management, performance analysis, building stock, Building Information Modeling.

3.3.1. Introduction

The current economy in the EU dictates a closer look at energy usage in buildings. Since the majority of buildings in Europe are older than 10 years (2002/91/EC), the focus should be on increasing the energy performance of existing buildings. It is beneficial to look at buildings' energy management from a broader perspective. Today, where prices of fuels are increasing, governments are interested, in how to achieve lower energy usage (EDEA 2011). The majority of society knows that main energy consumers are buildings. Some research claims that typical Combined Heating and Power Plants are the cheapest methods of lowering a building's carbon footprint. District heating plants can provide higher efficiency than typical single building solutions. Therefore, it can be beneficial to extend research into the area of energy management solutions for District and CHP networks.

European politicians, businessmen and average consumers are facing major challenges to integrate new and efficient technologies into everyday use. In Western Europe most existing buildings, either commercial or residential, are using separate integrated building heating systems. These systems are not necessarily efficient enough for upcoming EU challenges. EU-32 countries primarily due to inefficiencies are wasting at least 38% of energy (COWI, 2007)

However there are many fields for new challenges to be applied, energy used for heating is one of the major ones.
Furthermore, by doubling the use of district heating, energy reductions can reach 9.3% (Ecoheatcool, 2005). In practice, any decisions made needs to have clear reasons and facts that are concluded from available information and knowledge. Therefore it is important to have standard and comprehensive way of managing energy related information.

3.3.2. Knowledge management and Building Information Model

Engineering data and relative information can be gathered in two ways; manually or automatically. Before the IT industry evolved, any information about buildings and internal systems were stored manually, in the form of drawings, sheets etc. New technologies can be used to store any relevant information in a manual or automated way. One perfect example is a Building Information Model (BIM) which is a complete picture of information about the object or building. The design phase of any object or building produces multiple plans and drawings. Drawings are usually made using CAD packages and can be stored in electronic versions and easily disseminated if necessary. Together with drawings, there are multiple data sets that complete engineering designs: architectural, mechanical, electrical and other relevant information. With developing technology, most software packages are offering new 3D information models where all disciplines and relevant information are included. BIM is being widely incorporated into engineering areas where not only technical information is included but also different dimensions of the model like time, cost, resources etc.

On top of the information generated in the design phase, during the operation phase there is more crucial data to be stored. In order to determine performance, multiple meters and sensors have to be in operation. This data is usually collected automatically and stored in a database. Large amounts of data in processes, like data mining, can provide analysis results and information about a building or a building cluster’s behavior under external weather conditions. Fortunately, this is the case when newer buildings are being analyzed. However analysis of older buildings may be more work intensive, where the lack of data would lead to additional processes.

In this paper three potential buildings are considered. The oldest building was built in 1910. Information about this building was collected through archives but mainly through a surveying process. In 2009 the building did not have any measuring devices that could illustrate its performance. Therefore multi dimensional models were created for each of the buildings showing their main parametric data.
With the use of these models, simulations were carried out and some understanding of their performance was concluded.

Analysis of the heating network system had a similar level of required processing where only minimal information was provided. In the field of analysis, there are software packages that can simulate/calculate conditions of heating network behavior and also the performance of single buildings that are connected to the network.

In any industrial sector, knowledge management is widely used to provide information to employees on multiple security levels. In most cases knowledge management (KM) appears in the form of a system that, in an electronic way, can store data. When focusing on knowledge management for buildings or clusters of buildings this performance KM can be more complicated especially with older buildings where most of the required information is missing or provided in paper form. New approaches towards design and maintenance are offering digital approaches allowing better more efficient solutions and easier storage of building data.

A perfect KM system would be a server based storage system that compiles all relevant information about buildings, systems, and their performance.
Figure 2 presents a general architecture of a KMS for campus heating system. The graph describes how information can be fed into and stored in a server based location. It also contains a decision generation system that based on weather conditions can predict building’s and network’s behavior suggesting building’s energy demand and supply conditions. Knowledge Management System (KMS) comprises of four main parts.

### 3.3.3. UCC Case study

The UCC Campus is located near to Cork City adjacent to College Road and Western Road. The property portfolio of UCC consists of over 120 buildings. These buildings range considerably in condition, size, construction type and vintage. Included in the university’s portfolio are the newly constructed I.T. building, the Western Gateway Building which was constructed in 2009 and the Main Quadrangle, constructed between 1847 and 1849, which is a protected structure and a part of the original college campus. To meet the growing demand placed on the building stock by increasing academic needs and expanding student numbers, the college also rent a number of properties close to the college.

For the purposes of this project, this area will be used when referring to the campus and district of UCC. This area can be described as a district for a number of reasons. In terms of energy supply this district and its buildings are closely interconnected. This can be seen in the distribution of heat and electrical energy on campus. Heat energy is supplied to many of the buildings on Main Campus by the campus combined heat and power (CHP) plant. The plant produces steam which is distributed throughout the campus by means of an underground steam network. Many of the buildings on Main Campus are connected to this network. The CHP plant runs based on the demand for electrical energy.
on campus. The plant will attempt to meet the electrical demand and this will affect the quantity of steam produced by the plant. The CHP plant is backed up by two additional steam boilers which are also located in the Main Boiler House, to meet the demand for heating energy on campus. Buildings not attached to the steam distribution network are heated by individual gas boilers located in their own buildings. Figure 3 below shows the location of the Main Boiler House, the approximate arrangement of the steam and condensate mains (denoted by the red line) extending from the Boiler House which are in use, and the buildings connected to the Main Boiler house for heating purposes. A portion of the distribution network is not in operation and is not shown in the figure below. In addition to supplying steam for heating on campus the CHP plant also provides steam for domestic hot water to the Kane Building. Figure 3 shows three selected buildings that the research and the simulation model will be focused on, considering the different structure and construction types of the buildings.

![Figure 3: Campus Heating Energy Connections to Main Boiler House](image)

**Kane Building**

On a campus level the Kane Building is the only building on campus to use hot water directly from the CHP plant to heat the building. This is an ideal building to demonstrate this type of connection to a CHP plant and in the context of this campus, this building represents a unique opportunity to select a representative building heated by CHP hot water.

It has been suggested that this infrastructure could potentially support additional pipe work carrying steam or hot water to other buildings. Analysis of building energy performance with regard to the potential for future energy expansion, the energy consumption of this building and the potential for extending supplies from this building will be crucial to any future decisions to expand the network. The building also serves a range of purposes from providing teaching and research facilities, to facilitating a computer centre and computer training centre and also accommodating a large canteen.
area. This building could be used to demonstrate the energy consumption of a large multi-functional building. As with the CEE Building and Boole Library this building is also controlled by a BMS and metered data for the building is available from the Buildings and Estates Office.

Civil Engineering

Taken in the context of the wider campus the CEE Building is quite an old building, it was constructed in 1910 making it one of the oldest remaining campus buildings. However taking this into consideration it is also representative of many older buildings built in the same era. At the time many institutional buildings constructed in Ireland were of very similar construction.

The building retains many of its original features e.g. single glazed timber frame windows and cast iron radiators. This is also representative of many older buildings.

The building has undergone a retrofit to improve its energy efficiency. In this case, the building could be seen as an exemplar building as to how energy performance can be improved and monitored within buildings that traditionally perform poorly in terms of energy efficiency.

In the context of the wider campus, the CEE Building was the first building to have a heat meter installed and operational. Although heat meters are scheduled to be installed shortly on other campus buildings, the CEE Building represents the building with the longest record of heat consumption available for any campus building connected to the steam distribution network.

This building is also fitted with a Siemens BMS system which is connected to a wireless sensor network. The building has an individual electrical meter which meters electrical consumption attributable to the building.

Boole Library

The Boole Library is similar to several other buildings on campus in terms of heating energy. Steam is supplied to a heat exchanger where the heat is transferred to the hot water which is circulated through the building’s heating system. This is one of the most automated buildings the campus has to offer. An extensive wired sensor network throughout the building is also be utilized for the monitoring of temperature, humidity and CO$_2$ levels. The building is fitted with a modern Trend BMS and can be controlled from the Buildings and Estates Office or viewed from a remote location.

The roof is a large flat open space which could be used to accommodate any equipment needed e.g. weather recording equipment needed to provide additional data for building performance analysis.
3.3.4. Modelling building and network performance

The selected buildings have integrated BMS systems that provide a range of data used as performance measurements. During the last few months, several groups in UCC including PHD researchers and masters students have created multiple models and simulations. Where 3D models were created and performance simulations carried out. The results were calibrated with comparison to BMS sensed and metered data. There are three areas for which information was required for the BIM; building performance, Network Model, and network performance.

Table 1 represents general types of information required to gain complete knowledge about the campus and its performance. Some of the relevant data would be automatically stored in a database through the BMS systems with regard to buildings information. Unfortunately there is no data determining how the network performs.

Therefore to gain a full spectrum of building cluster’s performance it is required to determine missing information through multiple simulation activities. Retscreen Int. (Retscreen) an Excel spread sheet based fast software package, can provide (in cases where measured data does not exist) information about single building performance’s and also the performance of a cluster of buildings existing on district/campus network. In order to obtain more in-depth simulation results it is required to opt for more advanced energy simulation software like EnergyPlus, IES VE etc. These exercises may even require advanced knowledge about energy in buildings and a mechanical engineering background to provide missing information.
### BIM Building performance | District Heating Network Model | Network Performance

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<tr>
<th>Type of information</th>
<th>Architecture</th>
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<th>Heating plant metering</th>
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Table 1: Information collection process and selected outputs highlighted

#### 3.3.5. Campus heating network – Required Information

To create the campus model, data and information regarding the steam and hot water distribution network, the CHP plant and buildings connected to the network were required.

To model the pipe network CAD drawings of the campus were referenced. A CAD drawing of the campus showing the locations of all pipes, manholes, junctions in pipes and connections to buildings was imported to sisHYD (Bentley) and was the basis for the development of the model. This drawing also gave details of the pipe dimensions. Another CAD drawing showing elevations throughout the campus was used to calculate the cover levels for the steam pipes. Interviews with the plant operatives and correspondence with the CHP plant contractors provided additional information required within the model e.g. pressure levels with the pipe network, the material and characteristics of the pipe network.

Information regarding the buildings was gathered from a number of sources. Building drawings in both hard and soft copy were available from the Buildings and Estates Office. Detailed, comprehensive and up-to-date drawings were available in soft copy for buildings which had undergone recent construction works. While in the case of older buildings hard copies of building drawings or scans of the buildings original drawings were available in some cases these drawings
were not accurate and did not document all changes that the building had undergone following initial construction. A walk through of the buildings was carried out to confirm the drawing details. The Buildings and Estates Office provided access to the building’s BMS interfaces and metered data for the buildings. This provided details of the building’s HVAC systems and gave an indication of the heating loads in the buildings where heat meter data was available. Buildings and Estates department also was able to confirm details of the buildings construction and operation where these were not fully documented.

**Inputs to the Model**

The network was named 'UCC Campus Network’ and defined by the maximum pressure in the network, the maximum supply and return temperatures in the network system, the type of pipe system (supply and return), the medium (steam), the relative elevation and the type of pressure values used (gauge or absolute pressure).

The geometry of the pipe network was defined using an imported scaled CAD drawing of the pipe layout as a template for the input. The pipe network was defined as a series of pipes and nodes placed on the imported drawing. Nodes were created at pipe junctions or building locations and the pipes were connected at nodes.

Several types of pipe were used throughout the network and each was given a pipe type name and characterized by the following features; inner diameter size (mm), thermal coefficient (W/mK), wall roughness (mm), pressure level (bar), maximum pressure loss (Pa/m) and maximum velocity (m/s). A pipe type was then assigned to each pipe in the network. Valves and pumps in the network were defined in a similar way.

'UCC Main Campus' was defined as a ‘consumer group’ and all the buildings connected to the steam network were defined as ‘consumers’ of this consumer group. Each consumer within the group was defined by the common group attributes of required supply and return temperature and by the maximum and minimum limits of pressure difference, supply pressure and return pressure. Each consumer was then defined by its location (i.e. their start node and end node) and connected load (kW).

The ‘supply’ for this network is defined using the characteristics of the CHP plant; defining the supply location by its start and end node and using the pressure drop coefficient (bars²/kg²) and constant pressure drop (bar) associated with the CHP plant. According to figure 2 all the inputs above would be under "Network Specs" type of data. This would be fed to the software where the specific type of data would be stored into "Simulated Data" part of the database.

**Software Results**

SisHYD runs two types of calculations – steady state and dynamic. The results return a summary of the input data which the calculation is based on as and detailed results for nodes, pipes, consumers, suppliers, consumer groups, organization groups, model adaption, load factors and control. The calculations will be based on the inputs mentioned above (unless they are changed when defining the
conditions for the calculation), a load factor (%) and an ambient temperature. In the case of dynamic calculations a timeframe will also be added.

When the calculation has been performed the results are available in the Report Centre. They are categorized by result type and displayed in a tabular format. Results can become quite detailed for example in the case of pipes the results return values of mass flow (t/h), volume (m³), pressure loss (bar), velocity (m/s), diameter (mm), inlet and outlet pressure (bar), inlet and outlet temperature (°C), specific pressure loss (Pa/m), specific heat loss (W/m) for each branch or section of the pipe network under the conditions defined for the calculation. Where costs have been included in the inputs the investment required to lay each section of pipe is also included. At connections to buildings results of pressure (bar), temperature (°C), height (m) and heating load (kW) are returned. For the supplier values for mass flow (t/h), heating power (kW), supply and return temperatures (°C) and inlet and outlet pressures (bar) are returned.

These results describe the thermodynamic conditions throughout the pipe network under the conditions defined by the calculation input parameters to the model.

Conclusions

The data collection process is long and difficult. Especially when considering already existing older buildings where major parts of information are missing and surveying and engineering input are required. One of the major difficulties was the decentralization of data required to obtain model and performance information.

Some information was stored in the Archives Department or in the Building and Estates Offices, while other was non-existent or missing and finally some of the data was electronically stored in DB of separate BMS systems.

When focusing on KMS and its large amount of data that needs to be collected storage should be centralized. All the information should be placed into one server and agreed on specified type of files for specified type of information (CAD drawings - *dwg, 3D model – IFC etc.)

Considering constant IT industry development, future information/performance models should integrate in an interactive way all the information using a 3D interactive, fast and user friendly environment.

The figure below represents a mock-up of an interface that could be used for storing building information and building performance data using a graphical engine connected to several databases where obtaining information would be an easy process. The same solution could be implemented for the whole network system.
Figure 5: An interface mock-up of interactive information model – integrating its live performance.

References

[8] R. van Meenen BGP Engineers B.V.
[13] Retscreen Int. at www.retscreen.net/
[14] Ecoheatcool.org
[16] Bentley sisHYD www.bentley.com
4. Session: BEMS Integration Platforms & Ontology's

4.1. Paper: The IntUBE (Energy Information) Integration Platform

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Abstract

The European IntUBE project [1] focuses on integrating existing building/energy-related software functionalities by using Open Standards and their Open Source Software (OSS) implementations. Based on the open data from multiple life-cycle stages (in this case especially ‘design’ and ‘operate’) new advanced services can be developed like those to inform building inhabitants in intelligent ways on how to change their energy consumption behaviour to reduce energy consumption and related CO₂ emissions.

Existing integration approaches like ISO’s STEP [2], BuildingSmart’s IFC/IFD [3], OGC’s CityGML [4] and gbXML [5] are all more or less limited in their context, scope, functionality and/or underlying technologies. This paper will show how World Wide Web (W3C)’s Semantic Web technologies like RDF, RDFS, OWL and SPARQL [6] can be successfully utilized to model the (static) buildings (including energy installations) and (dynamic) usage and performance; ‘as-planned’ in the design stage and ‘as-operated’ in the operational stage of their life cycle.

IntUBE defines three data/information models or ‘ontologies’:

- A Building Information model (BIM) (static as-planned)
- A Simulation Model (SIM) (dynamic as-planned), and
- A Performance Information Model (PIM) (dynamic as-operated).

This focus of this paper is on the semantics of these three ontologies and how they are implemented in an open source, cloud-based, Semantic Web Server¹. Once defined in this server they can be instantiated and queried using the standard SPARQL query language by the relevant building software applications like Autodesk Revit Architecture for design, VABI Elements for energy simulation and OPC [7] for sensor measurements.

Keywords: Energy Efficiency, Information Integration, Ontologies, Open Standards, Open Source Software
Introduction

The IntUBE Energy Information Integration Platform (EIIP) (in short, the ‘Integration Platform’) forms the neutral ICT Infrastructure or ‘glue’ between all building/energy-related ICT functionalities (implemented in software applications or services) selected and/or developed within the IntUBE project to feature in end-user pilot demonstration scenarios aiming at energy/CO₂ reduction.

Besides openness or ‘interoperability’, the key aspect is smartness or ‘semantics’: ICT applications/services will communicate via this integration platform on the basis of semantic building objects, their properties and interrelationships directly (or indirectly like via the design stage) relevant to the energy management view in the operational stage of (existing) buildings, and their energy-related installations.

In this paper we focus on one of the key components of the Integration Platform: the ‘Energy Model’. The ‘Energy Model’ addresses a wide variety of relevant static and dynamic building information to be shared between the functionalities.

Figure 1: IntUBE Architecture

- A Building Information Model (BIM), covering data structures for storing ‘planned static’ building data.

1 More specifically, a Resource Description Framework (RDF) Server (‘Jena/Joseki’)
• A Simulation Information Model (SIM), covering data structures for storing ‘planned dynamic’ building usage data and estimated/simulated performance results.

• A Performance Information Model (PIM), covering data structures for storing ‘actual static’ ('as-built') but moreover the ‘actual dynamic’ usage and performance results, provided via an OPC Server.

These three ontologies are explained in detail in the next chapter.

4.1.2. The Energy Model

The Building Information Model (BIM)

The top-level class for the BIM ontology is the ProjectManager which is a container for zero or more actual Projects (including a currentProject). Each Project has one or more ProjectVersions where each ProjectVersion contains the ProjectData, the Building (in all its details, properties and components), the Shading and the Geometry.

In the ProjectData one can find the information about the Principal, the Consultant and further project details like the GeoLocation and potentially attached MultiMediaObjects like images. The Building, is the most important data set covering Rooms, BuildingParts and the energy installations as AirhandlingUnits, Generation and Distribution systems.

Figure 2: Example BIM fragment
Simulation Information Model (SIM)

The SIM contains two kinds of data: the 'Planned Building Usage' and the 'Simulated Building Performance'. The building usage information also covers the climate data (in a sense the environment the building is used in). Next, it defines all the design temperatures/hygrometry/etc. for summer and winter and also all relevant energy performance requirements. Furthermore, it contains a wide variety of usage options with respect to building elements and installation items.

The simulated building performance information is of course related to a specific BIM model extended with its actual usage. The results for the various analysis parameters are modelled in harmony with the PIM so that measurements can be easily compared with the simulation results. Often these results take the form of time stamped values or values over time intervals.

![IntUBE-EnergySIM.owl - ParsePMO](image)

Figure 3: Example SIM fragment
Performance Information Model (PIM)

The PIM is in a sense the real-life counterpart of both BIM and SIM. Since we have the assumption that the BIM 'as-built' is the same as the 'BIM as-realized' it here contains (only) the actual usage parameters ('is that window really open during that time interval?') and the actual performance parameters ('what is the actual average room temperature?').

That information can come from manual inputs by someone monitoring the building or automatically via sensors (in that case consolidated/integrated first via an OPC Server).

![Image](https://example.com/image.png)

**Figure 4: Example PIM fragment**

Detail levels modelled

It is stressed that all three ontologies can contain both global and detailed information potentially supporting multiple life cycle stages. Functionalities to derive aggregated/global information from detailed information available are seen as external to the integration platform. A BIM example would be the derivation of the total floor area of a building based on areas for the different floors. Another example on the SIM side would be the derivation of total building energy cost based on room level figures.
4.1.3. Methodology

**W3C Semantic Web Technology**

In IntUBE we decided to use semantic web technology for defining our information structures (‘ontologies’) and actual information. The resulting BIM, SIM and PIM ontologies have to be stored and made available in some implementation for a semantic web server. We decided to use the open source (Java-based) Joseki platform [1], initially developed by the research lab of Hewlett Packard (HP). Joseki [14] is part of the Jena framework [13]. Jena is a Java framework for building Semantic Web applications. It provides a programmatic environment for RDF, RDFS, OWL and SPARQL.

The Triple DataBase (TDB) [15] was chosen as database backend (alternatives are ‘plain files’ or SPARQL DataBase (SDB), the relational database variant which needs an additional underlying DataBase Management System (DBMS) like MySQL or PostgreSQL) as back-end.

All three ontologies, BIM, SIM & PIM, are first described as highly structured Microsoft Excel workbooks. The latest IntUBE-EnergyBIM.xls, IntUBE-EnergySIM.xls and IntUBE-EnergyPIM.xls are stored and accessible at http://www.bimtoolset.org/documents/. From these workbooks we fully automatically derive the three corresponding PMO ²-based OWL ontologies. The latest IntUBE-EnergyBIM.owl, IntUBE-EnergySIM.owl and IntUBE-EnergyPIM.owl are stored and accessible at http://www.bimtoolset.org/ontologies/.


Once installed and loaded with the IntUBE BIM, SIM and PIM ontologies we can query both the information structures and the information itself where ‘query’ means select queries (reading data) but also updating queries (changing data). All query possibilities are described in detail in the supported SPARQL specification [12].

The ontologies can also be interpreted and instantiated by TopQuadrant’s TopBraid Composer (TBC) Ontology Editor (free version). The ontologies and their corresponding data-sets can be exported by TBC as a TDB (TripleDataBase) which, when moved to the right folder of a Joseki Semantic Web (SW) Server (with TDB-back-end), can be accessed via the SPARQL query language over the web. In our case the web server is running for the BIM ontology at: http://www.rdfserver.org/sparql.html.

---

² Product Modelling Ontology, an upper ontology reused from the European SWP project, adding mechanisms like decomposition and units to standard OWL.
**PMO Configurator**

Within IntUBE, we developed a ‘neutral-native’ application called the PMO Configurator [6]. This software tool was developed initially in the European SWOP project and is now further developed for the use in IntUBE.

This tool can read any Product Modelling Ontology (PMO)-compliant OWL ontology (that is: any ontology using PMO as upper ontology for decomposition, units, default values etc.). Since this tool reads RDF/XML files we need to first get them out of the Joseki platform as showed earlier.

Once opened, we can start instantiating the ontology with actual data/content specifying amounts of instances and/or giving values for required and/or optional attributes or references for existing or new instances for relationships. When finished we can save the data file and load it (back) in the Joseki server.

An example for the BIM ontology is in the next figure.

![Figure 5: Example PMO Configurator screen](image)

4.1.4. Application in demonstration scenario

First Autodesk Revit (Architecture 2010) is used to populate the BIM server with static building info. Next this data is taken up by several building energy simulation applications extended with building usage information. These programs store their analysis results in the SIM (in context of a certain building usage) which can then be compared to actual monitoring/sensor-data stored neutrally in the PIM.

Beside this mere ‘integration’ IntUBE defined a number of demonstration scenarios that are business model oriented and that make a smart use of this IntUBE energy model, meaning a synchronous use of both BIM, SIM and PIM ontologies. As an example:

- The ‘Dweller’s Blinds Adviser’ proposes actions (opening or closing blinds/windows) for reducing energy consumptions according to different scenarios simulated by the SIM server;
- The SIM server is using the BIM modelling representation for its calculations;
- The actual results (e.g. energy consumptions) are recorded into the PIM server and are then compared to the previous corresponding simulation and can be used to further fine-tune the simulation engines and thereby the energy efficiency strategies.

Conclusions & lessons Learned

The three interrelated BIM, PIM & PIM ontologies proved ‘necessary and sufficient’ to support the planned IntUBE demonstration scenarios. In case information structures (classes, properties, data types or relationships) are missing they can be easily extended. A next evolution of the BIM/SIM/PIM-ontology set will be organized according to the principle of defined only once’. This means that there will be no duplicate common structures/data (like rooms) but SIM and PIM are only adding info to BIM. Currently we underestimated the burden of copying relevant BIM data to SIM and PIM compromising a bit the level of integration between these views. As a consequence the Excel sheet structure (and associated PMO/OWL generator tool) have to be adapted to support ontology import/reuse. Then, i.e., the SIM ontology could import BIM and adds its parts and properties to existing BIM rooms etc.

The chosen semantic approach proves to be very powerful especially by the provision of a common access method to the ontological data (via standard SPARQL queries). At the same time the ‘learning curve’ for the semantic web specifications like OWL and SPARQL is quite high. Once understood and interpreted in the right/intended way the specifications and their implementing software prove to be very powerful and consistent.

Also here we face the almost inevitable situation that we need people that are both expert in both the domain AND in modelling. Only by very close cooperation between the two types of experts this issue can be overcome.
On the implementation side the current open source implementation tools should be in future more robust/stable. Currently, errors in SPARQL query sometimes require the restart of the SPARQL-service or even the complete tomcat application server. In an operational, real life situation this would be a real showstopper. Also, these tools should pay more attention to performance aspects. Real-life models covering large sets of triples sometimes run into performance problems with respect to both space or time. A good example is the need for enough Java heap space which quickly requires in its turn the use of a 64-bit underlying operating platforms.

As final conclusion, it is possible to state that IntUBE provided a fully semantic/web-based, ‘Open Standards’-based\(^3\) & ’Open Source Software (OSS)-based’ Energy Model Server and connected essential energy-related software functionalities over the life cycle showing how an increase of intelligent information can decrease the amount of energy used. Besides mere integration we also showed how integrated information sources from design/simulation and operational data can be combined to enable new advanced functionalities.

Acknowledgments

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(Key) Abbreviations used

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tbody>
<tr>
<td>BIM</td>
<td>Building Information Model</td>
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<tr>
<td>IntUBE</td>
<td>Intelligent Use of Building’s Energy information</td>
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<td>(EI)IP</td>
<td>(Energy Information) Integration Platform</td>
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<tr>
<td>gbXML</td>
<td>Green Building XML</td>
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<tr>
<td>ICT</td>
<td>Information and Communication Technology</td>
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<tr>
<td>IFC</td>
<td>Industry Foundation Classes</td>
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<tr>
<td>IFD</td>
<td>International Framework for Dictionaries</td>
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<td>ISO</td>
<td>International Standardization Organization</td>
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<tr>
<td>OGC</td>
<td>Open geospatial Consortium</td>
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<tr>
<td>OPC</td>
<td>OPen Connectivity through Open Standards</td>
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<tr>
<td>OWL</td>
<td>Web Ontology Language</td>
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<tr>
<td>OSS</td>
<td>Open Source Software</td>
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<td>PIM</td>
<td>Performance Information Model</td>
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<td>PMO</td>
<td>Product Modelling Ontology</td>
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<tr>
<td>RDF(S)</td>
<td>Resource Description Framework (Schema)</td>
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<tr>
<td>SIM</td>
<td>Simulation Information Model</td>
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<tr>
<td>SPARQL</td>
<td>SPARQL Protocol And RDF Query Language</td>
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<tr>
<td>STEP</td>
<td>Standard for the Exchange of Product model data</td>
</tr>
</tbody>
</table>

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\(^3\) open technology, open information structures and open access
References

[8] IntUBE Deliverable D6.2, IntUBE (Energy Information) Integration Platform; Requirements & Specifications, Charvier, Brice; Böhms, Michel; Decorne, Régis; Plokker, Wim; Madrazo, Leandro; Sicilia, Álvaro; Cantos, Sergi; Dawood, Nashwan; Karhela, Tommi. 2010
Abstract

The networked operations along the life span of a building or an industrial plant require networks of focused experts. The state of the art of the information management in investment projects and in life cycle service operations is that the data is exchanged as files: spreadsheets, drawings, database dump files etc.

The automatic object-based data exchange between these organizations and their computer systems will bring about obvious benefits. Less time will be spent interpreting and transferring data, and fewer human errors will be generated. This paradigm shift requires the take-up of standards and software systems that support these standards.

The Finland based THTH association has developed the Sefram infrastructure for sharing data in the value network as objects and attachment files in a network of interlinked databases. Legacy systems are connected to Sefram through adapters. Sefram adds value to the file-based data transfer by providing version control and distribution control on the object level. Moreover due to the flexibility of the Sefram data model, 3D models, P&I diagrams, automation, electrical and building models can be integrated. THTH has decided to publish Sefram open source under EPL (Eclipse Public License).

THTH has also published the Simantics ontology kernel under the EPL license. Simantics, originally developed by VTT Technical Research Centre of Finland, is a software environment for integrating process simulation solvers into each other and into the life cycle data management using ontologies. Each legacy system is integrated into Simantics by implementing a plug-in and an ontology corresponding to the data model of the system. Data can then be mapped and transferred within Simantics by using semantic graph models.

This paper presents the Sefram and Simantics platforms and their approaches to data modeling and integration.

Keywords: Interoperability, Semantic Modelling, Engineering, Operation and Maintenance
4.2.1. Background and motivation

In different phases of the lifespan of a system, data is first delivered from the client to potential suppliers to specify the product, and then from the selected supplier to the client to describe the product. In both cases, it is vitally important that the sender and the recipient of the data have a shared understanding on what the data means. Any differences may lead to economic losses in the form of incorrect cost estimates, incorrect deliveries and time delays. The mismatches between physical assets and information presented to the end users may also lead to safety and environmental problems. The problems are similar in the building construction sector, in the process industries and in the manufacturing industries. In all of these industries, the automatic model-based data exchange is a dream as old as computerized engineering systems.

In order to ensure the shared understanding related to product specifications and product descriptions, the parties must agree on how the data is classified and exchanged. The classification of the data practically requires a reference data system, which contains the terms used in classes and attributes, and their definitions.

The benefits of this standardization are not limited to the avoiding of problems and the reduction of costs. In addition, this forms a platform for software and services related to e.g. the energy efficiency.

More consideration about the taking up of data standards was given in the recent CEN Workshop ORCHID Orchestrating Industrial Data [1].

The recent and ongoing changes presented in the following chapters are a part of the background and motivation for both Sefram and Simantics.

**Generations of information management**

Information management in both building construction and in plant engineering has gone through many changes during the last few decades.

- Computer-assisted methods took the engineers and architects away from the drawing tables and file cabinets (generation 2) and planted them in front of computer screens to draw process, automation, electrical and mechanical drawings.
- In many cases, we are still living the era of document management and document hotels (generation 3).
- However during the last decade, 3D- modeling has brought about yet another new way to design and model a facility. As electronic data management is becoming more efficient, we are currently moving away from document and drawing-based design towards product model-oriented design, where a conceptual model is defined in advance for the product structures. The plant engineering project then uses this model and transfers the planning data between
the various actors in this structural form (generation 4). Instead of the handover of documents, this method enables the handover of objects and models. In this approach, the traditional drawings or 3D-models are views into the product model.

**Networked engineering**

As the world becomes smaller through improved connections, the design of buildings and industrial plants is increasingly global and involves people from various organizations. These often complicated engineering projects are normally time critical and require skills and competencies not readily available in any single organization. Projects are often orchestrated in distributed environments, involving highly specialized personnel and expert knowledge. Different projects require different types of competencies and skills. The need for specialized expertise depends on product characteristics, local conditions or on the customers’ requirements to use e.g. specific engineering tools. Efficient communication between engineering partners is needed to ensure schedules and efficient delivery.

Large scale engineering projects are characterized by strict planning and detailed engineering work breakdown. The work is divided into “silos” where the work is carried out, using specialized and engineering disciplined specific IT tools. Traditionally, communication and interoperability over boundaries are difficult. The used tools are often proprietary products requiring costly license. As a consequence, the number of companies having the needed competences, skills and resources, are limited for a specific engineering task. SME engineering service providers face difficulties to offer their service.

**Open Source Software**

There are a number of good reasons why an open source software product should be selected for cross-disciplinary data exchange and management in a company network.

A. The life spans of industrial installation as well as buildings are long, perhaps longer than the life spans of software companies. Therefore, one should carefully consider whether to depend on a user community or a commercial software supplier.

B. From a data security point of view, it is a clear benefit to be able to check up the software source code for any backdoors or other risks for business critical data.

C. Open source software can be seen as a means to keep small and medium-sized enterprises involved, as the license fee is not an issue.

D. Open source software is a natural choice for the reference implementation of any standard. This will speed up the take-up of the standards in commercial software.

E. The open source paradigm enhances the collaboration of user companies and the research, as the results of research projects can be transferred to the benefit of the user community.
4.2.2. Sefram

Sefram [4,5] is a software infrastructure for the exchange and management of data organized as an object model. Using Sefram one can configure a data exchange network among the partners, control the flow of data and manage the versions of the contents.

In a Sefram-based system, each partner installs a Sefram database and bridges the background systems to it using adapters. The data is maintained in the background systems, and Sefram is used as a hub to publish the data to other partners and to receive updates from them. The Sefram databases form a master-slave hierarchy in which each database can have a master and a set of slaves.

![Figure 1: A process industry example of a SEFRAM based system](image)

The Figure 1 presents an example of a SEFRAM based system intended for the supply of data from the different stakeholders to the owner operator. The example originates in the process industry, however similar diagrams can be easily drawn to reflect the supply networks in the construction industry. The data exchanged can include both specifications and definitions related to the building and the infrastructure, process, automation, electrical and other systems.

The validity rules of the data contents i.e. the object classes, their allowed relations and attributes are specified in a ruleset. E.g. the ruleset may state that a wall can have one or more windows, and that a window has a width and a height. The ruleset is most conveniently edited using the graphical ruleset editor included in the Sefram environment. The ruleset is uploaded on the master, and it is automatically synchronized to the slaves.

Besides the ruleset, an equally important element in the semantic standardization of the data contents is a reference data system, which gives definitions to the terms used in the data exchange. In an ideal case, the reference data system covers the names of classes and attributes in the ruleset and the allowed string attribute values. Any lacks in the reference data system will cause potential misunderstandings and increase the human intervention in the data exchange.
A key feature of Sefram is that the data is managed on the object level, not on a file level. This applies to both the distribution and the version control of the data. The merging of two versions of the same spreadsheet is laborious and error prone. If the data is broken into objects transferred through Sefram, the version management is easier.

Sefram has three different Application Programming Interfaces (API’s):

A. Low level RESTful HTTP/XML API
B. Client API’s for .NET and Java with utilities for http and XML handling
C. Code generator that produces from the ruleset a .NET package for a client with native data types and domain classes

The Sefram infrastructure has been tested in cases related to the process industries. However, as the object model is fully configurable, Sefram could be used for managing a BIM or an integrated model of the building and the production process.

Sefram is an outcome from a series of projects conducted by the THTH Association for Decentralized Information Management for the Industry [9]. The projects have involved Finland-based companies active in the forest industry: owner-operators, engineering procurement contractors, equipment suppliers, control system suppliers, software suppliers and research. The Sefram core was implemented in a software company. The association has decided to publish the software open source under the Eclipse Public License EPL [3].

4.2.3. Simantics

The benefits of modeling and simulation in different engineering disciplines and tasks are widely acknowledged. Simulation has proven its advantages e.g. in virtual prototyping i.e. simulation aided design and testing as well as in training and R&D. It is recognized to be a tool for modern decision making [8, 9]. However there are still reasons that slow down the wider utilization of modeling and simulation in companies. Modeling and simulation tools are separate and not integrated into the engineering information management in the company networks. They do not integrate well enough into the used CAD, PLM/PDM and control systems. The co-use of different simulation tools is poorly supported and the whole modeling process is considered often to be too laborious [2]. This has been the motivation behind Simantics [6] integration platform development.

The needs for a modeling and simulation (M&S) integration platform can be divided into four sectors listed below. These requirements are more extensively analysed in [10].

1. Simulation and Design System Integration
Design systems (CAD) and simulation systems have traditionally been separate in many areas of engineering. Naturally there are exceptions like in electronic circuit design or piece good manufacturing processes where the design has been done in a simulation aided manner for a long time. The reason for this is also evident. The more deterministic the target process or product is the easier it has been to utilize computational models. This tradition has been different however in many engineering sectors, for instance, in the process industry, machine/vehicle and construction industries. 2D and 3D CAD systems have already been used for decades but these systems do not include simulation features. There are instead numerous separate simulation tools which can be utilized in different phases of the engineering process.

2. Advanced Use Environment for Existing M&S Tools

There are many simulation solvers, both in academia and in industry, that have sophisticated simulation algorithms, but they lack a good use environment. Common needs for a use environment are certain pre- and post processing capabilities as well as connections to other applications like design or control systems. Pre-processing capabilities include features such as 2D-flowsheeting support or 3D-geometry definition support, discretization support (meshing) as well as support for model validation, model structure browsing and editing, model component reuse, model documentation and searches, experiment configuration, model version control and team features. Post-processing capabilities include features such as 2D chart and 3D visualizations of the results, animations of the results both in 2D and 3D, experiment control visualization etc. All these requirements, at a high level, are generic and thus there is no concept of different parties maintaining their own use environment. Instead one framework could be implemented which can be further specified according to these different purposes.

3. Co-Use of Different M&S Tools

The need for the co-use of different simulation models arises from the same basis as the design system integration explained in the first item. The products and production processes that are modeled are complex. Heterogeneous multi-level models are needed which can be utilized across different engineering disciplines. In addition to the support of different levels of detail, users have also need to combine optimization computation and model uncertainty assessment into their simulation experiments.

4. Team Work and M&S Information Management

The chapter 1.1 presented four generations of information management. These sets needs for a modeling and simulation integration platform. Additionally, it can be anticipated that in the future we will be able to see how computational models will be integrated into the product models. Behaving product models will not only carry information on the structure of the product but also functions of
the product in the form of algorithms (generation 5). Different generations of information management are described in Figure 2.

![Figure 2: Different generations of information management](image)

The chapter 1.2. presented the change in engineering towards de-centralized global teams. This change is an opportunity for modelling and simulation as advanced methods are required for the quality control and knowledge management in organisations with limited human interaction. This, in turn, sets increasing demands on the design and simulation environment. Until now modeling and simulation environments have been almost always stand alone applications. The only way to share the modeling work between users has been by sending files stored from the modeling environment. There has been a similar procedure with the simulation data. There has been very little teamwork support in term of sharing experiment results with the other users. The results have very often only been stored to the hard disc of the user who ran them and the only visible item for the others is a report document. With this paradigm there is no way that others could repeat the experiment or create a slightly modified version of the experiment. Another problem is the version control of the model configuration and simulation results. Nowadays both of these are quite often handled manually. We may have simulation results in our hands, but we do not know with which model or design version these were generated. There is a clear need for the future integration platform to support teamwork and version control of both model configuration and simulation results.

Technologically the main cornerstones of Simantics Architecture are the following:

1) Semantic Data Driven Approach for Simulation

The single most important cornerstone of the Simantics architecture is the open and extensible semantic data model, which is used for describing all the simulation and other models in the platform.
The data model is semi-structured, which means that the data contains the rules about its own structure. This approach allows for co-existence of different interlinked data models, which can also be augmented with new pieces of data when needed. The data model is hosted in a database solution, which includes distributed teamwork and version management services.

2) Ontology based Mapping Environment for Integration

As an operating system for modelling and simulation, Simantics needs to be able to handle various different data models related to different tools, computational methods, and modelling methodologies. Successful co-use requires powerful integration and mapping tools between different models. Simantics addresses these needs by supplying an ontology based mapping framework for transforming models. Simantics will offer the user a specific Simantics Constraint Language (SCL) for developing user-configurable transformations.

3) Scalable Solution from Transient and Fast-Changing to Persistent and Shared Semantic Data

To be able to fully establish the first cornerstone of data driven architecture, Simantics supports a wide range of mechanisms for extending the application area of the semantic data model. Simantics offers seamless support for four levels of persistency of semantic data in a unified model. This solution covers cases from memory persistent, quickly changing, transient structures to database persistent parts, which are shared by different clients of database servers. Database persistent data is also fully versioned and can be synchronized between hierarchical servers across organisations.

4) Seamless Interface between Simulated or Measured Real Time Data and Semantic Graph Data

In a simulation system, we have a need to form a seamless interface between the (static) model configuration and (dynamic) simulation and/or measurement data. Simantics addresses this issue by semantic modelling of variables and their values and by specifying a software interface which is used for obtaining values for a given configuration of semantically modelled variables. The interface imposes a semantic connection from a data value to the concepts of the data model while allowing for free acquisition of values from any source. This framework for simulation data management makes Simantics unique among data modelling frameworks.

When designing and implementing an integration solution, it is highly important that it is as open as possible. This openness implies that the business model should also change in the future. The future modeling and simulation business will no longer be in the platform solutions but rather in the simulation components and services that are running on top of an open operating system for modeling and simulation. This openness also means that a neutral democratic forum for the decision making on maintenance and further development has to be established. The Simantics platform has been published as an open source under Eclipse Public License (EPL). For the democratic decision making, we have established the Simantics Division under the THTH association. At the time of
writing this article, there are 25 company, university and research institute members in the association.

4.2.4. Co-use of sefram and simantics

From the Sefram point of view, Simantics is an engineering system comparable to CAD software. From the Simantics point of view Sefram is a hub comparable to an integration platform of a commercial engineering software suite. This far two use cases have been identified, in which the co-use of Sefram and Simantics software products would serve a purpose.

As Simantics does not feature user access control, Sefram can be used for controlling the distribution of data between Simantics repositories. This data includes object class information, attribute values, geometries and links between objects. The use of Sefram as a hub will add value by improving data security.

The editors of Simantics can be used for visualizing data that resides in Sefram. The 2D editor of Simantics can be modified to display differences between two versions of the diagram. Similarly the Simantics 3D viewer, which will possibly be implemented, can be used for visualizing 3D models that reside in Sefram, and their differences.

Conclusions

The recent research and joint development has produced promising results in the field of data management for companies and research to take up and use. The results can help to achieve cost savings, to develop new business and to enhance innovation together with research.

It seems that the availability of technology is no longer an obstacle for the take-up. Platforms are now available for the companies to internally align their data and to gradually agree on the exchange in networks. Furthermore, these platforms can be used for services that build on the data, related to e.g. energy efficiency.

Acknowledgments

This paper was written in the IntUBE [4] project funded by the European Commission.

(Key) Abbreviations used

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>API</td>
<td>Application Programming Interface</td>
</tr>
<tr>
<td>BIM</td>
<td>Building Information Model</td>
</tr>
<tr>
<td>CAD</td>
<td>Computer-aided Design</td>
</tr>
<tr>
<td>CEN</td>
<td>European Committee for Standardization</td>
</tr>
</tbody>
</table>
CWA  CEN Workshop Agreement
EPC  Engineering Procurement Contractor
EPL  Eclipse Public License
HTTP  Hypertext Transfer Protocol
IntUBE  Intelligent Use of Building’s Energy information
ICT  Information and Communication Technology
IFC  Industry Foundation Classes
IFD  International Framework for Dictionaries
ISO  International Standardization Organization
OPC  OPer Connectivity through Open Standards
PDM  Product Data Management
PLM  Product Lifecycle Management
REST  Representational State Transfer
XML  eXtensible Markup Language

References

http://www.cen.eu/cen/Sectors/Sectors/ISSS/Workshops/Pages/workshopORCHID.aspx

[2] Computational Science: Ensuring America’s Competitiveness,President’s Information Technology Advisory Committee (PITAC), 2005
http://www.nitrd.gov/pitac/reports/20050609_computational/computational.pdf

[3] EPL Eclipse Public License,

[4] IntUBE, Intelligent Use of Buildings’ Energy Information, EU project no. 224286,
http://www.intube.eu/


[8] Simantics Community Pages
https://www.simantics.org/

[9] THTH Association of Decentralized Information Management for Industry
http://www.thth.fi/

4.3. Paper: Pervasive energy measurements for Buildings monitoring

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Abstract

From 2008, the HOMES programme [1] focuses on autonomous sensors [2] and an optimized energy management system answering to the need for energy efficient buildings, ensuring at the same time an adequate comfort level for their occupants.
In this frame, the role of human behaviours in generating efficiency is investigated through field experimentation on five pilot sites (i.e. two hotels, a primary school, an office and a public housing). The experiment consists in providing on-site (i.e. for occupants) and off-site (i.e. for energy experts) energy monitoring solutions and observing behaviour changes.
This paper focuses on the principles and the architecture of the HOMES energy monitoring, giving details on the on-site and off-site versions. The adopted solutions for data retrieving and mapping with real physical measurements are briefly explained. Moreover, the energy data model and chain are presented, while the pertinence of the Building Information Modeling (BIM) as a metadata provider is discussed. Some learned lessons are pointed out and next works are announced.

Keywords: Energy-efficient buildings, HOMES programme, energy management, energy sensors, data collection, data processing, Building Information Modeling.

4.3.1. Introduction

In the Fourth Assessment Report [3], the Intergovernmental Panel on Climate Change (IPCC) identified the buildings in the service sector as one of the main responsible for anthropogenic emissions of Greenhouse Gases (GHG) but also as the sector with the highest potential in terms of dramatic emission reduction.
One point in building energy efficiency is the building envelope, where mainly thermal insulation and air tightness (e.g. of windows and doors) can be improved. On the other side, the choices of people who have a link with the building (e.g. owner, operator, occupant) influence its energy performances. For instance, given the same envelope, an owner can proactively replace an inefficient heating system with a more efficient one, hoping that it could improve the value of the building on the market (i.e. through a higher energy efficiency rating). As an additional example, whatever the heating system and the envelope, an occupant could set a thermal point to 19°C in winter because he proactively wears adapted clothes.
Among other topics, the HOMES programme [1] investigates the role of human behaviours in generating efficiency through field experimentation on five pilot sites (i.e. two hotels, a primary school, an office and a public housing). The experiment consists in providing on-site (i.e. for occupants) and off-site (i.e. for energy experts) energy monitoring solutions and observing behaviour changes. These pilot sites were previously equipped with comfort and energy sensors, whose measurements are locally stored on-site and periodically sent to the HOMES server, where they are arranged in a data warehouse. In order to make this data accessible to occupants or energy experts, energy and comfort data must be able to come back to each site, after some algorithms are applied to raw data in order to let them become useful information.

This article presents the principles and the architecture of the HOMES energy monitoring. Section 2 presents briefly the pilot sites, the installed energy sensors and the lessons learned from this installation, then Section 3 shows how energy data must be processed before becoming useful information for the user. Subsequently, Section 4 explores potential applications of the Building Information Modeling (BIM) in the frame of the on-site energy monitoring. Finally, Section 0 gives an overview of the on-site and off-site monitoring contents and infrastructure, while Section 0 concludes the paper.

4.3.2. Data collection on HOMES pilote sites

The retained HOMES Pilot Sites include a primary school, an office building, a public housing building, a four-star hotel and a one-star hotel, located in different regions of France and aiming to represent the climate diversity in North-West Europe (e.g. Mediterranean, continental). On all these sites, sensors installation started gradually from August 2010 and one key point was finding the way for data to be easily retrieved. In this phase, the solution to the interoperability of sensor labels among the pilot sites was centred on the parameters needed to assess the energy performance of a building. Within the HOMES program, three categories were found:

- the type of energy used in the building (e.g. electricity, gas, fuel, wood)
- the type of services provided to the occupants (e.g. indoor temperature, luminosity, hygrometry)
- the type of exogenous phenomena which impact the energy consumption of the building such as real occupancy and climate conditions

One basic assumption of the HOMES programme is that energy and comfort control must focus on each building "zone" (i.e. a spatial subset of a generic four-wall space) in order to be effective. For instance, in an open work space, a zone control should better satisfy the compromise between comfort needs of occupants and energy conservation, whatever the real occupancy. Consequently, one key objective of the sensors instrumentation plan was to be able to retrieve data corresponding to the “zones” within the building. Finally, the application/usage (e.g. lighting, heating) is an additional class considered for each sensor. All these classes made up a vocabulary, depicted on Figure , which enables symbolic addressing to each sensor.
All data acquired by the various sensors are sent either by hard wires or by radio frequency networks to input/output data modules of a Remote Terminal Unit (RTU). These RTU’s send their data through a GSM link to two redundant servers located one in Marne-la-Vallée and one in Grenoble, where data are analysed by the HOMES researchers and processed for creating the monitoring functions for stakeholders, as illustrated on Figure 2.

The symbolic addressing is already available at the RTU level and is based on the vocabulary already described on Figure 1. Then, the symbolic name of a measurements flow is defined by juxtaposing:

- its site name
- its energy type (e.g. Water, Gas, Electricity)
- its associated usage (e.g. Lighting, Heating, Cooling)
- its zone type (e.g. Office, Kitchen, Bathroom)
- and the building specific identification (e.g. Office 1, Room 2)

As an example, the label corresponding to the energy used in the room 2 of the Windsor hotel (i.e. the four-star one) for lightning and heating are respectively:

"Windsor.Electricity.Lighting.Room.2"
"Windsor.Water.Heating.Room.2"

Due to the resource limitation within the RTU, it was not possible to use the full vocabulary but a shorter version instead was used, which is still “human readable”.
Considering the overall action for data collection on HOMES Pilot Sites, two major practical difficulties came out:

- the distribution networks (e.g. electrical, water) usually do not match the zone and usage breakdowns in building. For instance, usually electricians separate usage but not zone (i.e. one electrical feeder for the lighting, serving a given number of zones)
- some technical systems (e.g. heating/cooling multi-split), are closed systems and it was not possible to add some energy meters inside the system, without a loss of warranty.
4.3.3. More than Energy Data

One benefit of the HOMES approach in serving energy monitoring is the integration of raw data with three more categories of high-level heterogeneous types of source:

- Metadata (e.g. a description of the building, see Section 144)
- Reference Data (e.g. thermal building simulation results)
- Process Data (e.g. activity planning)

The raw data coming from HOMES pilot sites are merged with the other data above through a Business Intelligence (BI) process, which enables to enrich the physical signification of measurements. Then, all these data are neatly arranged in a data warehouse, including measurements and extra data. Due to the growing amount of data, an On-Line Analytical Processing (OLAP) solution is adopted, making data aggregation on dimensions and data filtering highly quicker than standard data warehouse. Indeed, the monitoring applications must be able to easily navigate into data. The overall process is showed on Figure 3.
Figure 3: the monitoring data flow, where energy data are merged with metadata, reference data and process data (i.e. on the right side)

But accessing easily to data could not be sufficient in order to stimulate energy-efficient behaviours in people, whatever their role (e.g. occupant, tenant). Indeed, HOMES marketing studies tend to say that “data do not generate energy efficiency, only information does”.

That is why one main challenge in the monitoring experimentation on HOMES pilot sites is extracting useful information from data, ideally up to suggest actions to be taken. Unfortunately, real-world constraints make it simpler to say than to implement in automatic processes. As an example, the flow of raw data coming from measurements must firstly cleaned, in order to remove out-of-bound or missed points. Moreover, as recalled in Section 4.3.2, some measurements are simply not available due to the building network (e.g. electrical) or equipment limitations. The entire process from raw data to useful information is illustrated on Figure 4.
4.3.4. How BIM data can enrich energy monitoring

The Building Information Modeling (BIM) has two main features:

- enable bi-directional exchanges between the different players (e.g. architects, mechanical, electrical and plumbing engineers) and the software packages they use along the entire life-cycle of the building
- store all data about a building in one single container, also known as BIM model

On Figure 5, neither a BMS (Building Management System) nor a Monitoring System is represented because they are not a common usage of BIM today. Anyway, data found in BIM models could be reused in BMS and monitoring systems, for instance in order to display a spatial representation of the building. Moreover, BIM models could provide information about zones of the building (e.g. volume, orientation) and pieces of equipment of building systems (e.g. a link to manufacturer’s datasheet).
Currently there is not a single and standardized way to “do” a BIM, but two distinct approaches exist:

- choosing a leading building CAD supplier (e.g. AutoDesk, Bentley, Nemetschek), then using software compatible with the main 3D CAD modeler
- selecting a common design enabling to exchange building data between applications that can export / import files using that format

Even if Industry Foundation Classes (IFC) is the official standard format [4] for the second approach, its usage as a neutral exchange format is quite rare in real projects. Indeed, the main barriers to a wider adoption are that the building market of today has dominating suppliers, who obviously want to keep their market share, and that only few legal obligations to use a standard format exist.

The monitoring system described in Section 0 gets most of live building data (e.g. temperature, CO₂ concentration) from physical sensors. In the frame of the HOMES programme, these sensors and related communication infrastructure have been modelled in a BIM software package, namely Revit Mechanical, Electrical and Plumbing (MEP).

The first type of information we can extract from the BIM model is the localization of sensors, for instance the installation zone, the exact geometrical position (e.g. height), the orientation with respect to windows. An example of sensors views in the building is given on Figure 6.
In addition to the spatial information, BIM software packages also enable to describe precisely the type of used sensor. Typical examples are parameters showing the usage conditions and validity thresholds of measured data, as illustrated on Figure 7.
Another important aspect depicted in the figure above is the “classification” data, in that case an OmniClass-based number [5] that allows software package to unambiguously “know” what type of sensor it is without having to refer to wordings like “Light and Movement sensor” that depend on languages.

In the BIM world, there are interesting initiatives to address that ontology issue, that is to say what BIM objects are and how they must/should be described. The most ambitious one being the International Framework for Dictionaries (IFD) [4], which is based on IFC. As the name may suggest it, IFD does not limit itself to translation, but aims at designing “a mechanism where the concept itself is a separate thing, only connected to the words describing it through relationships” [6]. However, software packages that implement IFD are experimental today.

In the frame of the HOMES programme, information about sensors like localisation (i.e. zone), measurement unit and validity range will be exported from the BIM model using the IFC standard. Then, all this data will be available for the energy monitoring and will contribute to a context-aware analysis that is expected to give an additional benefit to the monitoring services, particularly for Energy Experts.

4.3.5. Energy monitoring

**On-site, for occupants**

In the HOMES pilot sites, the information about energy monitoring is provided to the occupants through touch displays available in each room (e.g. classrooms, offices, hotel rooms), on which Human to Machine Interfaces (HMIs) are running.

Generally speaking, the site data come both from the local iRio (i.e. raw data) and from the remote server (i.e. processed data), as illustrated on Figure 8 respectively with the blue and red arrows. Indeed, local data refer to almost real-time measurements (i.e. refreshed each minute), while historical measurements are remotely stored.

Moreover, the remote server is not just a data warehouse, but it also provides intelligence to the overall system, as it executes some data mining algorithms. As an example, one goal is finding the existing correlation between measured events (e.g. the light is on when nobody is in the room).

Then, on the monitoring dashboard, the user can find not only the consequences of his behaviours (e.g. the system notifies that the lighting energy consumption decreases slightly later then the user turn it off), directly coming from the local base, but also some Key Performance Indicators (KPIs) on the historical use of heating/cooling system, electrical plugs and lighting.

Anyway, the showed information is always limited to the activity perimeter of the focused occupant (e.g. his office), as it is assumed that global information are less effective in generating behavioural energy efficiency. A particular attention is given to avoiding information overflow for the occupant.
Figure 8: Simplified on-site energy monitoring architecture adopted in the frame of HOMES programme (i.e. occupant-oriented)

**Off-site, for Energy Experts**

The occupants have a major impact on the building consumption, all the more when the building is recent (i.e. thanks to better thermal isolation and partial automation). Nevertheless, the simple occupant status does not enable to take fundamental choices, like investing on more efficient pieces of equipment. That is why a different HMI should be provided for an Energy Expert, that could for instance be someone in charge of monitoring the building energy expenditure and be paid for bringing it under a given consumption threshold.

This Energy Expert is often located off-site and is typically not a user of the building. For these reasons, the mean and the content of the energy monitoring are distinct with respect to these of the occupant. First of all, the HMI is available through a web-based platform, which seems to be more adapted to an on-demand professional use. Additionally, the fashion and the scope of the HMI are different from the occupant one. As the Energy Expert needs more analysis tools and does not fear big amount of data, HMI will provide more KPIs, mostly aiming at discover bad usages and/or bad habits.

One additional feature of the Energy Expert HMI is to provide practical suggestions for improving the building energy efficiency.
These functionalities can not be ensured without a necessary amount of historical energy data about the site, but do not need real-time updates. That is why the monitoring HMIs only receive data from the remote HOMES server, as depicted on Figure 9.

Figure 9: Simplified off-site energy monitoring architecture adopted in the frame of HOMES programme (i.e. for energy experts)

Conclusions and perspective

This paper presented an overview of energy monitoring challenges within the HOMES programme, focusing on how energy data are retrieved from real pilot sites, how they are classified and what additional data (i.e. metadata, reference data and process data) can enhance the monitoring experience, namely the BIM, and what are the expected benefits of this integration. In future works, the results of the monitoring experimentation in terms of energy efficiency gain will be published.

References

4.4. Paper: Method for Validation of Building Simulation Results using Sensor Data

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Abstract

In general, current Building Energy Simulation Tools are used for pre-construction design and comparison of designs rather than a full exact varying representation of reality. To provide the best level of detail full CFD analysis for the entire building would be required. However this is currently by far outside the scope of current computing power for a building energy system. Because these simulation tools are designed for comparison of potential designs and because of the difficulty in predicting occupant behaviour, very often the predicted results do not correlate with the real actual performance when buildings are in operation.

From project experience encountered in the EU FP7 IntUBE project, a deficit has been encountered whereby the correlation between simulation results and real measured data is not entirely accurate. This paper discusses a method of validation, which will provide a means of comparing measured data (e.g. sensors and weather data), and simulated data (e.g. near future simulations).

This method for validation of building simulation results initially involves a comparison of data from building simulation and respective measured sensor readings. From this comparison, value is added from correction of simulation results, and/or input to simulation parameters. Further worth can also be provided by gaining knowledge for creation of simulation profiles which are difficult to predict before construction & operation. Additional value can also be derived from identifying conditions of poor results and relevant factors which can be corrected. Simulation data and actual data is available from a housing unit in Barcelona Spain and research building in Cork Ireland.

The expected result to be derived from this method is to give an indication of quality of simulated data results and provide feedback. If the difference between simulated and real data is too large, steps to improve results will be suggested. In future it is envisioned that automated adjustments may performed to simulation inputs to correct results. Aside from near future simulation validation, the tool may be able to provide long term commissioning feedback to detect and alert users to long term degradation of systems and possible maintenance or repair remedies.

Keywords: Simulation, Data Modelling, Validation

4.4.1. Introduction

As new and retrofitted buildings are developed with more complex monitoring, control and automation systems, more data is being produced. A goal of the scientific and engineering community is to provide a holistic and integrated building information solution which can utilise this information
and provide value by reducing building energy consumption. Better use and more integrated use of building energy information can contribute to meeting requirements of both the European EPBD and the European 20-20-20 targets which require the EU to reduce Greenhouse Gas levels by 20%, reduce domestic home energy consumption by 20% and increase Renewable Energy by 20%, all by 2020.

A key part of this holistic energy information solution is the integration of building energy simulation tools. Energy analysis plays an important role in developing an optimal HVAC and Architectural design for new buildings and in determining optimal retrofit and commissioning measures for existing buildings. (Liu & Liu, 2011). However a barrier to this integration is that the majority of commercial building simulation tools are developed for design solutions rather than absolute accurate representations of minute by minute building performance. Therefore, pre construction simulations often do not exactly correlate with operating building performance even though building simulation tools operate with accurate physics algorithms (Clarke J., 2001). The reason for this mismatch is that detailed input information is required to produce the correct output (Kusada, 1981). To calibrate a dynamic building simulation, measured data from buildings can be used. Calibrating computer models to actual metered data is not a new practice (Liu & Liu, 2011). As early as 1970, recommendations were made to calibrate models based on measured data (Ayres & Stamper, 1995) Most calibration procedures require months of measured data. (Liu & Liu, 2011). Previous studies have developed a calibration procedure based on developing archetypes whereby patterns of similar buildings which operate alike would be developed and used for future similar buildings. This can be used to calibrate buildings to better predict future similar buildings (Flores Larson, Filippin, Beascochea, & Lesino, 2008).

Comparison of simulated cooling and heating energy simulation against time of day is a very important step in model calibration (Flores Larson, Filippin, Beascochea, & Lesino, 2008) and short term cooling load forecasting, with lead times from 1h to 7 days, can play a key role in the economic and energy efficient operation of cooling appliances (Clarke & al, 2004). The study under development presented in this paper is based on calibrating accurate building information models and associated simulation models with real measured sensor data procured from existing buildings.

4.4.2. IntUBE Energy Information Integration Paltform

The main aim of the IntUBE project is to develop intelligent Information and Communications Technologies (ICT) to improve the energy efficiency of these buildings. IntUBE will primarily focus on integrating existing software functionalities using open standards and their open source implementations. Based on the open data from multiple life-cycle stages (especially ‘design’ & ‘operate’) new advanced services will be developed to inform inhabitants in intelligent ways of how to change their energy consuming behaviour in ways that reduce energy consumption and improve comfort (Böhms, Plokker, Charvier, Madrazo, & Sicilia, 2010). At the core of the IntUBE approach lies an Energy Information Integration Platform (EIIP) which stores energy information generated along the different stages of the building’s lifecycle: conceptual design, design development, operation and retrofitting. The information is organised into three repositories, each dedicated to storing/retrieving
different kinds of energy information: a BIM repository for building descriptions, a SIM repository for the simulation results and a PIM repository for the monitoring data.

Problems for simulation, a common language is required, “nuances of capability” exist. (Crawley, Hand, Kummert, & Griffith, 2008) different simulation tools provide a challenge. Therefore a key output of the project is the value that can provided from integrating building simulation, the processes involved and the form used to provide a methodology for storing relevant information from simulations in the EIIP with reference to informing building operation. Although the IntUBE project made use of only two different energy simulation software tools (primarily VABI software) the EIIP is adaptable and can be altered for use with any other simulation tool. This paper describes progress made to date and plans for the future with reference to plans for integration of building simulation and measured sensor data.

4.4.3. Simulation Information Process

The simulation process can be considered to have a number of steps.

- Pre processing of Simulation Data
- Run Simulation process
- Export of results to SIM server

It is important to set up the simulation(s) to run depending on the required value or output. The easiest method of determining simulation value is to compare similar simulations. In the example of the Cerdanyola building informing users, two simulations are performed with only one variable differing, in this case blinds open or blinds closed. Whichever is predicted to be most energy efficient is presented to the occupant as the preferable position.

Value of Simulation

The value that can be derived from simulation is relative accurate prediction of near future performance of buildings to minimise energy use. Adjustments can be made to systems or building operation as simple manual adjustments such as opening or closing blinds or windows or as advanced as continuous adjustment of a HVAC system as occupancy/weather conditions and energy tariffs are altered. The output of the system could be a simple display to inform occupants or a complex integration into an intelligent building management system [IBMS].

Potential variables include but are not limited to

- Windows open or closed and degree of same
- Blinds open closed and degree of same
- Control of water radiator heating systems WRT timing and amount
- Control of ventilation systems WRT timing and volumes and treatment

These variables can be adjusted as inputs to the simulation to provide the best output to minimise energy use. This is the purpose of the simulation tool.
**SIM Ontology**

The SIM ontology has been developed as a SIM operational form. This form records all results from the simulation software and stores it in the EIIP for future use (See Table 1). Openness of form is provided by allowing for results from more than one simulation tool, whereby any information not created can be left blank in the form. The form can be expanded upon if any other simulation software has results not already covered or listed.

**Simulation Undertaken**

Results using VABI Simulation. Simulations were undertaken on the Cerdanyola building based on the BIM model from BIM tool set. Single day simulations undertaken with an appropriate lead in time with blinds open or closed provided very slight variations in energy consumption which can be used as a recommendation for occupant before leaving their property. From this research IES requires more automation; VABI software on the other hand is better developed.

**Time Stamps Frequency**

Simulation tools used in this project have the ability to perform simulations and create results in a selectable and adjustable minimum time frequency value, typically 5, 10 or 15 minutes. Running simulations at the shortest frequency will take longer to complete and produce more (possibly unnecessary) data. Producing results in greater time frequencies (e.g. 60 minutes or 120 minutes) will be more efficient from a computing point of view, but may not produce accurate representation of near future building conditions.

To provide balance between, it is suggested that 15 minute intervals are used for simulation results. A further advantage of using a 15 minute interval is that it is best suited to match PIM values, i.e. providing an easy comparison between real sensors readings and predicted simulation results. If greater results periods are required (daily/monthly/quarterly/annual) if any other function, these can be extracted and summed from 15 minute results stored in the EIIP.

**Initial Results**

This section provides a short description of the set up and results provided from initial simulations for a social housing block in Cerdanyola. Two similar but contrasting simulations were performed using Vabi simulation software. These simulations were performed on the “L” shaped apartment in Cerdanyola. The only difference between these simulations is that the simulations were run with and without solar protection. As a general trend, it was observed that in winter months and cold days that with the shading device, the heating demand is greater and comfortable temperatures will be met.
### Operational Simulation Form

#### General Building Load Data (15 no Variables)

<table>
<thead>
<tr>
<th>Description</th>
<th>Unit</th>
</tr>
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<tbody>
<tr>
<td>Room heating plant sens. Load</td>
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</tr>
<tr>
<td>Room hum. Plant load</td>
<td>kW</td>
</tr>
<tr>
<td>System air heating load</td>
<td>kW</td>
</tr>
<tr>
<td>Aux vent heating load</td>
<td>kW</td>
</tr>
<tr>
<td>Boilers load</td>
<td>kW</td>
</tr>
<tr>
<td>Ap Sys boilers non-DHW load</td>
<td>kW</td>
</tr>
<tr>
<td>Ap Sys boilers DHW load</td>
<td>kW</td>
</tr>
<tr>
<td>Room cooling plant sens. Load</td>
<td>kW</td>
</tr>
<tr>
<td>Room dehum. plant load</td>
<td>kW</td>
</tr>
<tr>
<td>System air sens. clg. Load</td>
<td>kW</td>
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<tr>
<td>System air lat. clg. Load</td>
<td>kW</td>
</tr>
<tr>
<td>Aux vent sens. clg. Load</td>
<td>kW</td>
</tr>
<tr>
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</table>

#### Weather Variables (14 no variables)

<table>
<thead>
<tr>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry-bulb temperature</td>
<td>ºC</td>
</tr>
<tr>
<td>Wet-bulb temperature</td>
<td>ºC</td>
</tr>
<tr>
<td>External dew-point temp.</td>
<td>ºC</td>
</tr>
<tr>
<td>Wind Speed</td>
<td>m/s</td>
</tr>
<tr>
<td>Wind Direction(E of N)</td>
<td>º E of N</td>
</tr>
<tr>
<td>Direct radiation</td>
<td>w /m²</td>
</tr>
<tr>
<td>Diffuse radiation</td>
<td>w /m²</td>
</tr>
<tr>
<td>Global radiation</td>
<td>w /m²</td>
</tr>
<tr>
<td>Solar altitude</td>
<td>º</td>
</tr>
<tr>
<td>Solar azimuth</td>
<td>º</td>
</tr>
<tr>
<td>Cloud cover</td>
<td>oktas</td>
</tr>
<tr>
<td>Atmospheric pressure</td>
<td>Pa</td>
</tr>
<tr>
<td>External relative humidity</td>
<td>%</td>
</tr>
<tr>
<td>External moisture content</td>
<td>kg/kg</td>
</tr>
</tbody>
</table>

#### Model Energy Variables (18 no variables)

Table 1: Example of SIM form
During summer months and on warmer days with the shading device will reduce heat gains and provide temperatures that are more comfortable.

Therefore value can be provided by these results by advising use (or not) of shading devices, determined on a day by day basis, with the aim of minimising heating energy providing that maximum temperature does not exceed a comfortable level.

As the data extracted from the EIIP is in Microsoft Excel workbooks, it was decided to undertake early analysis using this format. Although general patterns could be compared, unfortunately initial results of simulation and real sensor data did not closely match, as would be expected. The main contributory factor for this was differences in weather data. Further deficits on a micro level occurred due to differences in expected occupancy patterns and volumes. As mentioned previously, this real sensor information will provide input to the simulation to improve accuracy. Development of this early feedback loop will compromise part of future research.

4.4.4. Energy Simulation Validation/Checker Tool

The future step is for the tool is to integrate as part of the EIIP system and will act as a validation tool which will provide a means of comparing measured PIM data (e.g. sensors and weather data) and simulated SIM data (e.g. near future simulations). The value derived from the tool is to give an indication of quality of data, simulated in particular. If the difference between simulated and real data is too large steps to improve results will be suggested. In future system may be developed to allow automated adjustments to be performed upon simulation inputs to correct results. Aside from near future simulation validation, the tool may be able to provide long term commissioning feedback to detect and alert users to long term degradation of systems and possible maintenance or repair remedies.. Possible anomalies could be sourced from alterations to building fabric or use which may not been updated on the BIM model. Another BIM correction may be the potential to identify differences between the “as built” model and real building.

An alternative method of providing value is to allow output from the tool to perform adjustment of results from the SIM to match real measured results. For example if simulation temperatures are continuously too hot, a crude adjustment of results could be undertaken. Further value could be derived from identifying conditions of poor results and relevant factors which could be corrected.

Matching of similar SIM and PIM data will be a straightforward comparison between simulation results and real data in many cases, e.g. straightforward comparison of maximum room temperature or daily meter readings. Greater complexity will occur from adjustment or providing corrective measures if a close comparison does not occur.

4.4.5. Current and Future Plans

The process described in this paper comprised a small section of the IntUBE project which has now concluded. Future development of the process will be undertaken as part of the SFI funded ITOBO project (http://zuse.ucc.ie/itobo/). Early comparisons have been performed using excel, it is envisioned that macros will be developed to better utilise this information.
Live instantaneous simulation can provide benefit from tuning BMS for near future tweaking of BMS/control systems (continuous commissioning), building certification and IntUBE energy profiles, design performance review.

Possible scenarios which could be implemented include:

- **Design Review and comparison:** During design phase, inputs for “Design SIM” are estimated future building usage, occupancy density, etc. For “Operational SIM”, inputs can be real functional data, from BMS and observation. “Operational SIM” can provide a design check on the Design SIM allowing feedback to designers for future Design SIM improvements.

- **Building Benchmarking:** Benchmark building energy use as compared to other, similar buildings to identify need for improvement. Will also allow for potential improvements/alterations to BMS setpoints to be simulated to allow for energy savings.

- **Energy Use Tracking:** Track energy use to monitor changes. Continuous simulation can identify deviations from previous trends or simulated “should be” trends to identify damaged equipment (e.g. broken fan/condenser) or altered user conditions (e.g. change of use, from office space to server room). This can aid facilities managers in detailing the work required for repairs of equipment or building operator to change BMS setpoints.

- **Trend Data Analysis:** Trend key system parameters to detect problems early and assess system performance. As above.

- **Recommissioning or Continuous commissioning:** Perform ongoing recommissioning activities to ensure that the building meets its current needs. Identify and correct deviations from “Ideal” initial operating conditions.

- **Creation of Building Certification:** can provide a more efficient method or an automatic Operational phase building simulation

Further worth can also be provided by gaining knowledge for creation of simulation profiles which are difficult to predict before construction & operation. Additional value can also be derived from identifying conditions of poor results and relevant factors which can be corrected. Simulation data and actual data is available from a housing unit in Barcelona Spain and research Building in Cork Ireland. The expected result to be derived from this method is to give an indication of quality of simulated data results and provide feedback. If the difference between simulated and real data is too large steps to improve results will be suggested. In future it is envisioned that automated adjustments may performed to simulation inputs to correct results. Aside from near future simulation validation, the tool may be able to provide long term commissioning feedback to detect and alert users to long term degradation of systems and possible maintenance or repair remedies.

**Conclusion**

This paper describes a small portion of the EU FP7 IntUBE project whereby comparable data is produced from energy simulation software and real measured sensor data. The process for providing useful raw data has been completed; future research will focus on providing more value from this
data. Although the IntUBE project ended in April 2011, the simulation validation process described here is to be developed further as part of the ITOBO research project. It is envisioned that this will take shape towards Q4 2011.

References

5. Session: Ontology's for Heterogeneous Physical Devices

5.1. Paper: Enabling energy efficiency through device awareness using ontologies

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Abstract

Achieving energy efficiency in buildings through interconnected embedded devices, such as sensors and actuators has become one of the leading research topics in Europe in the last decade. Systems devoted to improve energy efficiency tend to work in heterogeneous environments, interfacing with different devices from different manufacturers. The use of semantic technologies, such as ontologies is a solution to the latter problem. This paper describes the ontology for device awareness, developed in the context of the eDIANA project, whose main objective is to provide the eDIANA concentrators of a semantic description of the connected devices. In addition, this paper covers the methodology used to create the ontology, and a case study showing a usage example.

Keywords: Energy-efficient buildings, Ontology, Device awareness, eDIANA.

5.1.1. Introduction

Energy efficiency technologies applied to buildings are becoming an important topic for the scientific community. Devices devoted to reducing, or at least controlling energy consumption without reducing comfort parameters are struggling to reach the market and our homes. However, these devices face the non-trivial task of communicating with other devices in the buildings, often leading to closed proprietary solutions that become too expensive for end users. The eDIANA project (eDIANA project, 2011) tries to cope with this issue through the definition of a reference architecture for energy efficiency in buildings.

The eDIANA reference architecture (i) provides open interfaces to device providers easing interoperability, (ii) uses strict component orientation, and (iii) defines two different hierarchical layers. Among these aspects, this paper will describe the research results obtained for the first characterization of the platform; in particular, the paper covers the ontological approach developed to cope with devices discovery within eDIANA.

Ontologies are formal descriptions of the concepts and relationships that can exist for an agent or a community of agents, usually inside a specific domain. They define entities, properties, interactions,
actors and basic concepts that compose the common vocabulary for all members of the domain they define. One interesting property of ontologies is that they are extensible. That means that existing concepts can be refined, and new elements can be added. Some frequent uses of any ontology are:

- To share common understanding of the structure of information among people or software agents
- To enable reuse of domain knowledge
- To make domain assumptions explicit
- To separate domain knowledge from the operational knowledge
- To analyze domain knowledge

In the context of eDIANA, the usage of ontologies not only supports the platform in the task of recognizing devices that connect to it, but also enables the incremental development of the platform, extending and refining concepts and devices as technology evolves.

This paper is structured as follows: Section 2 briefly describes the eDIANA reference architecture and the device awareness problem associated to it; section 3 discusses some related works; section 4 covers the methodology applied in the development of the ontology; section 5 describes the ontology implementation; section 6 discusses a case study of the ontology usage, and, lastly; section 7 presents some conclusions.

5.1.2. DEVICE AWARENESS IN eDIANA

The main objective of this ontology is to define the universe of concepts or classes and their relations in the domain of eDIANA Platform Architecture, related to device awareness. The eDIANA Platform Architecture provides a wide and heterogeneous list of devices in two hierarchical levels: MacroCell and Cell (see Figure 1). The knowledge of the context in which each element is, their relevant characteristics to other elements as well as how they interact with other elements is essential to allow the scalability of the architecture and the replacement, suppression or inhibition of architecture elements.

Figure 1: The eDIANA reference architecture (R. Ukmar et al. 2010)
As shown in the latter figure, devices connected to eDIANA are classified in different groups depending on their functionality. At top level of the hierarchy, we find the concentrators, both in MacroCell and Cell levels. The MacroCell Concentrator (MCC) is the only device of the eDIANA platform at MacroCell level (that is, building wide level), and its role is to concentrate the information gathered from each Cell, and to provide recommendations and energy consumption patterns to the Cells. The Cell Device Concentrator (CDC) is the concentrator at Cell level (that is, single house or office level), and it manages all the devices at the lowest level. These devices might be (i) Cell Monitoring and Metering (CMM) devices if they are devoted to obtain data from the Cell (i.e. sensors); (ii) Cell Control and Actuation (CCA) devices if they implement functions that may affect the status of the Cell (i.e. blinds controller, light switches, HVAC systems, etc.); or, (iii) Cell Generation and Storage (CGS) devices if their functionality is devoted to the management of energy inside the Cell (i.e. boilers, batteries, etc.).

For the sake of openness, all the devices connected to the Cell share the same interface, as depicted in figure 1. However, it is clear that all devices will not be able to process or produce the same type of messages (e.g., a sensor will provide data, while an actuator will consume it). Thus, it is easy to understand that the CDC will require the characterization of each device, enabling it to distinguish a temperature sensor from a lighting switch. Additionally, similar devices may understand different kinds of messages; for example, a lighting switch may define only two positions (on/off) or a lighting percentage value. Finally, it is very likely that new devices appear in the market refining one or more of the currently existing devices, or providing new functionality. The CDC should be able, in these cases, to provide at least some support for these devices. Taking into account the requirements described above, ontologies and semantic approaches are considered as the most appropriate technologies to use.

5.1.3. Applied Methodology

Even if there is not a single correct way to develop ontologies, most of the methodologies proposed by the literature follow some basic rules (Cuenca et al. 2008):

- There are always viable alternatives. The best solution usually depends on the application that you have in mind and the extensions that you anticipate.
- Ontology development is necessarily an iterative process.
- Concepts in the ontology should be close to objects (physical or logical) and relationships in your domain of interest. These are most likely to be nouns (objects) or verbs (relationships) in sentences that describe your domain.

Following these rules, the eDIANA ontology for device awareness has been developed in several iterations, with collaboration from many different partners. The process stopped after three iterations; nevertheless, the explicitness that an ontology can achieve is almost infinite. Before starting creating concepts and relations; that is, before facing the development of any ontology it is important to determine its domain and scope. These aspects can be addressed by
answering the following two questions: what is the domain that the ontology will cover, and what is the ontology going to be used for. The answers are clear in the context of eDIANA. Since the main objective of the ontology is to enable device concentrators to recognize devices connected to the Cell and discover their interfaces, the domain of the ontology will be focusing in Cell level devices. For the sake of completeness, the ontology will also cover MacroCell level concepts; yet, these concepts will be developed in less detail than Cell level ones.

It is also important to define what kinds of questions the information in the ontology will provide answers for. In the context of eDIANA, possible answers include:

- Environment understanding
- Types of components and devices
- Profiles of components and devices
- Identification of components and devices
- Components and devices services

The development process of the ontology for device awareness was an iterative cycle. Each cycle consisted of three steps: (i) brainstorming step, (ii) categorization step, and (iii) property definition step. The brainstorming step consisted in the enumeration of different concepts that were important in the context of the selected ontology domain without paying much attention to the relation among them. Once the terms had been placed in the table, the categorization step analyzed these terms, discarding any concept that did not fit the ontology scope, and categorizing valid ones in a hierarchy of classes. Lastly, in the property definition step, each concept was refined, where necessary, through properties that enriched the semantics behind it.

After each iteration new concepts were added to the ontology, including terms not covered in previous iterations, providing more generic terms that enriched the class hierarchy, etc. In addition, the definition of properties in these iterations often led to find missing concepts that were completed in the next iteration.

5.1.4. Implementation

The eDIANA ontology for device awareness has been implemented in OWL, using the Protégé tool (H. Knublauch et al. 2004). The ontology has been structured in three different semantic layers:

- **Information layer.** The information layer of the eDIANA ontology for device awareness contains different categories of information that will be referenced by the elements defined in the other two layers, namely services layer and devices layer. The information layer only defines the semantics and direction of the exchanged information and not the syntax or protocols used between the nodes exchanging data.

- **Service layer.** The Service structure layer of the ontology focuses on the definition of the different interfaces present in eDIANA. This definition was made at a very high level in an early stage, since the actual interfaces had not been designed yet at the time the ontology was constructed.
- **Device layer.** The Device layer of the eDIANA ontology for device awareness defines the different categories of devices that compose the eDIANA platform. This taxonomy of devices will enable device awareness services and plug-and-play services by characterizing the devices, their properties and their interfaces.

Figure 2 provides an overview of the classes of the three semantic layers described above. The three semantic layers can be split into two groups: on the one hand, the device layer provides the core of the semantics of the eDIANA domain; on the other hand, information and service layers, model concepts that refine the semantics of the core concepts.

![Figure 2: Excerpt of the class breakdown of the ontology layers](image-url)
The information layer includes concepts to model the type of information exchanged between eDIANA devices; for example, humidity, noise, temperature, etc. model information that has implications on the comfort of the eDIANA users. Smart actuator commands include mode switching, turning devices on and off, or sending new usage programs. Furthermore, each message can also be described as an input or an output for a particular device (e.g. humidity data will be an output for a humidity sensor and an input for the CDC).

The service layer is used to describe the interfaces of the eDIANA devices. These descriptions include information on the interface type (e.g. intelligent Embedded interface (iEi) (García J.U. 2010), Internet interface (WWWi) (Buratti C. et al. 2010), etc.); and a description of the commands accepted by a particular device on a concrete interface. For example, a simple temperature sensor will only accept commands asking for reading sensor data; however, a complex device comprising a smart appliance and a power consumption sensor will be capable of accepting configuration change commands, sensor, status and user data gathering, reset commands, smart commands, etc.

Finally, the device layer describes all the device types that will connect to the eDIANA platform. This layer defines not only the semantics behind each of the devices in eDIANA; but also, their interfaces and produced information, using the information and service layers. At the top level, devices are split into three categories: concentrators, simple devices and complex devices. Concentrators include the CDC and the MCC, each of them working as concentrators at Cell and MacroCell level respectively. Simple devices represent individual elements that can be connected to the Cell, such as sensors, appliances, actuators and user interfaces. Each simple device is described in terms of the iEi commands they accept. Additionally, some simple devices are refined to enrich their description (e.g. differing simple physical sensors from threshold sensors). Although, simple devices include many concepts, the majority of the devices that connect to eDIANA are complex devices. Complex devices are composed of several simple devices; for example, a HVAC system will be typically composed of a smart appliance and a power consumption sensor; and a complex sensor may connect different sensors (e.g. temperature, lighting sensors) using a single iEi interface connection.

5.1.5. Case Study: eDIANA Simulation Framework

To demonstrate the capabilities of the proposed ontology to enable device awareness, we developed a simulation framework, based on the Eclipse Modeling Framework (EMF) (D. Steinberg et al. 2009). The simulator has been used to evaluate the energy efficiency algorithms implemented at Cell level. The algorithms use as main inputs for their calculations replicas of the databases of the CDC, which are updated in runtime with the information collected from the different devices connected to the Cell. Additionally, the concentrators also use the information in these databases to send the adequate commands to the actuator devices (e.g. switches, appliances, etc.). The configuration of the simulator is made using an EMF implementation of the ontology for device awareness, the MacroCell Definition Language (MCDL).

The MCDL was defined taking into account the elements of the eDIANA platform specification. Figure 3 shows the implemented editor with the available elements of the model on the palette on the left side, and an example of an instantiation of a MacroCell and one Cell on the right.
The file of a MacroCell defined with the MCDL serves as input for the generation of the simulated eDIANA platform artifacts. Generated sensors, actuators and loads connect to the CDC is a simulated manner taking into account their profiles as defined by the ontology. These profiles are stored according to the CDC database schema.

The connection between the MCDL editor and the simulator allows speeding up the validation and verification of these functionalities by simulating the connection of devices to the Cell using the generated profiles, and their information exchange inside the Cell (J. M. Marcos et al. 2011).
The simulator allows the user to define, in a very detailed way, the simulation scenarios using the concepts of the ontology. For example, sensors can be activated declaring outgoing communications, appliances can indicate energy consumptions with a defined period, and cameras can detect movement in different zones of the Cell.

Conclusions

This paper describes the eDIANA ontology to achieve device awareness in a heterogeneous platform. The convenience and applicability of ontologies have been addressed, taking into account that the devices connected to the eDIANA platform may evolve and provide new functionalities. Finally, a case study involving an eDIANA simulation framework has been described, highlighting its applicability for testing the Cell functionality and algorithms.

The work done in eDIANA to link ontologies with device awareness and simulation has proven to be a successful approach. Ontologies not only provide a common understanding of the domain and all the devices it implies; but also supports the seamless evolution of the domain when new elements are added without affecting already running systems. eDIANA will work on the evolution of the ontology to fully support the domain of energy efficient buildings, and to foster the openness of the platform.

Acknowledgments

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References


Abstract

In this paper we present LinkSmart, a generic middleware solution developed within the FP6 European Project HYDRA. LinkSmart as a middleware framework defines an abstraction layer on top of heterogeneous communication protocols. It provides services and development tools to application developers, hiding thus for them the complexity of underlying device specifics and network protocols. LinkSmart combines the use of ontologies with semantic web services, supporting thus true Ambient Intelligence (AmI) for ubiquitous networked devices. It introduces the Semantic Model Driven Architecture (SeMDA), which aims to facilitate application development and promote semantic interoperability for services and devices. The SeMDA of LinkSmart includes a set of ontologies, and provides tools, which can be used both at application design time and runtime. The ontologies are used for both static information storage and also complex query answering purposes.

Since LinkSmart was implemented as a generic middleware, it provides a technological basis for further projects applying the middleware solution in various application domains, such as energy efficiency, Internet of Things in the enterprise and crisis response.

Keywords: Middleware, Ambient Intelligence, Semantic Technology, Ontology Modelling
side effects or further instability leading to an uncertain malicious behaviour sneaking into the overall system, regardless how careful the developers are.

An approach to overcome these issues of heterogeneity is to abstract those diverse standards in a higher layer, which offers a uniform interface. This is where a middleware comes into play. A middleware framework hides the complexity of an underlying infrastructural system technology while presenting, for instance via its API, a consistent view to application developers.

This paper describes the LinkSmart middleware, which addresses these requirements. The middleware was developed in conjunction to the HYDRA project [http://www.hydramiddleware.eu/], which was a 52-months European Union funded research project. LinkSmart outfits developers of Ambient Intelligence applications with a set of sophisticated software components and related development tools.

The middleware provides a transparent and secured communication channel that takes into account mobility and dynamic addressing of devices and related services. It utilizes a semantic modelling technology for representing devices or any aggregation of devices that allows application developers addressing network nodes semantically. In the following we present the LinkSmart middleware, describing its software architecture and design, device classifications, and the use of ontologies for semantic application development. We then give a brief overview of follow-up projects that apply and extend the LinkSmart middleware.

5.2.2. LinkSmart middleware

LinkSmart as a middleware framework defines an abstraction layer on top of heterogeneous communication protocols. It provides services to application developers, hiding the complexity of underlying device specifics, so that service interfaces are decoupled from the network protocol. For instance, LinkSmart utilizes OSGi Service Platform for local calls between Java-based modules and for remote calls SOAP over various network protocols such as HTTP, UDP, and Bluetooth.

Software Architecture and Design

Figure 2 shows the LinkSmart middleware framework and its relation to the network infrastructure and applications.
Components inside the dotted square comprise the middleware. This figure clearly visualizes that LinkSmart is located between the physical communication layer and the application layer. The physical layer depicted in Figure 2 represents the different device communication protocols that can be abstracted with LinkSmart.

The middleware architecture follows strictly a service-oriented and component-based design adhering to the principles of loose coupling and separation of concerns. LinkSmart consists of several components called managers (see Figure 2). Each manager encapsulates a set of operations and data that realize a well-defined functionality. Some of these managers are essential (e.g. Network Manager) while others provide optional functionality (e.g. Context Manager or Storage Manager). Each manager has a clearly defined role, offering a set of services to be used by other managers or application level components. Further, as LinkSmart aims at supporting the development of distributed AmI applications, managers can be deployed on different hosts, communicating via web services. In consequence LinkSmart supports the development of scalable applications, from simply connecting two computers to full-fledged pervasive environments supporting e.g. security, distributed storage and context awareness.

The LinkSmart SoA is implemented with WS-I [http://www.ws-i.org/profiles/basicprofile-1.1-2004-08-24.html] conformed Web Services based on either Java or .Net providing interoperability among different systems and platforms. Java based components make use of the OSGi [http://www.osgi.org/] service platform as it represents a comprehensive framework for the development of modular and extensible applications.

Besides such architectural considerations, LinkSmart introduces the distinction of device developers and application developers allowing developers to best apply their expertise to specific tasks in AmI application development. A device developer is responsible for connecting any kind of networked
device to the LinkSmart middleware, exposing its functionalities as LinkSmart conformant services. Once integrated, the application developer can then transparently employ this device in a LinkSmart application.

**Device Classification**

The LinkSmart network architecture is based on IP networks with the communication scheme based on Web Service calls. If a device’s communication protocol does not implement the IP layer, it will need means to be integrated in the LinkSmart network. The way this is done depends on the device’s capability to host LinkSmart components. Therefore, LinkSmart introduces different device classes, to provide to device developers guidelines on how to integrate a certain device:

- **D0 devices** are not able to host the minimally required subset of the LinkSmart middleware and do not support IP communication. D0 devices are typically legacy devices with very limited power in terms of processor and memory using communication protocols like Bluetooth, ZigBee, IrDA or RS-232 among others. Sensors and actuators are D0 devices.
- **D1 devices** cannot host the LinkSmart middleware but do implement IP communication and are suitable for running embedded Web Services. PDAs and mobile phones are examples of D1 devices.
- **D2 devices** can host the LinkSmart middleware but do not implement IP communication. Thus, communication needs to be bridged by a device that is capable of IP. Some PDAs are examples of D2 devices.
- **D3 devices** are able to host the LinkSmart middleware and provide IP support. Examples of D3 devices are powerful mobile phones, personal computer or laptops.
- **D4 devices** are D3 devices that host proxies for D0 and D1 devices.

![Figure 3: Device classification decision flow chart](image)

Figure 3 shows a decision flowchart to help developers decide how they should develop a LinkSmart device. First, we have to check whether the device can host the LinkSmart middleware or not. If the
device is not powerful enough, it is a D0 or a D1 device. If the device can host a web service and has IP communication capabilities, it is a D1 device. Otherwise, it is a D0 device. On the other hand, if the device can host the middleware, we have to check if the device in question supports IP communication. If the answer is negative, it’s a D2 device. If the answer is positive and the device can control D0 and D1 devices in the system, it’s a D4. Otherwise, it is a D3 device.

**Ontologies in LinkSmart**

The HYDRA project combined the use of ontologies with semantic web services, supporting thus true Ambient Intelligence for ubiquitous networked devices. HYDRA applied the Semantic Model Driven Architecture (SeMDA), with the aim to facilitate application development and promote semantic interoperability for services and devices. The SeMDA of HYDRA, currently released as open source under the name LinkSmart, includes a set of ontologies, and provides a set of tools, which can be used both in the application design- and run-time.

Most of the models used in LinkSmart are created as OWL-Lite (OWL, 2009) ontologies, in some cases OWL-DL. With respect to the characteristics of the domain, careful modelling strategy was applied. The development of ontologies strictly followed the user and application requirements to keep them simple. The ontologies in LinkSmart are used both for static information storage and for complex query answering purposes. An introduction to particular ontologies of LinkSmart is provided below. The basic structure of ontologies is depicted in Figure 4.

![Figure 4: Basic structure of LinkSmart ontologies.](image)

The LinkSmart **Device Ontology** represents concepts describing the device related information, which can be used at the design- and run-time as well. The basic ontology is composed of several partial models representing specific device information. The initial device ontology structure was extended based on the FIPA device ontology specification (FIPA, 2002) and the initial device taxonomy was adopted and extended from the AMIGO project vocabularies for device descriptions (AMIGO, 2006). The core ontology contains taxonomy of various device types and the basic device
description that includes a model and manufacturer information. The additional ontology modules include the following model.

The **Device services** are modelled in the terms of operation names, inputs and outputs (Figure 5). The services are also organised into taxonomy. The services are the basic executable and functionality units in LinkSmart. To enrich the service description, additional information items can be annotated to the model of the service, such as various capabilities, quality of service or security properties etc. The model of services used in LinkSmart was inspired by the OWL-S ontology (OWL-S, 2004). Since the OWL-S was too exhaustive for the project purposes, a more suitable approach was to create simple and customised ontology for service description.

![Figure 5: A part of the LinkSmart service ontology.](image)

**Device capabilities** represent the hardware properties, software description and energy profiles. The mentioned information profiles are modelled as static structures, where only one profile of each type can be attached to the device.

**Discovery models** contain models of all discovery information provided by the low-level communication protocols. The Discovery model is mandatory and is attached to each device. The purpose of the device discovery information is the ability to resolve the suitable device semantic model when new device joins the LinkSmart network and is initially described only by low-level discovery information depending on the communication protocol used.

**The Semantic device model** represents logical aggregates of composed devices to provide a more advanced application related functionality. Semantic devices are modelled as a set of semantic
services specified by preconditions, which have to be satisfied for the semantic device to be executable. The preconditions specify static or dynamic requirements for devices embedded in the semantic device.

**Application models** contain a set of ontologies dedicated to various application domains. Each application model specifies the domain entities and relations in order to achieve a context-awareness of the application.

**Quality of Service (QoS) model** contains descriptions of various aspects of the service quality. High level properties, such as taxonomy of service functional capabilities (e.g. play video or measure temperature) are modelled. The QoS ontology contains also specification of the lower level service properties, such as response time, availability or reliability. The QoS ontology also contains taxonomy of various units (such as temperature, time, pressure, currency, etc.).

**Device malfunctions** represent various types of errors and failures, which may occur when using the device at run-time. For each malfunction a set of possible remedies in the form of text descriptions is assigned.

**Security properties** specify various security properties, such as protocols, algorithms or objectives, which may be attached to the devices or services. To describe the security properties, the third party NRL ontology (NRL, 2007) was integrated and annotated to the device ontology.

**Configuration model** supports a device creation using the DDK (Device Development Kit) tools. For each created device, information on the configuration and implementation files used by the particular IDE (Integrated Development Environment) is stored. These files serve as templates of a code or IDE project files and can be reused, when new similar devices are created. Another purpose of the configuration models is the support for automatic device code generation (e.g. selecting suitable device implementations) for the device development.

**Using Ontologies in LinkSmart**

SeMDA of the LinkSmart provides a set of tools helping the application developer to use any wireless or wired device easily. All devices in the LinkSmart application are accessible in a uniform way – as a semantic web services. In order to achieve this, developer has to prepare all the devices, which will be used in the application with the help of the SeMDA tools. For each device a semantic description, which can be used for the purpose of the device discovery, calling the device services satisfying various requirements (such as a suitable quality of the service) or context-awareness of the application, is created. This functionality is ensured by SeMDA, thus the development process is simplified and the underlying implementation is transparent to the developer. This section will briefly introduce the basic scenarios of using Semantic Web technologies in application design and at the run-time.

**LinkSmart enabling device**

At the application design-time, each device has to be prepared for usage in the LinkSmart. This process is called the LinkSmart-enabling of the device. Developer can LinkSmart-enable a new device using so-called Device Development Kit (DDK). The new device is annotated to a suitable class in the
device taxonomy (e.g. a mobile device) and the basic description, such as the device model name and number, manufacturer information, energy consumption profile or device discovery information is added. Since the particular devices have different connection and communication capabilities, the service calls have to be transformed into web service calls. For each service, the developer has to add the custom implementation. Each service is also annotated to the suitable service taxonomy class.

The whole process of the device LinkSmart enabling is guided by the ontology. The developer browses the taxonomies provided by the ontology when selecting a suitable device or service class. Basic information and energy consumption are entered into the forms, automatically generated from the ontology. Once the device is prepared, the new ontology instances are automatically generated and the ontology is extended by the new device basic model. The ontology contains one instance for each specific device model.

**Semantic device discovery**

When a new device enters the LinkSmart network, it is discovered using one of the low-level Discovery managers dedicated to various low-level communication protocols such as Bluetooth or ZigBee. In most cases, the low-level discovery retrieves only “weak” information dependent on the particular protocol capabilities. At the run-time, this information is used to identify the corresponding semantic device model in the ontology containing full description of the device, its services and other relevant information assigned to the device model at the design-time. The semantic resolution is performed by comparing the actual low-level discovery information to discovery information assigned to the device ontology templates within the LinkSmart enabling process. Each low-level communication protocol represents device discovery information in a very different way. Sometimes, the available device information includes only device model name and the number, sometimes various manufacturer information. In case of more sophisticated protocols, such as BlueTooth or UPnP, a list of services or other extending information can be available. For each low-level discovery information there exists a model in the ontology. The low-level discovery information is translated into the SPARQL (SPARQL, 2007) query and the solution of the semantic device resolution is transformed into a graph-matching problem. In many cases, the execution of the query retrieves more matching candidates, which has to be further investigated by heuristic comparison of possible additional information items. The possible additional information for each communication protocol is modelled in the ontology, so in the implementation of the comparison procedure there is no need to hard-code the particular comparison cases.

**Extending the device semantic description**

Semantic descriptions of the device models created in the LinkSmart enabling process represent only the basic information necessary for the device functionality. This information can be further extended using the Eclipse based IDE, which serves as an ontology and annotation editor. The LinkSmart ontology was extended by models of hardware, software and energy profiles, quality of service properties and security properties. The Device ontology was also extended by properties used to annotate the extended information to the device models. Since in the most cases the requirements were to search for services having several properties, the domain of annotation properties is mostly
the classes from the service taxonomy. The hardware, software and energy consumption information are modelled as static structures, there can be one hardware, software or energy profile per device. There can be multiple annotations of the quality of service and security properties. Using the extended semantic descriptions, the devices and services have the full semantic support and are searchable in various ways.

**Application context-awareness**

In HYDRA, the application domain models were integrated into ontologies including properties for annotating devices to the context entities. When the developer creates the application, he or she can select, which devices will be used for the context computations. These devices can be annotated using the ontology editor IDE to the relevant context entities. Then, in the application logic implementation, it is possible to call pre-implemented and parameterised ontology search services. The parameters of the query are formulated in a specific notation developed for the purposes of simplification of the query mechanism. The query is formulated using the IDE (Figure 6), where the developer can simply select, which parameters are searched and which parameters should be retrieved for further processing. The IDE translates the required parameters into the SPARQL query, which is executed against the ontology. The search methods then retrieve all the devices matching parameters to be satisfied.

![Figure 6: Ontology Manager IDE – Query Builder.](image-url)
Semantic devices

Each physical LinkSmart device provides a set of specific services, which can be directly used by the application developer. The concept of the semantic device brings the idea of specifying the application specific behaviour achieved as a composition of several LinkSmart devices organised into complex units (Kostelnik et al., 2008). Simply said, the semantic devices are logical aggregates of devices. Semantic devices can include both basic (physical), but also other semantic devices. Each semantic device is defined by a set of semantic services. Each semantic service is composed by a set of requirements in terms of preconditions. The preconditions are used at the run-time to generate the candidates matching the specified requirements.

At the design-time, the developer has to define and implement semantic device services using the DDK tool. At the run-time, each time the new device enters the application, the semantic devices are rediscovered and the required devices satisfying defined preconditions are automatically tied with the semantic devices.

Implementation of the semantic device is realised as a combination of statically defined devices and the orchestration behaviour. The static definition is used only in the case, when the semantic service has to work exactly with some specific devices. However, this specification does not entail any limitation for using also the orchestrated devices. For example, the developer may decide to create a specific temperature alert device using just some selected thermometers in the room, which have to be specified (thermometers are specified as the concrete devices – static mapping).

At the run-time, the presence of devices in the LinkSmart network may change. When the devices enter or leave the LinkSmart network, the ontology is continually queried and all the affected semantic devices are rediscovered. Each change may cause that some of the available semantic devices are disabled, and some may be enabled for the usage. Furthermore, semantic devices have to ensure real-time orchestration of the embedded devices. Each time when the semantic services are executed, the ontology has to infer the actually presented devices matching the specified preconditions.

5.2.3. Applications and projects

Adapt4EE project (starting in November 2011) aims at augmenting the contemporary architectural envelope by incorporating business and occupancy related information thus providing a holistic approach to the design and evaluation of the energy performance of construction products at an early stage and prior to their realization. One of its objectives is to design and implement an Open Semantic Based Middleware for Integrated Management of Multi-Sensorial Clouds, built upon the well proven Hydra middleware concepts and respective semantics, allowing for integrated, unified and consistent management of all devices comprising the multi-sensorial network as a single organization.

Furthermore, an enhanced Adapt4EE Device Ontology and respective Inference Rules will be produced incorporating Energy Efficiency, Building Information (BIM) and Business Modelling (BPM) aspects. This, among other issues also includes the development of an Adapt4EE ontology for combining business and asset management information with energy profile definitions. Related existing non-
semantic models will be annotated, enhanced or upgraded to advanced knowledge models, like gbXML. The project starts at the beginning of November of 2011.

The BRIDGE project \([\text{http://www.bridgeproject.eu/}]\) (started in April 2011) aims at increasing the security and safety of European citizens through improved multi-agency coordination in large-scale emergency management. The focus is on solutions to facilitate multi-agency collaboration in large emergency relief efforts by enabling data and systems interoperability and providing a common operational picture for such agencies. The project will develop solutions for providing stable network infrastructures and interoperability among network nodes in harsh environments. Such infrastructure must be able to deal with unstable conditions i.e. highly dynamic unreliable networks, breakdown of single network nodes or whole networks. These conditions also lead to the requirement of seamless integration of various heterogeneous devices and interoperability among them. In BRIDGE, LinkSmart will be applied and extended with features of ad-hoc networking and highly dynamic network environments.

The CUBEE project, submitted proposed under CIP ICT PSP, priority „1.2 ICT for Energy Efficiency in Public Buildings“, also intends to build on the HYDRA middleware (if approved for funding). The CUBEE project aims to set-up four pilot sites, in four different European Countries, for testing and validating an innovative ICT platform enabling the reduction of energy consumption, the reduction of up to 15% CO2 equivalent production, improving the use of micro-generation and enhancing the comfort of students and teachers in public Campuses and Universities.

The ebbits project \([\text{http://www.ebbits-project.eu/}]\) (started in September 2010) envisions integration of physical devices, systems and components directly into optimised systems, i.e. managing workflows, people, processes, information and knowledge, and turn them into useful, value-added business services or service components. Its aim is to enable interoperability between various subsystems in manufacturing environments across manufacturing cells, manufacturing lines end entire manufacturing plants, regardless of geographical location with the aim to support production and energy optimization. The LinkSmart ontology models have to be expanded to cover new domains of interest. For example, the device ontology will be extended with new devices and resource consumption models for optimising energy consumption. Service composition and orchestration capabilities will be added to the services ontology and a business process ontology will be developed to enable semantic maintenance of business rules and higher-level business processes. Further, a model for events generated by devices, which may trigger specific activities in business processes will be developed.

The goal of ME3Gas (started in May 2010) is to put consumers in control of their appliances to effortlessly optimize energy efficiency usage without compromising comfort or convenience. ME3Gas specifically addresses reduction in energy usage and CO2 footprint in households. ME3Gas will use real-time energy information as energy-awareness services for all residents and combine household specific services with a community portal. ME3Gas will extend the LinkSmart middleware to develop an energy-aware middleware platform providing necessary functionality and tools to add energy efficiency features to device networks. It will build on the LinkSmart SeMDA extending existing ontologies with information about the domain and energy efficiency.
**SEAM4US** (starting in October 2011) aims at developing advanced technologies for optimal and scalable control of metro stations. The project’s main outcomes will be the creation of systems for optimized integrated energy management, and the development of a decision support system to drive mid-term investments. SEAM4US will apply and further extend LinkSmart to integrate energy metering and sensor-actuator networks with existing systems (e.g. surveillance, passenger information and train scheduling), to acquire grounded user, environmental and scheduling data.

**SEEMPubS** [http://seempubs.polito.it/](http://seempubs.polito.it/) (started in September 2010) aims at reducing energy usage and CO2 footprint in existing public buildings and spaces without significant construction works by introducing intelligent energy consumption monitoring and control. Based on the LinkSmart Middleware, the SEEMPubS platform will provide control of appliances to effortlessly optimize energy efficiency without compromising comfort or convenience for end-users. LinkSmart will be used to integrate existing building management systems and sensor networks with new technologies to be developed within the scope of the project. An energy efficiency ontology will be developed dealing with the requirements of heterogeneous sensing and control devices and systems including building management systems (BMS), wireless sensor networks (WSN) and smart meters. The system will be installed and evaluated in a large university, bringing with it diverse domain specific requirements regarding usage of rooms, numbers of people, usage of appliances, etc.

### Conclusion

We presented the LinkSmart middleware for developing AmI applications. LinkSmart solves the compatibility issues in AmI applications by abstracting heterogeneous devices and communication protocols. Introducing the Semantic Model Driven Architecture, LinkSmart provides semantic interoperability between devices and services. Furthermore, decoupling the application development from the device programming brings advantages with regard to modularity, reusability and extensibility. Application developers also benefit from this separation as they are faced only with web service interfaces instead of a broad range of communication protocols.

Besides the functionality presented in this paper, LinkSmart offers a set of extended features such as security, context awareness, quality of service, distributed storage, etc. These features help application developers build high quality applications within a short time.

Currently, LinkSmart as a middleware is being reused, applied, and further developed in a couple of European projects within different domains.

### References


6. Session: Middleware for EupP (Energy using or producing Products), White goods, HVAC, Storage and Micro Renewables

6.1. Paper: Middleware for energy aware appliances

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Abstract

Efficient energy consumption, intelligent monitoring and interactive control of energy consumption in homes/residential buildings, as well as the control of energy consumed outdoors, in public or private areas are key factors to Europe’s ambitious goals of sustainable development, reduction of energy demand peaks and activities related to avoidance of climate change effects. This paper proposes a solution to this problem based on minimizing white goods’/consumer electronic devices’ energy consumption, balancing energy distribution and thus saving energy and reducing the service cost of the power distribution network. The basic issue in energy control is the seamless monitoring of the various energy consumption elements and devices, as well as the scheduling of their operation in order to minimize peaks, balance loads, and ultimately achieve predictable large-scale energy-consumption profiles. This paper describes our experience on the development of a user-friendly/consumer-centric middleware platform based on the OSGi framework for the control and scheduling of operation of energy-consuming appliances and service providers’ access equipment. The proposed solution implements an innovative appliance control system that presents options for optimizing appliances’ operation and scheduling of events. It is also able to act automatically in a single-building level depending on the model of the building embedded in the controller.

Keywords: Energy-efficient buildings, Home Automation, Load Shifting, Demand Side Management, Optimization
6.1.1. Introduction

In this paper, we propose a home automation system (together with a wider ICT infrastructure resembling in certain respects a smart grid) with the goal to target environmental sustainability, energy efficiency and new contract business models in the retail side of energy distribution. Our aim is to design, develop and evaluate an innovative, energy-aware and user-centric solution, able to provide intelligent energy monitoring/control and power demand balancing/shifting at home/building & township level. The goal of our system is to interconnect legacy professional/consumer electronic devices with a new generation of energy-aware white-goods, where multilevel hierarchic metering, control, and scheduling will be applied, based on power demand, network conditions and personal preferences.

Our solution combines innovation in a number of areas:

- **Intelligent personalized energy-management/control and small-scale power demand balancing platform**: Different users have different priorities, preferences and needs and consider the energy commodity from different viewpoints. The idea of intelligently controlled appliances has been found in market research studies to be very appealing to the greatest percentage of consumers, with at least 70% of consumers inquired finding the idea "interesting" or "very interesting" (B/S/H 2007) yet it is at the same time recognized that the right balance has to be struck between either taking too many unwarranted decisions or requiring intensive user engagement. Both extremes are unwelcomed by home consumers. The solution we propose is balanced and at the same time goes beyond mere automation by including demand-side management features and delivering electricity bill benefits to the consumer (assuming time-varying energy tariffs).

- **Smart Buildings**: Efficient energy management in buildings requires extensive use of communication network infrastructure as well the provision of the necessary interfaces to home appliances, local distributed generation and energy and service providers.

- **Electronic marketplace for energy**: The introduction of Smart Energy Grids and deregulation is resulting in a transformation of the European energy market. New players are appearing and the roles of incumbent players are changing. An electronic marketplace for energy must provide the necessary interfaces and information exchange mechanisms. It should also be open to support new applications, players and roles.

- **ICT-related improvements to white goods’ power consumption**: According to research performed by CECED (2001) domestic appliances in the 15 EU countries in 2001 consumed about 250 TWh of electrical energy in year 2000 - about 30 TWh less than in 1990, due to the improvements of the efficiency of various products. From an architectural perspective, we envisage that all home appliances (including white goods) include ICT enhancements. This will allow the home automation software we propose to control them over open interfaces.

- **Small scale renewable energy resource integrated with home network**: Our solution takes advantage of the opportunity to reduce energy consumption and CO\textsubscript{2} emissions at home level by integrating a CPS panel, which produces energy and hot water (Giaconia et al. 2009).
CPS offers two more levers (local energy production and hot water) for energy management in order to maximize energy and environmental savings at home (Di Dio et al. 2009; Miceli et al. 2009). Clever scheduling of washing machine cycles when the temperature of hot water in the pipes is estimated to be higher (due to the solar panel) is an example of how synergistic ICT-related benefits can decrease white goods power consumption.

6.1.2. The proposed business model

In a deregulated electricity market where multiple electricity companies compete for customers, the need for service/product differentiation to avoid commoditization and price-only-based competition is even more pronounced (Clarkson 2006).

Presently, in the typical case when no demand-side management solution is implemented, the relationship between the electricity company and the electricity consumers is a clean-cut producer-consumer relationship. When demand-side management is introduced the picture gets a bit more complex in that the entity responsible for the demand-side management could be the electricity company itself or another entity (e.g. the grid administrator). In a typical de-regulated electricity environment there can be many electricity producers feeding power into the grid, but the grid as a whole is a shared resource managed by the grid administrator and the stability of the grid is something that affects all market participants.

The proposed business model (or rather the proposed business model framework) is even more complex in that it introduces three additional points:

1. **Demand side management and load shifting takes place by utilizing a whole array of measures**: not just the cents/kWh price of energy but many different incentives/counterincentives that can influence (with varying degrees of effectiveness) electricity demand. Moreover, these measures are modified at real time. Such measures (in addition to the sell price of energy), can include a power ceiling, a penalized power ceiling (above which a surcharge is applied to the price), the buy price of energy, and others.

2. **Communications infrastructure**: in contrast to traditional demand-side management solutions which view the user as part of the market-driven response loop, in our solution the communication of the incentives/counterincentives takes place through an ICT infrastructure and it is taken into consideration not by a human user (who would be swamped by all this influx of information) but by a software module (the Home Energy Management System Scheduler).

3. **Households as energy producers**: we allow households to be themselves energy producers. Incentives propagated from the grid administrator can include time-varying inputs not just for the “sell price” of electricity, but also for the “buy price” meaning the system is not strictly demand-side management but can also influence a (small but potentially critical) component of the supply side.

Given the above, Table 1 that follows juxtaposes the proposed “Business Model” with traditional demand-side management business models in the electricity retailing business. Note that in what we
term “traditional way” we do not consider the case of direct load control by the electricity retailer / grid administrator as our focus is on non-compulsory approaches.

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Traditional way</th>
<th>Proposed Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Means available to shape demand:</td>
<td>electricity cost (mainly)</td>
<td>electricity cost, but also others</td>
</tr>
<tr>
<td>Measures influencing demand ...</td>
<td>... are announced on traditional media outlets and are received and acted upon by humans or can be fixed in a static contract structure</td>
<td>... are published in electronic format (web-services) and are acted upon by software</td>
</tr>
<tr>
<td>Decisions in response to these measures ...</td>
<td>... are taken by humans (consumers) after they have been announced using traditional means (radio, TV, human-readable web pages) and are effected by manually interacting with the appliances usually locally but perhaps also remotely</td>
<td>... are taken by the Scheduler software (running on behalf and under the broad outlines / directions set by the consumers) after receiving notification of incentives / counter-incentives through a web services interface</td>
</tr>
<tr>
<td>Burden of “optimization” ...</td>
<td>... is borne by the home consumer</td>
<td>... is transparent to the home consumer and is borne by software</td>
</tr>
<tr>
<td>Updated measures with the goal of influencing demand can be sent ...</td>
<td>... not too frequently (usually daily) considering that human users will need to learn about them using traditional media channels</td>
<td>... very frequently considering that the software is always “on” and is always “listening”</td>
</tr>
<tr>
<td>Complexity of measures ...</td>
<td>... must be low enough (usually price hikes) to allow the users to comprehend the effect their actions will have on their monthly bill and to make obvious the kind of behavior expected</td>
<td>... can be arbitrarily complex since an optimizing scheduler will be used to find out the optimal solution</td>
</tr>
</tbody>
</table>

Table 1: Juxtaposing traditional demand-side management with the proposed approach.

6.1.3. The proposed Conceptual Model for Demand-Side Management

With the risk of oversimplifying, the diagram in Figure 1 that follows depicts the concept proposed to achieve demand-side management.
Figure 1 is an abstract diagram yet it still identifies the key properties underpinning the proposed approach. We refer to Figure 1 as the Monitoring and Control System Conceptual Model ("MCSCM"). Each plane of the MCSCM corresponds to a certain scope for control. At the base plane of the hierarchy the entities on which control is exercised are more localized, consisting, usually of single, discrete appliances. As we move up the hierarchy planes, the scope of control becomes broader extending to apartments / homes, buildings, townships and larger geographical regions. Attendant with the change in the location scope is a change in the kind of control that is possible at each plane. Moreover, different actors are envisaged in each layer.

The two key concepts (hierarchical propagation and semantic translation) of the MCSCM are discussed below.

**Hierarchical Propagation.** Propagation of incentives / counterincentives for demand-side management is done in a hierarchical approach. The hierarchy is organized according to spatial scope: from larger geographical regions and agglomerations on the upper layers to neighborhoods, buildings, homes and, eventually, appliances at the lowest level.

**Semantic Translation.** The incentives / counterincentives measures propagate from the higher planes to the lower planes and undergo several "semantic" translations at each plane so as to be consistent with the scope of that plane. For example, a typical propagation / refinement would be the following:

1. a request to lower the total demand on a geographical area gets translated to ...
2. ... multiple requests to lower demand in various regions (cities, neighborhoods) that collectively comprise that area, each of which is further translated into ...
3. ... a set of incentive / counter-incentives, distinct for each home which will (hopefully) influence scheduling decisions and they are ...
4. ... ultimately effected by scheduling household appliances or otherwise modifying aspects of their operation.

Feedback then works its way up in much the same way.
6.1.4. Enablers required

To flesh out an architecture that can support the requirements of the MCSCM described in the previous section the following enablers are required:

- Scalable, easy to use, reliable and secure communication services as the basis for the required Smart Energy control networks,
- Self-configuration and adaptation capabilities at different scales enabling dynamic registration and deregistration of participants,
- Ultra-reliable, potentially cloud-based control services and systems for energy flow control, integrity protection and further advanced applications,
- Easy-to-use and scalable IT-based Energy Management Systems for data collection, control and visualization purposes,
- Development of adaptable IT service portfolios to support the evolution path towards the future Smart Energy scenarios and applications.

A promising approach is to leverage on the Future Internet for most of the reliability, security and scalability requirements and thus develop Future Internet-enabled ICT solutions for intelligent energy management of residential and public buildings. This is the approach of the Finseny project (Finseny 2011) and is depicted in Figure 2 that follows.

![Figure 2: Leverage the future internet to build energy aware ICT solutions for buildings.](image)

6.1.5. The Prototype Software Architecture Proposed

Based on the conceptual model of Figure 1 and the vision of Figure 2, Figure 3 that follows depicts the technical prototype proposed.
It is also easy to see that the architecture of Figure 3 is consistent with the MCSCM presented in Figure 1.
Demand-side management is implemented by infusing “intelligence”, understood here to mean ICT-type intelligence in all the levels at which electricity consumption can be meaningfully assessed, monitored, influenced or controlled.

6.1.6. Semantic Interoperability

Referring to Figure 3, there are two important interfaces related to semantic interoperability within the proposed solution / framework:

- The control and monitoring interface with the actual home appliances (IF 1 in Figure 3)
- The home-grid interface (IF 2 in Figure 3).

These two interfaces and the data models they comprise are described in the sections that follow.
Appliance Control Interface

Appliances’ APIs are intended for monitoring and control of the various appliances from the Scheduler application. I.e., the APIs, which the Scheduler uses to monitor the status, get information about instant power demand (and energy spent in some cases) and control of the appliances. Appliances controlled by these APIs are: Washing Machine, Dishwasher, Refrigerator, Energy aware Smart Plug (Watcher), Smart Meter (Subscriber Meter) and CPS (Combined Photovoltaic Solar).

APIs and data model definition has been guided by four principles:

1. Simplicity - the basic APIs necessary to fulfill devices monitoring and control from the Scheduler have been defined. Extra functionality the devices might offer is not included in the framework and should be defined as extensions of the basic APIs.
2. Clarity - method and parameter names are sometimes lengthy but clearly describe the semantics and are consistent with standard Java language coding conventions.
3. Consistency - the same approach is used in all the interfaces and uniform naming conventions have been used for methods and parameters.
4. Generalizations when applicable - use of interface inheritance to capture commonalities between interfaces.

The class diagram of Figure 4 depicts the inheritance relationships among the appliances’ interfaces.
The diagram of Figure 4 follows standard UML class diagram conventions except with regard to the coloring which is only done to make the inheritance relationships more readable. The actual interfaces are defined in Java and are available to system integrators as a self-contained OSGi bundle or Java JAR file to simplify integration. They are described in detail in (BeyWatch Consortium 2011).

**Home / Grid Interface**

This information flow is used to allow the Coordinator to update critical contract parameters in a Scheduler. Such critical contract parameters include the energy price, the power ceiling for the household as a whole and other more nuanced parameters. By updating these contract parameters the Coordinator can hope to influence the energy consumption behavior / patterns in a household and thus (when taking into consideration all households so influenced) implement demand-side management and load shifting measures on a wide geographical scale. Although the Coordinator can fan-out to an arbitrary number of Schedulers (only limited by practical / network considerations but typically thought to be in the thousands or tens of thousands), the information flow with each one of them is unique, so it is defined in the context of a single Coordinator - Scheduler communication.

**Data Models in the Home / Grid Interface**

The basic data model that is present in this flow is the contract model as the main purpose of this flow is to update critical parameters of that contract. The contract model is a purely conceptual entity that can have many possible technological bindings, all semantically the same. Possible bindings with which we have experimented include HTTP-based web services following the REST pattern (Richardson and Ruby 2007), exchanging information in the form of JSON objects (www.json.org) or database / JDBC access.

The contract is properly understood as consisting of both a meta-contract and an actual "contract instantiation". The relationship between the two is that at any given moment in time a home is under a specific instantiation of the meta-contract. An instantiation ties the meta-contract parameters to specific values, for the duration of that instantiation. The Scheduler thus experiences, over time, a succession of contract instantiations (all emanating from the same meta-contract).

**Meta-Contract Data Model**

The meta-contract model is defined by the following:

- a list of the contract parameters (e.g. price of energy, power ceiling), together with some reference values, and
- the definition of the mechanism used to constrain the possible variations in the value of each parameter. Variations of course are necessary since this is the way to implement demand-side management measures.

The extent of variations may be constrained both in scope (e.g. the price cannot be hiked more than 25%) and in time (e.g. the duration of price hikes cannot exceed more than 30% of the total time). This limitation is necessary to provide some kind of contract-backed assurance to the consumers that their reference contract parameters cannot be arbitrarily tweaked without any bounds.
Similar constraints are in place for all other contract parameters. It is clear that one can devise many ways to "restrict" the changes in values of these contract parameters. Consider for instance the case of energy price. Possible formulations to restrict changes (in this case hikes) could be:

- Specify a standard hike duration, e.g. 1 hour, and a standard hike percentage, say 25%, and limit the number of hikes per day and / or per week and / or per month. One can also combine this with special rules for weekends.
- Specify a number of standard hike percentages (e.g. 20%, 50%, 100%) and a standard duration for each hike (e.g. 1 day) and again limit the hike instances per hike category per calendar year. Hike percentages can be named ("green days", "red days", "white days").
- Specify a structured, standard variation of energy price during the day (e.g. higher price during typical high-demand time intervals in a 24-hours day) and specify three different baselines to start with. Together with some constraints on the number of high cost days this is similar to the "tempo" tariff system used in France.

The mechanism we have employed and which is described in the remainder of this section is actually flexible enough to act as a superset of all the above mechanics. Table 2 below defines the contract parameters that form part of the meta-contract.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Type</th>
<th>Definition</th>
<th>Typical reference values</th>
</tr>
</thead>
<tbody>
<tr>
<td>buy energy price</td>
<td>Numeric</td>
<td>the retail price of energy for the home consumer</td>
<td>13 cents / kWh</td>
</tr>
<tr>
<td>sell energy price</td>
<td>Numeric</td>
<td>the price of energy at which the grid agrees to buy energy from the home (in case of PV installations)</td>
<td>20 cents / kWh</td>
</tr>
<tr>
<td>power ceiling</td>
<td>Numeric</td>
<td>The total power available to the home. This is a hard limit. Consumption above that limit will not be allowed by the Scheduler.</td>
<td>5 kW</td>
</tr>
<tr>
<td>penalized power</td>
<td>Numeric</td>
<td>The value of power above which a surcharge on the retail price of energy will be applied to penalized further consumption. This is a soft limit. The Scheduler or the home consumer can require more power beyond that limit, but the price of energy will be commensurately higher.</td>
<td>3 kW</td>
</tr>
<tr>
<td>penalized energy surcharge</td>
<td>Numeric</td>
<td>This is the additional surcharge (on top of the normal 'buy energy price') that the consumer will have to pay for the energy whenever the power demanded exceeds the 'penalized power' soft limit.</td>
<td>3 cents / kWh</td>
</tr>
<tr>
<td>forced consumption</td>
<td>Boolean</td>
<td>This flag forces the Scheduler to direct locally produced energy from PV to the home grid as opposed to selling it to the Grid administrator.</td>
<td>false</td>
</tr>
</tbody>
</table>

Table 2: Meta-contract parameters.
Each contract parameter is given, as part of the contract, a reference value, which defines the baseline. To implement demand-side management measures the Coordinator will in all cases move that parameter value in one direction only (either upwards or downwards) for certain periods of time. The direction in which the value is forced depends on the semantics of the parameter. Put simply, in all cases there is only one obvious direction in which the value should move, in order to curb demand. E.g. in the case of price, demand is reduced only if the value of that parameter (i.e. the price) is moved up. In the case of the power ceiling, demand is reduced only if the value of that parameter (i.e. the power ceiling) is moved down. As such, to simplify discussion we will speak in terms of a particular parameter "moving away" from its reference value rather than "moving up" or "moving down" (since the direction should be obvious). Given the above, the mechanism by which demand side management measures are implemented is by having one or more of the contract parameters move away from their reference value for certain durations, within one billing period. Which parameter(s) is (are) tweaked, and by how much, is constrained by limits placed on the area defined in a time plot between the actual value of the parameter and its reference value. This area corresponds to an integral over time. Figure 5 illustrates this concept.

![Figure 5: Calculating discretionary hikes in contract parameter values' fluctuation over time.](image)

The mechanism therefore works by constraining the value of these integrals, per day and per calendar month. Table 3 below provides some typical values in a contract structure.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>discretionary hike per day</th>
<th>discretionary hike per month</th>
</tr>
</thead>
<tbody>
<tr>
<td>buy energy price</td>
<td>200 cent × hour / kWh</td>
<td>4000 cent × hour / kWh</td>
</tr>
<tr>
<td>sell energy price</td>
<td>300 cent × hour / kWh</td>
<td>5000 cent × hour / kWh</td>
</tr>
<tr>
<td>power ceiling</td>
<td>50 kWh</td>
<td>1000 kWh</td>
</tr>
<tr>
<td>penalized power</td>
<td>50 kWh</td>
<td>1000 kWh</td>
</tr>
<tr>
<td>penalized energy surcharge</td>
<td>250 cent × hour / kWh</td>
<td>7000 cent × hour / kWh</td>
</tr>
<tr>
<td>forced consumption</td>
<td>5 hour</td>
<td>100 hour</td>
</tr>
</tbody>
</table>

Table 3: Constraints on the integrals of discretionary hikes (example values).
Contract Instantiation Model

The Contract meta-model is used to create contract instantiations. A contract instantiation simply provides the exact values of the parameters of Table 2 for a specific interval in time (hourly quarters usually). The actual, instantiated values may deviate upwards or downwards from their reference values that are given in Table 2 but the total extent of these deviations must fall within the limits identified as part of the contract (as in the example shown in Table 3). New contract instantiations are created as often as necessary. The Coordinator supplies the Scheduler(s) with many contract instantiations well in advance of the current time (typically for 24 hours ahead) so that Schedulers can schedule appliances in an optimal way. Typically as each contract instantiation covers a span of 15 minutes, it takes 96 contract instantiations to cover the span of a day. Actually, the Scheduler itself has no concept of a meta-contract. Only the Coordinator understands the meta-contract concept (and thus the limits placed on the discretionary hikes). What the Scheduler sees is a succession of contract instantiations for every hourly quarter for the next 24 or so hours. The enforcement of the meta-contract constraints of Table 3 is also part of the Coordinator implementation.

Conclusions

We have presented an ICT architecture that facilitates non-compulsory demand-side management measures under a time-varying electricity tariff system. The architecture manages to reconcile two apparently conflicting goals: control ultimately rests with the human consumer and at the same time the consumer is not overburdened with the need to perform constant optimizations or worry about frequent tariff changes. We have identified the future Internet enablers that can be leveraged to deploy such an architecture and have described the basic interoperability interfaces.

References


6.2. Paper: An EuP Classification for Partially Decentralized Domestic Energy Management

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Abstract

The general problem addressed in this paper is optimal utilisation of renewable energy resources by managing the demand of appliances in private neighbourhoods and small offices/businesses. The core idea is to use wireless sensor/actor nodes to control electrical appliances in a way that local renewable energy resources like wind energy and photovoltaics are maximally exploited. Forecasts for the local renewable energy production are pre-processed by a central energy management unit which generates abstract cost functions. These cost functions might capture also other aspects like tariffs or load forecasts, and are then issued through the wireless network. The final decision making is then shifted to the sensor/actor nodes, and is based on these cost functions as well as the class of the appliance which is controlled. To this end, a classification of electrical appliances is presented which is suitable for the application scenario, and it is discussed how each class can be handled regarding energy management.

Keywords: demand side management, smart grids, classification, energy using products

6.2.1. Introduction

The goal of SmartCoDe (SmartCoDe, 2010) is to provide a wireless communication infrastructure for energy management (EM), or more precisely, demand side management (DSM) in the domestic sector. Wireless sensor/actor nodes are integrated into appliances to enable remote control by an Energy Management Unit (EMU). The nodes have to be cheap (<3€) and small in size (e.g. 1cm•2cm•2cm), in order to make the application attractive both economically and technically. SmartCoDe builds on the ZigBee wireless standard and employs highest-grade information security to ensure robustness against malicious attacks and intrusion.

The general concept of SmartCoDe considers a “local energy resource cluster” with:

- Local renewable energy resources like small-scale wind turbines and building-integrated photovoltaics. Via weather forecasts and other statistical means predictions of the renewable’s energy output are integrated into the energy management process.
- Local energy storage such as car batteries (plug-in hybrids, electric vehicles) which might also provide energy to the cluster if needed.
- Energy using Products (EuPs) such as HVAC, electric lighting, consumer electronics and white goods, whose power consumption is monitored periodically.
The EMU gathers the available data and controls the components of the cluster via the wireless nodes. Since the cluster can also sell energy to the grid, it is necessary to have predictable consumption/production behaviour. A common business model today for large consumers is that they pass their planned or expected load profiles to the grid operator, and are charged according to how far the profiles could be met. Therefore we assume that the local cluster has a certain target load profile to the grid. This load profile might be issued by the customer to the grid operator like described above, but could also be issued by the grid operator implicitly via time-dependent tariffs. It might even change over time due to dynamic tariffs and/or automated negotiations by both parties. Figure 1 shows an overview of the overall scenario.

Figure 1: Conceptual Overview of a SmartCoDe cluster

An important aspect in designing such a system which is suitable for general cases is appropriate abstraction. For the problem at hand, we need a classification of EuPs in our target area (households, small businesses, i.e. not industrial) which covers all relevant cases such that each class can be treated the same way regarding DSM. Thereby we concentrate on electrical appliances.

This document is structured as follows: In Section 0, we present our proposal for such an EuP-classification, where we go into detail on the consequences regarding DSM for each class in Subsection 0. In Section 0 we sketch the overall EM-approach for SmartCoDe, before concluding in Section 0.

6.2.2. An EUP classification with respect to energy management

Figure 2 shows an overview of our proposal for the classification of Energy Using Products (EuP), and Table 1 on the following page goes more into detail. The first three columns of Table 1 contain the class name, the source of the class name, and a brief description of the class. The "Parameters" column contains three sub-columns:

- Configuration: These parameters are updated rarely by the user through the EMU, or by the EMU itself according to a schedule or a policy defined by the user.
- Sensor input: These parameters are provided either by the EuP itself or by the SmartCoDe node's sensor interface.
• Online user input: These parameters are updated frequently by the user directly at the device (possibly through the SmartCoDe node).

Note that only those parameters are listed which are specific to the particular class. There are additional generic parameters which are relevant for every class, like the power consumption of an EuP.

The column labelled "Action" gives an outline on how this EuP class could be handled by SmartCoDe depending on the parameters. The actions are described in a way that leaves open which part of the action is handled by the EMU and which part is handled by the SmartCoDe node. For example, the action described for the class VARSVC (which effectively constitutes a control loop) could be handled by the SmartCoDe node itself. It also leaves open the question of how far SmartCoDe parameters are used for the handling of the specific device. The last column gives some examples of EuPs falling into the respective class.

Relevance regarding Demand Side Management

In this section we discuss what leverage each of the classes provides regarding DSM. From a practical point of view, the two most interesting classes regarding demand side management are VSTSVC and SKDSVC.
**VSTSVC**

The advantages and properties of virtual storages like freezers or heaters are well known, see for example (Kupzog & Roesener, 2007) or (Malik & Cory, 1997). The core idea is to cool down (resp. heat up) in favorable times (e.g. when wind energy is abundant or grid energy is cheap), such that the appliance can be turned off in unfavorable times. This is possible since the (virtually always thermal) services provided by VSTSVC EuPs is inert enough. However, the time frames involved can reach from several minutes (fridge) to even a day for large building air-conditioning. Forecasts on the energy conditions are not essential for DSM of VSTSVC EuPs. They can react instantaneously to changing conditions, unless they are at the “opposite end” of their boundary conditions, e.g. fully cooled down to their lower threshold already when the solar panel output increases. If energy forecasts are taken into account, such circumstances can be avoided. However, a temperature forecasts must be used also in order to make control plans.

**SKDSVC**

The idea of using EuPs with a schedulable service (like washing machines or dishwashers) for DSM is simple: In addition to a program, the user inputs a latest stop time until the service has to be finished. Then the program is started within this time frame such that the runtime lies within favourable energy conditions. This can be done effectively only if a forecast on the energy conditions is available. Also, having a typical load profile available for the specific program is helpful for planning, since SKDSVC EuPs will seldom draw a constant load when they run. A washing machine, for example, has typically a load peak at the program start, when water is heated up, and at the end of the program during centrifuging.

In principle, it would even be possible to interrupt a specific program. However, this might result in a quality loss in the respective process (e.g. washing clothes). Measurements like these have to be developed closely with the process experts, i.e. the white goods manufacturers. At the moment, we only consider to run a specific program completely once it’s started without any interruption.
<table>
<thead>
<tr>
<th>Class Abbrev.</th>
<th>Description</th>
<th>Sensor input</th>
<th>Online user input</th>
<th>Action</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>SKDSVC</td>
<td>schedulable service</td>
<td>The EuP provides a service which runs for a certain time and can be scheduled within a certain time span.</td>
<td>runtimes &amp; power profiles of the different programmes</td>
<td>earliest start time, latest stop time</td>
<td>washing machine, dryer, dishwasher, baking machine</td>
</tr>
<tr>
<td>VSTSVC</td>
<td>virtually storableservice</td>
<td>The EuP provides an inert service which can serve as a virtual storage.</td>
<td>interval defining upper &amp; lower tolerance bounds</td>
<td>value describing the current state of the service, mostly temperature</td>
<td>current user demand</td>
</tr>
<tr>
<td>VARSVC</td>
<td>variable service</td>
<td>The EuP provides a service which might vary due to user interaction and/or daytime.</td>
<td>interval defining upper &amp; lower tolerance bounds</td>
<td>value describing the current state of the service, e.g. illuminance</td>
<td>current user demand, lighting controlled by illuminance level (e.g. in garden, at entrance), dimmable lighting, blinds</td>
</tr>
<tr>
<td>ETOSVC</td>
<td>event-timeout controlled service</td>
<td>Device is switched on and kept on by sensor events, and switched off in absence of sensor event.</td>
<td>absence time span for switching off</td>
<td>event, e.g. presence detection</td>
<td>lighting controlled by presence detector (e.g. on corridor)</td>
</tr>
<tr>
<td>COMCON</td>
<td>complete control</td>
<td>Charging and using up power decoupled; latter only restricted w.r.t. time slots &amp; minimal service.</td>
<td>minimal runtime per time span, time slots</td>
<td>current charge status</td>
<td>robot vacuum, robot lawn-mower</td>
</tr>
<tr>
<td>CHACON</td>
<td>charge control</td>
<td>Charging and using up power decoupled; latter is mostly (or solely) user-dependent.</td>
<td>charging policy current charge status, device presence</td>
<td>device removal</td>
<td>battery &amp; cellphone chargers, hand-held vacuum, emergency backup storages</td>
</tr>
<tr>
<td>CUSCON</td>
<td>custom control</td>
<td>Device does not fit into other classes, therefore custom control by user and/or EMU.</td>
<td>non-user demand / EMU demand</td>
<td>SmartCoDe does not control the device except through direct user-input or EMU control</td>
<td>HiFi, PC, Oven</td>
</tr>
</tbody>
</table>
CHACON and COMCON

Regarding DSM, battery chargers are somewhat in between VSTSVC and SKDSVC. On one hand, they can be regarded as providing a service (the charge status), which only deteriorates marginally when the charging is stopped; this resembles VSTSVC. On the other hand, the ultimate goal is a full charging, possibly until a certain deadline. This aspect is more like SKDSVC, especially when keeping in mind that the charging process might even exhibit a specific load profile; see e.g. (Dung & Yen, 2010).

Depending on the rechargeable battery technology it might not be advisable to interrupt the charging process once it has started (battery lifetime issues), i.e. the safest strategy is to plan charging in one go according to an energy forecast, taking specific charging profiles into account. Therefore, CHACON EuPs can indeed be treated like SKDSVC. However, with a more detailed knowledge on the battery’s characteristics, more elaborate schemes can be developed.

An interesting variation of CHACON is the COMCON class, which encompasses robotic services where the EMU can have complete control on when to charge and also when to use up the stored energy. A good example here is a robot-lawnmower which could be controlled such that it mows the lawn of an estate completely on average every two weeks, scheduling the charging and mowing according to energy availability and cost. We won’t work out details on DSM of such robotic services in the project, since they are still very exotic, and there are also many ways to trigger the operation (e.g. sensors, minimal duty cycles or user demand) depending on the precise application. But it is obvious that this class could provide an excellent leverage regarding DSM.

VARSVC and ETOSVC

We collect these two classes together here since they mostly cover lighting applications, although fans fall also into the VARSVC class (the cooling effect is not inert), and e.g. a public message screen controlled by a presence detector would be part of the ETOSVC class. For our typical application scenario, a household or office in the European Union which is connected to the public grid, VARSVC provides virtually no leverage regarding DSM. While it would be possible in general to dim lights according to the current energy conditions, it is unlikely that the typical user in this scenario would tolerate that. However, this may be different in islanded scenarios (i.e. with no grid connection), where such unpleasantness might be tolerable to ensure more vital operations like fridges.

The DSM possibilities of the ETOSVC class are minimal regardless of the scenario. The only possibility would be to manipulate the timeout-thresholds according to the energy conditions. Therefore, we foresee no cost-function dependent EM for VARSVC and ETOSVC in SmartCoDe. However, the basic approach in these classes, e.g. dimming lights in order to exploit natural light and using presence detection is energy-saving per se. Also, the two approaches could be combined.

CUSCON

This collects all these EuPs which won’t allow for automated DSM activities, mostly because of high user interaction. While we don’t foresee cost-function based EM, we still allow for the EMU to switch CUSCON EuPs directly. That way, the user can still define custom EM schemes, or even use the
SmartCoDe infrastructure for safety purposes, e.g. switching off an oven when no one is present in an apartment.

**Technical and legal limitations of EuPs**

For some EuPs, there might be limitations regarding how often they can be switched on and off:

- Fridges can break (compressor failure) due to too high switching rates.
- Certain lamp types (e.g. high pressure lamps) have time limits for switching them on again after the last switch off.

For other types of EuPs, certain requirements regarding the duty cycle might need to be met:

- Boilers might be obliged to heat up water to certain temperatures in certain limits for hygienic reasons (e.g. 70° C once a week to avoid Legionella contamination, see (Deutscher Verein des Gas- und Wasserfaches e.V., 2004)).
- Water pumps might need certain minimal operation (e.g. once a week for one minute) to avoid jamming even if the water they pump is not needed.

These limitations have to be considered when necessary, but will not be explored further here. In general, they will result in extra boundary conditions to be incorporated into the energy management process.

6.2.3. A partially decentralised DSM approach

From the previous section it becomes apparent that the EMU has to have a somewhat detailed knowledge of the EuPs it controls, depending on the EuP class and the application scenario considered:

- load profiles of different programs
- temperature characteristics
- battery charging policies and load profiles
- minimal/maximal duty cycles

That is, the EMU basically has to maintain a “virtual copy” of the SmartCoDe cluster with respect to the relevant parameters. This, in turn, would result in a significant overhead every time an EuP is removed, replaced or added to the cluster.

Therefore we propose a partially decentralised approach where the EMU issues abstract cost functions on which the SmartCoDe nodes act autonomously. That way the EMU does not need to care about the class specific conditions and DSM strategies, since these are handled by the wireless node software locally at the EuP.

The idea of the cost function is that it provides abstract energy costs for a certain future time period, taking into account tariff, forecasts of local energy production and even power consumption forecasts based on usage statistics. For example, the abstract energy cost for a certain time span might be minimal even if the grid tariff during that time is at a maximum because the local power production is so high (e.g. a sunny & windy day) that it covers the lot of the possible local power consumption.
The SmartCoDe nodes now take this abstract energy cost figures into account regarding their local control decisions. Figure 3 shows how this would work with a heater as a representative of the VSTSVC (virtual storages) class. Basically, the algorithm is a simple bang-bang control, but the heater is switched on resp. off earlier if the cost function suggests this. It tries to avoid heater activation in costly times, and tries to turn it on in cheap times. To this end, it makes use of an internal forecast for the temperature it controls.

The format of the cost function is straightforward: It has a starting time, followed by several pairs of a time period and the value the function has during that period. That is, we describe the cost function as a step function. This is basically a generalization of the load control event in ZigBee Smart Energy (ZigBee Alliance, 2008); the abstract energy costs there are expressed as criticality level.

Figure 4 shows how the cost function approach fits in the global DSM strategy of SmartCoDe. To manage load balancing, we have to use several cost functions. That is, each cost function "controls" a certain subgroup of the EuPs. $E_1, \ldots, E_n$. This avoids the severe imbalances that might be caused if a large number of EuPs obey to a single cost function. The EuP grouping (with possible dynamic re-grouping) has to be done by the EMU.

Since we want the EMU to need as little knowledge as possible about the specific EuPs, it also does not know how an EuP reacts on a cost function. In the case of VSTSVC, for example, this would involve knowing the current temperature managed by the EuP. Therefore, we foresee the EuPs to report an estimate of the future power consumption. The idea is as follows: when the wireless nodes get their cost function, they make a control plan for their EuP for a certain time interval. Out of this control plan, they can then compute the expected power consumption, and pass this information on.
to the EMU, possibly together with a record of the past power consumption. This could be realised as a simple load-profile, again expressed as a step-function. The EMU can now take these power estimates into account when computing the next round of cost functions.

The exact format of tariff $t$ and the forecasts $f_1, \ldots, f_r$ (for the renewables power output) are of no concern here. Indeed, an advantage of the cost function approach is that it is independent of tariff models, forecast formats and even optimisation targets. Any changes there only have to be implemented in the EMU, the cost function format and the node algorithms can stay the same.

Another important advantage of this partially decentralized EM approach is that the control decisions for the respective appliances can be prepared by those with the most competence for that task: the manufacturers. While they have to adapt to the communication infrastructure (e.g. ZigBee wireless communication and the interfaces), the implementation of the control algorithm lies completely within their hands; they just have to take one more parameter into account: the cost function. Therefore, the needs of the particular EuP (like those listed in Section 0) and the service/process they provide can be addressed better than by a 3rd party EMU. In fact, from discussions with white good manufacturers it became apparent that they reject the notion of outside 3rd party control of their products, such that our approach should be largely acceptable for the industry.

**Conclusion and future work**

In this paper we presented the classification of Energy using Products (EuPs) used in the SmartCoDe project. The classification is specific to our application scenario in the domestic / small business area with renewable energy resources nearby but a usual public grid connection also available. We outlined the options for demand side management (DSM) for each class, and sketched a partially decentralised energy management (EM) approach where part of the control decision remains with the
wireless sensor/actor nodes within the EuPs. This also leaves the EuP-specific parts of the control in the responsibility of the manufacturer.

Future work will include working out the details of the partially decentralised EM concept. This includes handling the big control loop in Figure with an appropriate controller in the EMU, which raises several questions and issues, for example:

- What are good time frames for cost functions updates?
- In how far has the class of an EuP to be considered by the EMU-controller?
- How can stability issues be avoided?
- How can we ensure robustness against bad/imprecise forecasts regarding energy production (renewables) and energy consumption (EuPs)?
- How can we communicate power consumption flexibility from EuP to EMU?

To evaluate our approach and tackle these questions, we use a SystemC-based simulation environment which is also used for virtual prototyping and software development, and a real-life demonstrator will also be built.

Acknowledgements

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References


[5] SmartCoDe. (2010). *SmartCoDe - Smart Control of Demand for Consumption and Supply, EU-founded project (FP7)*. Von www.fp7-smartcode.eu abgerufen


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Abstract

One of means of reducing CO₂ emissions for individual household is to adopt sustainable energy lifestyles. Lack of information, however, on energy consumption of electric appliances and other sources increases the difficulty in motivating households to adopt positive ecological behaviour. This is compounded with deficiency in provision of recommendations on conserving energy. One of the key objectives of The Digital Environment Home Energy Management System (DEHEMS), which is an EU funded project, is to monitor energy consumption across a wide range of households and analyze the energy consumption data in order to give users relevant real-time recommendations to conserve energy. This leads to a need to process and convert the collected energy consumption data into meaningful information and semantics, which can be reasoned over with other services to derive appropriate advices. This paper gives an overview of a semantic system with various semantic services, which have been developed in the project to address the above issues. This paper also reports lessons learned from implementing and deploying the system.

Keywords: Energy-efficient buildings, Energy conservation, DEHEMS project, Domestic energy management.

6.3.1. Introduction

The consumption of energy generated from fossil fuel is directly linked to emission of CO₂ gas, which is a major contributing factor to global warming. Initiatives like United Nation sponsored Kyoto Protocol (Kyoto 1997) which legally binds the member states to reduce greenhouse gases and European Climate and Energy Package agreed by EU to reduce greenhouse emission in EU by 20% by 2020 (EU 2007) came into existence aiming at addressing the issue of global warming. Any attempt to deal with the issue of global warming requires the reduction in CO₂ emission, which in return requires reduction in use of energy generated by fossil fuel. Global warming and rising energy prices have led to many research and development initiatives to optimise the energy consumption in domestic, commercial, public and industrial sectors. Electrical appliance manufacturer are focusing on developing more energy efficient appliances. EU has made it mandatory for manufacturer that their electrical appliances must carry EU Energy Label. EU Energy Label enables consumers to compare the energy efficiency of appliances.

The presence of the standards and regulation governing emission of CO₂ are alone not enough to effectively deal with the issue of global warming. A comprehensive approach involving communities is
desired to create awareness of global warming and energy consumption in wider public. The DEHEMS (http://www.dehems.org/) focuses on involvement of communities through living labs in order to increase household knowledge of energy saving, reduce carbon footprint and empower them to control their energy consumption.

Household energy use accounts for more than a quarter of all energy used in the UK, but the typical household waste is around a third of that energy each year (POST, 2005). This energy waste is mainly due to lack of visibility of energy consumption and feedback to households. Research shows that direct feedback of energy consumption result in energy savings from 5% to 15% (Darby 2006). Our focus in this paper is on energy management in domestic environment. It is crucial to provide household with the knowledge of their energy consumption in order to influence their behaviour towards efficient energy consumption and create awareness of CO₂ emission. The ultimate goal of the DEHEMS is to make energy consumption of each appliance visible to household in real-time and provide them advice on how to optimise energy consumption of each appliance.

Real time energy consumption monitoring and feedback are crucial to maximise energy efficiency in domestic environment. There are many energy consumption solutions available in market. These solutions range from individual appliance energy consumption monitoring to overall household energy consumption (http://www.microsoft-hohm.com/, http://www.plogginternational.com/). The DEHEMS departs from these solutions by incorporating a semantic system and social aspects through real life conditions by means of living labs. The semantic system plays a role of expert energy advisor by enabling household to get appliance level energy consumption advice in an interactive style dialog as well as proactively generating energy efficient advice based on household energy consumption historical data and neighbourhood energy consumption data.

This paper is organised as follow. Section 2 presents a brief introduction to DEHEMS. Section 3 briefly describes the related work. Section 4 provides a brief description of the semantic system. In section 5, we present the architecture of the semantic system. Section 6 reports on lesson learned and finally 7 concludes the paper.

6.3.2. Digital Environment Home Energy Management System

DEHEMS is an EU funded Framework 7 project which aims at investigating the ways in which state of the art technologies can be used to improve domestic energy efficiency by influencing household behaviour and hence reduce CO₂ emission. The main objective of DEHEMS is to support households to reduce their energy usage through better management and analysis of their energy consumption. The DEHEMS employ a sensors network of energy consumption measuring sensors to measure energy consumption at appliance level. The sensors collect energy consumption data of electrical appliances every three minute and send the data to a local data collector, which in turn forwards the data to the central server using broadband connection. The DEHEMS also employ gas consumption measuring sensors in order to measure gas consumption of space heating, water heating and cooking.

The sensors attached to an electrical power consuming appliances has sensory, limited computation, and wireless communication capabilities. These sensors form a Zigbee mesh network and a coordinator node coordinates the communication between data collector and sensor network.
Each sensor in the network has a unique identity that is used to identify its associated appliance. This identity is sent to the central server along with every energy consumption reading to enable the server to identify each appliance data uniquely.

The central server stores the energy consumption data over a long period in order to enable the households to view the history of appliances level energy consumption and enables the recommender subsystem to generate efficient usage advice based on appliance level energy consumption data.

DHEMS allows the household to perform following major tasks:

- View energy consumption data at appliance level in real time and historical data
- Current and historical information is stored in central database allows trend analysis and comparative features across any time of period.
- Set weekly/monthly energy consumption targets
- Browse the tips on ways to save energy
- Manage profile for participation in neighbourhood comparison of energy consumption
- Compare energy consumption performance with similar households in the neighbourhood
- Get alert regarding energy consumption targets and appliances abnormal energy consumption behaviours
- Get appliance level energy consumption advice from semantic system
- Share energy consumption experience with other households
- Sends automatic notifications of excessive energy usage

6.3.3. Related work

Several research efforts have been carried out in recent years to design smart home environment where various appliance forms home area network, such smart home environment provides ideal infrastructure for home energy management systems. Home automation technology and ubiquitous wireless communication protocols provide a great potential for home energy management systems to be included in smart home environment. Such an automated environment provides supporting infrastructure for home energy consumption monitoring systems. A number of initiatives have been started recently in an attempt to deal with the issue of energy management.

Control4 has introduced EMS100 energy management system to facilitate a two-way communication between utilities and their customers. Utilities can use real time energy consumption data of consumers to effectively manage demand while customers can reduce energy use and costs by controlling how and when specific devices in the home use power (http://www.control4.com/energy/).

Cisco offers Cisco Home Energy Controller (HEC) which is part of the Cisco® Connected Grid portfolio of solutions for the smart grid (http://www.cisco.com/web/consumer/pdf/white_paper_c11-606976_v3.pdf). HEC enable utility’s customers to view and control smart appliance and smart plugs in their home. It communicates energy consumption data to smart grid network; and receives and reacts to utility demand-response requests.

GreenWave offers a home energy management solution called Reality (http://www.greenwavereality.com/solutions/). This system enables utilities to enhance the value of smart meter deployments by providing consumers an affordable, secure, and easy-to-use system to
gain a more comprehensive understanding of their energy consumption. It incentivizes the customers to move their demand from peak to off-peak periods.

Intel’s intelligent home energy management platform is based on the Intel® Atom™ processor and it offers energy management in domestic environment (http://edc.intel.com/Applications/Energy-Solutions/Home-Energy-Management/). It uses smart adaptors to enable existing appliances to communicate wirelessly with an electronic dashboard. Energy consumption of each appliance can be viewed on dashboard. Unlike these systems DEHEMS focuses on management of energy consumption at appliances and influencing household behaviour through feedback and advice.

AIM is a FP7 funded project (http://www.ict-aim.eu/) for design and implementation of a system that aims to minimise energy waste in a domestic environment. In contrast to DEHEMS, the focus of the AIM is to exploit the use wireless sensor monitoring network to control home appliances according to user profiles (Barbato 2009).

Sarnadas et al. proposed architecture for home energy appliances management and control (Sarnadas 2005). Their proposed system is more focused on use of hardware components such as sensors, actuators, and communication network to manage energy consumption in home environment. Another strand of research focuses on providing intelligent interfaces to increase awareness of energy usage and hence influence the household’s behaviour (Karlgren 2008, Wood 2007).

In February 2009, Google introduced its free Web-based energy monitoring tool called PowerMeter (http://www.google.com/powermeter/about/about.html). San Diego Gas & Electric in collaboration with Google PowerMeter gives its customers access to their energy information through Web. In a way Google PowerMeter provides web-based interface to energy consumption measured by a smart meter.

There are a number of freely available web-based tools for providing householders advice on their energy consumption (http://www.imeasure.org.uk/index.php, http://www.microsoft-hohm.com/) but these tools heavily rely on users’ manual input and provide common sense advice on efficient energy use. There are also a number of commercial ICT based energy management systems available (http://www.plugwise.com/en/domestic/home-use, http://www.agilewaves.com, http://www.plogginternational.com/). These tools and systems broadly focus on issues of energy consumption monitoring, displaying energy consumption data and basic statistical analysis of the data. On the other hand, the goal of the DEHEMS is to empower household in use of their energy consuming appliances by increasing visibility of energy consumption data and providing intelligent advice on their energy use based on their profiles and appliances profiles.

6.3.4. Semantic System

The semantic system is composed of subsystems, which operate cooperatively in order to broadly provide following functionality.

a. Allow household to view alerts concerning their energy consumption targets and other abnormal energy consumption by appliances and possible remedial actions/advice
b. Allow household to rate energy saving tips and submit their thoughts and experiences on efficient energy consumption

c. Enable household to browse energy saving tips based on various grouping such as cooking and washing etc and also individual appliance level

d. Upon household login display more personalized and useful tips

e. Provide interactive menu for households, which allow them to interact with system by providing answers to various questions concerning missing information in the system. It works like a diagnostic tool and tries to find the underlying causes of abnormal energy consumption

A high-level view of semantic system and its place in DEHMS is shown in Figure 1. In terms of implementation, the semantic system draws upon ontology for domain knowledge representation, expert system for intelligent reasoning, SQL Database for data storage and management, Java Enterprise Edition for server side programming.

Figure 1: High Level View of Semantic System

The operation of the semantic system is organised into three layers, known as service demand layer, service broker layer and service provider layer. The demand layer receives input from household and
translates the request to machines understandable goals. The role of the service broker is to take the system goals and translate them into services required to achieve machine readable goals generated as a result of household request. The service provider provides the services required by the broker in order to meet the desired goal. For example household send request to system for advice on a percentage reduction in energy consumption. The broker layer sets the request as a goal and identifies the services required for fulfilling this goal. The broker considers various options for fulfilling this goal based household’s appliances and neighborhood comparison. The provider layer is then activated by broker layer with various service requests. The provider layer consists of system enabling capabilities of accessing to appliances consumption data, appliances sensors and actuator (household may act as actuator). The semantic system uses mixed initiative interaction and brings household as an actuator in control loop whenever necessary.

6.3.5. System Architecture

Semantic system architecture provides a conceptual framework view of the system. The semantic system architecture is shown in figure 2.

The main architectural components are data server, knowledge and reasoning. The components of the architecture are described in the following subsections.

![Figure 2: DEHEMS semantic architecture](image)

**DATA SERVER**

High resolution energy consumption data from appliances causes performance degradation problem and real time data cannot be efficiently processed for the recommending system. In addition,
statistical or rule-based reasoning over a large amount of data is often a time and resource consuming process. These constraints bring the difficulty to satisfy the efficiency required by real-time applications. In order to enable efficient reasoning high resolution data needs to be summarised for the recommender system to produce energy efficient recommendations. The nature of the application requires having both real time energy consumption data and summarized data in order to meet real time data demand from household and aggregated data for recommender system. The data server consists of two types of data: raw energy consumption data and summary data. The real time collection of data in DEHEMS makes it possible to understand correlation between appliances, statistical analysis, intelligent advice generation and various kinds of query support. It also allows householders to see the effect of their energy consumption activities in real time. The amount of the data generated by the sensors grows rapidly. To extract meaningful information from the database is a very resource consuming task. In order to reduce the response time and satisfy the users’ queries, the raw data needs to be pre-processed and analyzed, so the system needs to convert these data into meaningful information and store them in Summary database. The summary data is tagged with the semantic information such as household identity, consumption period, and appliance etc. This enables summary database to be interrogated from different dimensions such as time, household, appliance peak energy usage, the duration, the frequency and so on. We can compare an appliance’s use in a household with themselves based on a specific duration. For example, its average usage over a period of time compared with another period of time to determine if there is any deterioration or improvement. We can compare an appliance in one household with another which has the same appliance to examine if there is any difference in performance or usage. This comparison exploits information available at the social community level.

**REASONING**

The reasoning component provides the semantic system’s core functionalities. JESS expert shell ([http://www.jessrules.com/](http://www.jessrules.com/)) is used to provide reasoning capability. The reasoning component comprise of intelligent interactive system, recommender system and group rating and consensus system.

**Intelligent Interactive System**

The intelligent interactive system has capability to interpret the requests from the households to provide appropriate functions by identifying and composing appropriate services. The goal of intelligent interactive system is to engage user with semantic system and provide energy saving advice cooperatively. In case of abnormal energy consumption of an appliance, the semantic system attempts to identify the possible underlying causes by invoking recommender system. If the cause for abnormal energy usage is not established by the recommender system then the semantic system engages household in interaction with intelligent interactive system to get relevant pieces of information from households. The intelligent interactive system then uses system information in combination with information obtained from household to identify the possible cause of the energy inefficiency. In case, the fridge has consumed energy which is more than the weekly average, in
response to this event the system alters the household and asks the questions in order to identify the underlying cause and to give appropriate recommendations. The system invokes the knowledge base when the user gives the answer. This process continues until all the uncertainties in the knowledge base have been clarified and the right recommendation is concluded.

**RECOMMENDER SYSTEM**

The recommender system proactively provides recommendations on energy saving to the users according to the expectation of energy usage from individual households and DEHEM neighbourhood, the condition of their appliance usages, or environmental variables. It includes a context model to record the norms in energy consumptions based on different groups of households and neighbourhood.

The recommender system attempts to compare energy consumption of similar houses, the similarity criteria includes number of family members living in a house and type of houses. If a household has consumed more energy than the average of its similar type of houses and family, the system starts to look up for possible causes and give them related advices. The recommender system proactively provides energy consumption advice to household, for example on starting of washing machine the system checks weather forecast service provided by Google and generates advice of drying clothes outside permitting the weather conditions.

**GROUP RATING AND CONCESUS SYSTEM**

The knowledge base system contains numerous tips or recommendations for energy saving. Most of the knowledge is only applicable to specific conditions, but some of them are generic. In addition, the appliance conditions or other factors which influence the appliance performance sometimes cannot be determined, so all the possible recommendations will be given. In order to improve the system effectiveness, we ask users to give their feedback on these recommendations in terms of effectiveness, timeliness, and convenience. Therefore, the feedback or comment can be fed back into the system for improvement. Since different users have their subjective opinions and preferences and the process involves multiple evaluation criteria, we adopt the Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) (Chao et. al 2010) method to identify their consensus in order to rank the recommendations. Normally, the top three highest ranked recommendations are shown to the users.

**KNOWLEDGE BASE**

Appliance and Tips ontology provides semantic system with the knowledge required for its effective operations. Both ontologies have been implemented using Protégé tool (http://protege.stanford.edu/). A partial graph of the hierarchy of our implemented appliance ontology is shown in Figure 3.
In development of home appliance ontology, we focus on encoding energy efficiency characteristics of the appliances as much as possible to provide a rich knowledge representation for reasoning tools to not only reason about short-term energy efficiency of an appliance but also provide a long term operational aspects of the appliance energy consumption. For example a washing machine that consumes less energy per cycle but consume more water may not be an energy efficient machine in the long term.

Energy saving tips are encoded into tips ontology. The tips ontology classifies tips into various energy consumption activities and provides semantics to each tip.

The tips ontology is used by the recommender system for generating automatic energy saving advice, and by intelligent interactive system for proving interactive advice and group rating and consensus system for update tips rating based to group consensus. Figure 4 shows the structure of the tips ontology.
6.3.6. Lessons Learned

It is a challenge to observe and influence energy consumption behavior of users in domestic environments. Living labs have proved to be an effective methodology in influencing user behavior towards efficient energy usage. Although the long-term constant user engagement with the system is difficult to maintain, through effective feedback and energy consumption advice over a period of time helps increasing their understanding of energy consumption and influencing their behavior. It was observed that initially some users were motivated by money saving while others by saving the planet. Therefore, it is important to accommodate both groups of people in system design and development.

The ontology provides a standard and rich knowledge structure of home appliances, which could be used by variety of problem solvers in home energy management domain to optimize energy consumption and generate timely and context sensitive advice to influence energy consumption behaviors of the households. The developed ontology fits into Suggested Upper Merged Ontology (SUMO) (http://suo.ieee.org/) ontology and serves the objective of providing standard ontology for home appliances.

Various vendors and manufacturers of electrical appliances use their own arbitrary classification instead of using a single standard classification system for home appliances and there exists no uniformity of appliances specifications among these vendors. It is not possible to use such classification by various problem solvers in a unified manner. SUMO provides the solution to this
problem. Also Energy Star rating is still not available for many appliances, it hinder the comparison of appliances energy efficiency using Energy Stars attributes.

Implementation issues involve uses of JESS Expert shell which seems to be heavyweight tool for our purpose. It causes performances issues when used with application server. When using JESS with ontology care must be taken to load only necessary portion of ontology into JESS working memory also JESS memory should be kept clear of unnecessary facts in order avoid performance degradation.

Conclusion

The semantic system presented in this paper is at the heart of DEHEMS. The DEHEMS been has deployed in 250 households in the UK cities of Manchester, Birmingham and Bristol and the Bulgarian cities of Plovdiv and Ivanovo, where each city form a Living Lab. DEHEMS system is developed in three cycles by incorporating users’ feedback into system design from each cycle.

The analysis of energy consumption data collected before and after deployment of the DEHEMS shows that there was 8% reduction of daily energy consumption against baseline of period of 4 weeks (Sundramoorthy 2010). The survey result based on data collected before and after the deployment of the system shows an increased awareness of global warming and energy saving amongst living labs participants.

Currently the appliance ontology is being used in DEHEMS system, and it is not available in public domain yet. We intend to submit the ontology to Standard Upper Ontology Working Group (SUO WG) which will be available in public domain once approved.

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References


Abstract

A key challenge for home/building automation applications, especially energy management, is to enable the indirect integration of legacy home/building appliances and building components that do not have a network connection to the home/building network, to make it possible to monitor and partially control them. We propose a mechanism and system for the iterative identification and self-configuration of these devices through a shared backplane of networked sensors and actuators available in the building. This makes it possible to integrate these devices and interface them through a software proxy as if they were state of the art networked devices, thus extending the range of the network and the associated middleware towards all kinds of physical entities of that make up the home/building. These entities are supposed to be described in a model repository and a domain-specific ontology. The matching of the entities being discovered in the home/building environment to these known models is done by analog pattern matching, instead of requiring an exact match as would be the case with a standard digital networks protocol, so that it lends itself to iterative approximation. The architecture and OSGi-based implementation of this system are described. Examples are provided for typical home appliances and other subsystems of the home/building that may be dealt with in a similar way.

Keywords: Home/Building Automation, Internet of Things, Ontology, Hybrid discrete-state model

6.4.1. Introduction

Home and building automation systems have a decades-long track record, but they have yet to move beyond specialized applications tied to their own dedicated infrastructure. Sharing a multipurpose backplane of sensors, actuators, networks and local server/gateway devices to support a broad portfolio of home/building applications should make it possible to amortize the cost of this infrastructure across the board and to jumpstart the take-up of applications that has, so far, proved vexingly elusive.

Among these applications, energy management has appeared as a new pacesetter, spurred on by the rising cost of energy and the requirement to shrink the carbon footprint of buildings, potentially
warranting the investment in such a shareable open ICT infrastructure for the building. Home energy management services have been taking off slowly, with offerings that are so far mostly limited to energy monitoring or simple load shedding/shifting. Building energy management is more advanced when taken up by energy service companies, but still relies mostly on dedicated infrastructures. The next stage in home/building energy management systems will be towards the integration of all energy-relevant devices, appliances and components of the building in a comprehensive monitoring and control system relying on a shared infrastructure for this.

The ReActivHome project (https://reactivhome.rd.francetelecom.com) aims at designing and prototyping such a comprehensive home energy management system. This system is intended to manage and optimize at the home level the balance between energy sources and loads according to both local and global criteria. This system relies on the monitoring and actuation of these sources and loads through a complete shared infrastructure of sensors and actuators.

The project addresses the home environment, but most of what is put forward here can be directly transposed to the building environment, so that whenever we mention home in the following, it can be usually generalized to building.

A key issue in such a comprehensive home energy management system is how to integrate in the perimeter of the system the energy-consuming, -storing or generating components, devices and legacy appliances of the home, knowing that these do not have any kind of digital interface to a data network, neither for monitoring nor for control, and that setting up such a system should not be made conditional upon an all-out state-of-the-art upgrade of the building and its appliances where such interfaces could be taken for granted. Moreover, this integration should be as automated as possible and should not require a complex and costly manual configuration of the system by a skilled technician (or an extremely savvy and motivated end-user). The inspiration for this spontaneous integration can be in state of the art zero-configuration or network discovery protocols, especially at the level addressed by service-oriented architecture that make it possible to “recognize” devices according to a high-level model, supposed to be known and shared beforehand. How to emulate this spontaneous model-based identification of state of the art digital devices for legacy physical entities is the problem addressed by this paper.

The paper is organized as follows. We describe related work in this area in section 2. Section 3 gives an overview on the principle of the proposed approach and of the models it relies upon. Section 4 presents the overall system architecture. The more detailed architecture of the monitoring and control core component of the system is described in section 5, together with a prototype based on this architecture and experimentation. Finally, we will open a perspective on future work.

6.4.2. Related work

A broad concerted effort has been set up in the past few years to investigate the use of ICT for energy efficiency, under a specific chapter of the seventh Framework Programme. Among these projects we can mention AIM (www.ict-aim.eu/), Beywatch (www.beywatch.eu), and Beaware (www.energyawareness.eu/beaware/).
HOMES (www.homesprogramme.com) is a more short term industrial project whose purpose is to develop a framework for the integration of sensors and power-controllers to optimize energy management in buildings, targeting exclusively the building envelope and its fixed equipment. Like the ReActivHome project already mentioned that targets exclusively the home but broadens the scope to all kinds of energy-relevant equipment, it is a national collaborative project in France. New possibilities offered by the home as a “smart space”, equipped with a multipurpose shared backplane of sensors and actuators, had been widely explored in European FP6 projects dealing with ambient intelligence. Among these, the Amigo project (www.amigo-project.org) has been exploring early on the semantic-level interoperability of a middleware that would support both the individual home appliances and the sensor-based infrastructure providing context-awareness to the home as a smart space. It has been advocated (Privat, 2008) that this vast body of research can now be exploited for a new application, energy management, that could lead to a renewed, more pragmatic interest in smart spaces.

With a narrower focus on devices themselves rather than on the smart space, SOA-like and semantic-level distributed software infrastructures for the home with spontaneous configuration capabilities have been widely addressed and are an obvious inspiration for the solution presented here is, as already mentioned, what is done with classical zero-conf mechanisms for networked devices, at all levels. Besides the efforts from standardization bodies to elaborate complete solutions such as UPnP and DPWS, we can mention the following. Kushiro (Kushiro, Suzuki, Nakata, Takahara, & Inoue, 2003) provides a Residential Gateway Controller with Plug & Play mechanism. In their architecture, they integrate home appliances using the Echonet (www.echonet.gr.jp/english/8_kikaku/index.htm) communication protocol. Joo I. et al. (Joo, Park, & Paik, 2007) developed an ontology for Intelligent Home Service Framework (iHSF). In the iHSF architecture, a device handler has been designed. The system manages all existing devices in the home by means of the device handler. They assume that a preexisting mechanism brings and configures together the handler and the corresponding physical device. DomoNet (Miori, Tarrini, Manca, & Tolomei, 2006) is an approach that helps to integrate conventional home automation systems following the service oriented computing paradigm. DomoNet architecture describes a SOA model which essentially consists of a network connecting application gateways called TechManagers(TM). Each TM handles one home automation subnet such as UPnP and X10.

All of these solutions require not only that the target devices should be natively endowed with the proper network interfaces, but also that these interfaces comply with corresponding standards at all appropriate levels, up to the semantic level. They also require that the most specific device types are known beforehand for their physical instances to be discovered. The proposed approach differs radically from this previous work in broadening the perimeter to integrate all non-networked legacy home appliances. It requires neither a prior equipment of these devices with standard interfaces, nor that these devices are known on the basis of the specific type or make that they belong to, as devices are identified only by approximation to a generic model. To our knowledge it is the only architecture whose goal to enable a comprehensive and spontaneous integration of such devices in the home/building environment.
Another very important strand of research and development has pursued a similar goal of network integration of physical entities, with a focus on the low-end of the device spectrum. This is what the Internet of Things is all about, at least in its most widely received acceptation. RFID is, under all its variants and guises, the most widespread technology for this, but the Internet of Things should not be limited to any such individual technology. The broader conceptual underpinnings of the present work have been laid out in (Privat, 2011) under the definition of phenotropic interfaces that make it possible to extend the reach of networks beyond sensors, so as to include in the network analog physical objects that have neither an interface in a digital networking protocol, nor a universal digital identification scheme such as RFID. In the approach presented here, the “things” to be identified and attached to the home/building network are the appliances or building components that are identified by iterative approximation to a model instance. Phenotropic interfaces, i.e. interfaces that operate through pattern recognition-from multidimensional and multimodal sensor data, are the intermediary that supports this identification process, so that the present work goes clearly much beyond RFID and the concept of phototropic interfaces.

Finally, in addressing as “subsystems” of the home/building both individual devices and subsets of the building such as rooms, our approach reunites the two separate strands of research that had been pursued under the ambient intelligence agenda (Streitz & Privat, 2009): smart devices/things on the one hand, smart spaces on the other hand.

6.4.3. Principle of the proposed approach

Target home subsystems

The problem addressed by our proposed approach can be stated in the most general possible way as follows (Figure 1): a generic extension of a home ICT system is set up to monitor and control individual physical entities that are self-contained sub-systems of the home itself and fully-fledged physical systems in their own right: they can be, at their most relevant level of granularity, individual rooms of the home or regular home appliances/devices (possibly including non-electrical appliances and energy generation or storage devices). Sensors and actuators are distributed as monitoring and control intermediaries through the home. Absent any native ICT interface on these subsystems sensors and actuators are supposed to be the only means to monitor and control the target physical subsystems, providing an indirect distributed coupling between the home ICT system and the home as a physical system.

The target subsystems of the home are defined as the components of the home that are relevant for being controlled and monitored by an application such as energy management, home security or home automation, using the ICT system that is being setup in this way as a generic supporting layer,
The ICT system will “shadow” or mirror these physical entities/subsystems individually through matching self-contained ICT subsystems that will in turn be the primary building blocks of its own architecture. The ICT system should have the capability to create and configure these entities automatically, both for the initial configuration stage and when reconfiguration would be needed because of a change in the environment. This implies the need to associate automatically the subset of sensors and actuators that are used as intermediaries for the monitoring and control of a given subsystem, and to update the model of the subsystem accordingly.

The proposed approach is to dynamically create a “shadow” ICT component for each individual target subsystem of the home. We call this component the Subsystem Identification, Monitoring & Control component (SIMC) in the following. It connects to the physical subsystem through a dynamically configured set of potentially shared sensor and actuators, chosen among those available in the relevant environment. The sensors detect events and changes of state from the physical subsystem as their inputs and the SIMC sends the controls to the actuators to effect required actions on the physical subsystem. The system comprising the SIMC together with the physical subsystem and the sensors and actuators makes up a closed-loop control system.

**Home subsystems ontology**

Our approach is based on a pre-defined ontology that captures generic knowledge about the devices, appliances and rooms of the home domain through a multi-criteria hierarchical categorization and the definition of generic hybrid finite state models for each of the target subsystems. Initiating and configuring the SIMC for a given entity actually amounts to identifying, loading and iteratively adapting the most appropriate subsystem model from this model repository.
This ontology subsumes several relevant categorizations of the appliances or room. As illustrated in Figure, it can be structured as a directed acyclic graph that makes it possible to follow a path from the most generic parent models (closer to the root of the graph) to the more specific models (closer to the leaves). At the root is the main class *Subsystem*, as understood above, which in the scope of this paper specializes into two descendant classes: appliance and room. Appliances and rooms can in turn be specialized and classified according to several different criteria that are either intrinsic to their main usage, or relative to the application (in our case energy management and energy efficiency). Examples of these criteria are illustrated below, each of them corresponding to intermediate nodes in the graph. Models are associated not only with the terminal nodes of the graph corresponding to the most specific categories, but also to the intermediate nodes. This full hierarchy of models provides a mechanism to identify a subsystem in an incremental way on the basis of observation data, starting from the most generic model if observed sensor data is inconclusive, and refining this first match to more specific models down the graph when further observation data becomes available.

We chose to model both devices and rooms with hybrid finite-state discrete-time models, where state information is possibly complemented with continuous-valued attributes. These states and the relevant attributes are then stored as the state of the shadow ICT subsystem. These hybrid models represent a tradeoff between expressivity and ease of identification. The full description of a physical system such as the target rooms and appliances would normally require a continuous state & continuous-time model, but automatic identification of the parameters of such models would be nearly impossible. Examples of such models are given below for a category of appliance (a generic washing machine) and a category of room (a living room modeled by its different states).

![Figure 2: Home subsystem ontology and corresponding hybrid discrete state model examples](image-url)
Model identification and parameterization

Model identification is the process of matching a target subsystem to a category (a node of the graph) in the domain-specific subsystem ontology. This category may be very broad or very specific, depending on how much sensor data the system has available to perform the identification with. This category is associated with a default model of the target subsystem.

Once a given model has been identified, parameters for the corresponding model may be updated incrementally from new sensor data from the runtime SIMC, or the model may be modified so as to better fit observations: this may correspond to either changing continuous-valued state attributes, invalidating state transitions, or removing states from the state diagram. An example of this updating process is shown in Figure 3 for a washing machine, where the final (most specific) model reached in the model identification stage is refined by removing an unused state or an unused transition (in this case the washing machine is updated from the generic one as having no tumble-drying function).

Adding new states is not considered possible here, and if the model does not fit the observations it is always possible to revert to the previous stage, starting with a new model one rung higher (i.e. less specific) in the hierarchy.

SIMC life-cycle

We now detail the SIMC life-cycle and the configuration mechanism involved in SIMC creation. As mentioned above, Figure presents the finite-state machine model used by a washing machine SIMC. The SIMC can be in either of two main modes: configuration or runtime. The configuration phase is used to associate the kind of specific state automata that best represents the appliance, in our concept it is called Runtime State Machine (RSM). During the runtime phase, it represents not only the states where the SIMC may be in but also but also checks the conformance via the state sequence matching. The configuration phase consists in associating sensors, actuators and a Runtime State Machine (RSM). There are three predefined states. The newborn state is active when the existence of a physical washing machine has just been discovered from a set of sensors. The
configuring state is active when a dedicated washing machine SIMC instance is associated with real sensors/actuators and its RSM. The destroying state is active when the physical washing machine is removed from the home or disconnected from the system; it corresponds to the deletion of the corresponding SIMC instance from the system.

The washing machine Generic Runtime maintains as persistent variables the current states of the SIMC while the physical entity works. For example ON/OFF states are specific to the generic kind of detected appliance. In runtime mode the SIMC component may always go to the waiting for synch state when an error occurs, or when the state is unknown.

A reconfiguration stage may occur at anytime. For instance if we found there is no dry state for the washing machine, we go back in configuring mode, change values and set the SIMC in the waiting for synch state.

**SIMC classification engine**

The SIMC classification engine is a fundamental element of the system. As a classification or pattern recognition engine, it selects the best approximating prototype from a multidimensional dataset of sensor reading. Various algorithms from the machine learning repertoire may be used for this. Based on this principle, it is used in three cases: the identification of the best approximating model of the target physical subsystem; the identification of the instantaneous state of the subsystem according to this model, and the state sequence conformance checking. For instance, at the beginning, the recognition engine should identify the type of detected washing machine and spawn a generic washing machine model. Then the new captured data should be used to find which state the washing machine is in, matching it to one of the defined states of the automaton.

**6.4.4. Architecture and implementation**

**Overall Architecture**

The SIMC management system is hosted on a dedicated home server called Home Automation Box (HAB), itself connected to a wireless network of sensors and actuators (WSN). As shown in Figure 4.4, the system hosted on the HAB maintains a virtual representation of each physical entity as a distinct SIMC instance. Those representations interface the application layer with the managed physical subsystems. At the bottom of the HAB architecture a sensor/actuator layer provides an abstraction of the various types of connected sensors (Gurgen, Roncancio, Olive, Labbé, & Bottaro, 2008).

Each SIMC is associated with a set of sensors and actuators, which are shared between different entities. For instance, a microphone can be used to detect noise originating from different appliances; an infrared camera can also detect heat radiation patterns from several appliances. In the home context, SIMCs associated with rooms may “contain” those associated with appliances in this room in the sense that a room SIMC can use a heating SIMC as one of its associated actuators to effect changes in temperature, or use another appliance as a presence sensor. Our architecture assumes that the sensor-actuator network is available and has been deployed beforehand. Contrary to these
“generic” sensors and actuators, the SIMC of an appliance used as a sensor or actuator is configured during the initialization phase of the system.

We focus on the legacy appliances which should be integrated in the management system in a similar way to what is done with regular networked devices. This means that they have to be identified and matched to an existing type of equipment.

Figure 4 : The SIMC management architecture

Figure 5 shows how the SIMC management system handles subsystems. A "root" SIMC contains a recognition engine and a runtime state machine (RSM). Its duty is to monitor the global context. When new appliances are installed, the "root" SIMC tries to identify them and spawns a new SIMC with "Generic" type. Those "Generic" SIMCs work in their own life-cycle and each can finally reach a "specific" SIMC. Note that the "root" SIMC, the "Generic" SIMC and the "specific" SIMC has the same architecture, the purpose is to keep the same recognition mechanism.

Figure 5 : SIMC mechanism illustration
**OSGi-based implementation**

The OSGi specifications (OSGi, 2009) define a standardized, component-oriented computing environment for networked services that is the foundation of enhanced service oriented architectures. Using the OSGi framework for HAB adds the capability to manage the lifecycle of software components. They can be installed, updated, or removed on the fly without ever having to disrupt the operation of the HAB. Core features of OSGi are based on an original Java class loader architecture that allows code sharing and isolation between modules called bundles (Bottaro, Simon, Seyvoz, & Gérodolle, 2008). A bundle contains Java classes that implement zero or more services. Bundles are deployed in an OSGi service platform to provide application functions to other bundles or users (Lee, Nordstedt, & Helal, 2003).

Our purpose in choosing OSGi is to enable HAB application reconfiguration at runtime. So, each SIMC functional module is modeled as a bundle, and its application functions are packaged in the bundle as services.

**Conclusion and future work**

New home applications such as energy management require the extension of present-day Home Area Networks to legacy non-networked devices and building components, so as to acquire fine-grained real-time information about the operation of these entities and control them in return. We have described a system that identifies and monitors these non-networked entities using a shared sensor-actuator backplane. The identification is performed incrementally on the basis of a hierarchy of predefined models that approximate the behavior of the target entities according to relevant criteria. We prove the feasibility of our solution by validating the prototype on an OSGi execution environment.

In our future work we plan to test the system with a larger set of devices and corresponding models under varied operating conditions. We will investigate more closely the potential improvement of the system from operating as a closed loop control system, where actuators come into play not only for the runtime control of the plant, but also for the self-configuration of the control system.

Taking in a classification of home appliances such as the one from EHS (European Home System, www.ehsa.com) we will draw upon related work (Sommaruga, Perri, & Furfari, 2005) (Joo, Park, & Paik, 2007) to further enrich and refine the home devices ontology.

We plan to investigate fuzzy-state models (Reyneri, 1997) as a potential enrichment of the hybrid discrete state models we presently use.

We will also port the system to an energy-efficient device such as a plug computer (www.plugcomputer.org) that is well adapted to be used as an always-on server inside the home, in order to evaluate the performance and scalability issues of the SIMC system on such a resource-constrained platform, notably which parts would need to be offloaded on a remote service platform across the wide area network.
References


7. Session: Prosumers Micro Energy
Trade Semantics

7.1. Paper: Modeling of Flexibility in Electricity Demand and Supply for Renewables Integration

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Abstract

The use of renewable energy sources is increasing due to national and international regulations. Such energy sources are less predictable than most of the classical energy production systems, like coal and nuclear power plants. This causes a challenge for balancing the electricity system. A possibility to meet this challenge is to use the flexibility in electricity demand for balancing with unpredictable electricity supply. In this paper, we introduce a model for flexibility in electricity demand and supply and give some examples of flexibility models for existing devices. In addition, we describe the business advantages for using flexibility and some pricing mechanisms that provide financial incentives for using flexibility by the consumer and the balance responsible party in the grid.

7.1.1. Introduction

Use of renewable energy sources is enforced by national and international regulations, c.f. 0 and [2]. Drivers for such policies include mitigation of climate change due to emission of greenhouse gasses and reducing dependency on fossil fuel reserves. Due to the intermittent character of renewable energy sources such as photovoltaic or wind power, integration of such sources creates a challenge in maintaining balance between demand and supply. Indications of such challenges in countries with e.g. a high penetration of wind power are already showing in prices on power exchanges reaching zero or negative energy prices, see e.g. [3]. In general, without mitigation measures, an increase in the use of intermittent renewable energy sources leads to a diminished ability to guarantee security of supply.

Within the research project MIRABEL [4], executed within the European Union’s 7th framework program, an ICT system is designed that will enable the integration of a higher rate of distributed and renewable energy sources into the electricity grid. The main goal of this system is to use flexibilities in electricity demand and supply. Consumers and producers own devices in which flexibility in electricity demand and supply is possible, such as washing machines, dishwashers, photovoltaic cells, micro combined heat power units, electric heat pumps, and electric vehicles. These flexibilities include
temporal shifts of activities (e.g. delay operations), temporary reductions of load comparable to existing demand response schemes and adjustments in load profiles of charging of electric vehicles. The MIRABEL system allows for scheduling of flexibilities in load and distributed generation. Thereby, the developed system enables electricity suppliers, or balance responsible parties in terms of the ENTSO-E Harmonized Electricity Role Model [5], to balance energy demand and supply in near real-time and thus, allows the integration of more renewable energy sources whose availability cannot be influenced. The use of flexibility is scheduled and is negotiated with the party offering the flexibility. The project uses a hierarchical approach for aggregation in order to cope with vast amounts of participants in the system.

In this paper we present the flexibility approach and focus on the generic MIRABEL information model for expressing flexibility in load or distributed generation. In addition, we describe how the model can be used for semantic interoperability between providers and acquirers of flexibility, i.e. for the information exchange between consumers and balance responsible parties.

In section 2., we provide an overview of the MIRABEL approach and present some business advantages and global financial incentives. In section 3., we compare it with the related work as demand response is in itself not a new field. In section 4., we give an overview of the types of actors in the grid and their interactions involved in the approach. In section 5., the model of energy flexibility is described and section 6. contains some examples of its use. In section 7., we describe possibilities for integration of our flexible energy model with data models for building energy management systems. Possible incentive schemes for use of the approach is described in section 8. and conclusions and future work are stated in section 9.

7.1.2. Mirabel Approach

The MIRABEL system deals with generating offerings of flexibility in load and distributed generation. It provides the means to issue so-called flex-offers indicating these power profile flexibilities, e.g. shifting in time or changing the energy amount. In the flex-offer approach, consumers and producers directly specify their demand and supply power profile flexibility in a fine-grained manner (household and SME level). The MIRABEL system is able to dynamically schedule flex-offers in near real-time, e.g. in case when the energy production from renewable energy sources, such as wind turbines, deviates from the forecasted production of the energy system.

The Flex-offer in the Energy System

The central concept of our approach is the flex-offer specification. Essentially, a flex-offer is a request for demand or supply of energy with specified flexibilities as shown in Figure 1. The bars represent an electricity profile which is split into six time intervals. The flexibility in time is represented by the minimal and the maximal start time. The white, light grey and dark grey sections of the bars visualize the flexibility of the amount. The given flexibilities enable the scheduling of requests on higher hierarchy levels.
On the prosumer level, a flex-offer is bound to a device consuming or producing electricity, e.g. a dishwasher, dryer, washing machine, swimming pool pump, electrical heating, heat pump device, charging of an electric vehicle, and combined generation of heat and power. The profile of the flex-offer corresponds to the profile of the device (and its flexibility).

Local energy management for consumers and producers is realized at the lowest level of the hierarchy, and it uses functionality either provided by a smart meter or a separate energy management system. From the perspective of metering and data management, we distinguish between demand and supply. The system stores historic data and uses it to forecast demand and supply for the near future in prosumer profiles (i.e., day ahead and intra-day). Prosumers can issue flex-offers usually one day ahead or intra-day, i.e. real-time. The Balance Responsible Party (BRP) further aggregates the flex-offers, schedules them depending on several factors like the current market situation, the availability of renewable energy and the energy prices, and negotiates the price, the use and timing of flex-offers with the prosumers. By using schedulable flex-offers, a BRP is able to use more renewable energy, because rescheduling can be performed in near real-time in reaction to the availability of renewable energy.

Our approach allows a BRP to re-schedule requests in a way that (1) the plan is met within the day, i.e., that no imbalances are caused, and (2) options for the shift of demand or supply can be sold to the TSO or traded on a wholesale market. A TSO could use options to shift demand or supply provided by a BRP to stabilize the electricity grid with a time horizon of some minutes. The benefits for a prosumer could be better prices for electricity (lower price for demand and higher price for supply) and an environmentally conscious behavior.

**Business advantages and global incentives**

The conceptual and infrastructural approach that is developed within the MIRABEL project offers advantages throughout the energy domain. In general, the flex-offer concept increases the ability to balance consumption and production in the electricity system.

Currently, the power output of most renewable energy sources (RES, e.g. windmills, photovoltaics) is intermittent since it depends on external factors, e.g. wind speed, the amount of sunlight, etc. Hence, available power from RES can be predicted, but not planned. This makes it difficult for energy distributors to include RES into their daily schedules exactly. As an unfortunate consequence, power from RES sometimes has to be traded against very low prices due to a lack of demand. The flex-offer mechanism provides the ability to adjust the power profile of load and/or distributed generation in order to maintain balance within the system. Forecasting of e.g. weather conditions can
be used to predict the production of renewable energy more accurately. As a consequence, the uncertainty in renewable energy production can also be used in matching with energy demand. In the end, the net effect of matching demand and supply by scheduling with flexibilities is that the necessity for usage of reserve power due to imbalances, and thus the level of financial consequences, is decreased. This should be a first financial incentive for the electricity suppliers to include flexibilities into the matching of demand and supply. This financial advantage for the electricity suppliers can be partially passed on to the energy consumers to give them the incentive to make use of their flexibility against a lower energy price. On the other hand of the energy chain, the producers of energy have an incentive to produce more RES-based energy, because it can be used more effectively and waste of RES-energy can be avoided more often. Finally, the “business case” or incentive for government to support MIRABEL’s flexibility mechanism is that, as a consequence of the incentives of energy producers, the amount of RES-based energy will increase and (inter)national treaties on energy and promises to decrease the level of greenhouse gasses can be met.

7.1.3. Related Work And Comparison

The flex-offer approach is one of many approaches towards demand response management. There are several ways of implementing demand side management. Four different approaches are presented below:

The first approach is direct control by a third party. In this case one or more devices - such as CHP systems or air-conditioning - in a household can be controlled directly by a third party. The customer usually receives a discount for handing over some of the control. An example of this approach is the SmartRate project by PG&E in California. In this project air-conditioners are controlled by energy company PG&E. When deemed necessary air-conditioners are instructed to run in a limited mode that restricts their energy consumption considerably for a period of 15 minutes. This enables PG&E to actively manage the load on the network when faced with capacity problems. In exchange for providing this ability consumers pay less for their energy.

The advantage of this approach is the ability for the energy supplier to exercise a fine grained control over energy demand due to the large amount of devices that it can influence directly. The disadvantage is apparent. Gain of control for the energy supplier is loss of control for the consumer. The consumer no longer has complete freedom to make his own decisions about energy consumption and production in the household. Of course the consumer voluntarily gave up some of his autonomy for a financial reward.

A second (very popular) approach towards demand side management is to use some form of dynamic pricing as an incentive for certain demand-response behavior. Pricing information is sent to consumers to influence their behavior in an indirect manner. Consumption is being stimulated with low energy prices and discouraged when prices are high. An example of such an approach is the Bidirectional Energy Management Interface (BEMI) D where a price profile (consisting of 15 minutes time slots) is sent to the consumer. The price profile is either determined by an energy supplier or generated by a market place. Although the price profile can be interpreted manually by consumers it is much more convenient to use an Energy Management System (EMS) to do this. The advantage of
this approach is its simplicity; all it requires is sending a price profile to a consumer, there is no need
for two-way communication. The disadvantage is that the consumers are quite passive; they can only
react to a price profile but they cannot offer their own production to others. Another disadvantage is
that the use of price profiles by energy suppliers makes it difficult to transparently compare the offers
of several suppliers.
A third option is to copy the approach taken by energy exchanges. Traditionally energy exchanges
trade large volumes of energy and are not accessible to smaller consumers or producers. By enabling
trading of energy for smaller volumes as well an exchange can be an effective means to adapt
demand to intermittent supply. An example of this approach is the PowerMatcher [6]. The
PowerMatcher couples intelligent agents with devices such as washing machines, heat pumps, CHP
systems, etc. The agents are responsible for buying energy for consuming devices and selling it in
case of production. Agents representing a consuming device are willing to pay more for energy when
a device really needs to run, e.g. a heat pump that has to operate because of the temperature hitting
its lower threshold. The willingness to pay for energy is expressed in a bid curve. The opposite holds
for producing devices.
The big advantage of an exchange is its simplicity. It is relatively easy to process all the biddings and
to extract an equilibrium price that should balance supply and demand. The exchange approach
works best when the “needs” of devices are evenly spread; some devices just consumed energy and
can do without for a while, some are willing to consume energy when the price is right and some
devices find themselves in a must-run situation and are willing to pay any price. However there are
cases where such a spread of device states is not very likely. Consider the charging of electric
vehicles that return home in the evening and need to be recharged at 7 am in the morning. Their
agents will all behave in similar ways. They will first wait and see how prices on the exchange develop,
then at some point they will reach a must-run state because of the lengthy load process. This may
very well give rise to capacity problems because all the loading is concentrated at the second half of
the night, while the first half was spent waiting. These situations are disadvantageous for the
exchange approach.
The flex-offer approach differs from the other three approaches in that participants explicitly specify
how much flexibility (both consumption and production wise) they are willing to offer to other parties
in the market. These other parties may operate intermittent energy sources and could exploit flexible
demand to direct energy consumption to those moments in time their sources produce energy in
order to maintain a better balance. In this case one is willing to pay for the ability to shift energy (in
addition to volume based prices). The advantage of this approach is that it combines the possibility
for fine grained control (as with the third party control approach) by the party that buys flexibility
with the full autonomy (that is also maintained by the price profile and exchange approaches) for the
party that sells it. Revisiting the electric vehicle charging example; owners of these vehicles offer the
consumption of the energy needed for a recharge to be flexibly shifted over the entire night. A
network operator can take advantage of these flex-offers by assigning part of the charges to the first
half of the night and the other part to the second half thereby actively preventing capacity
bottlenecks. A disadvantage of the flex-offer solution is that it can be quite complex to satisfy all the
flexibility constraints that can be expressed in a flex-offer when large numbers of these offers need to be processed.

The common denominator among all approaches is that they try to exploit flexibility that is present in consumption and/or generation devices. This flexibility is used to counter the intermittent character of renewable energy sources.

7.1.4. Roles Context

The flex-offer approach is aimed to be applied within a multi-actor context. In principle any actor which has the ability to control load or (distributed) generation resources is capable of offering the flexibility in these resources to other actors. These actors acquiring the offered flexibility may provide compensation for such offerings.

Providers and acquirers of flexibility

Figure 2 provides a schematic view on the roles of acquirers and providers of flexibility in load and/or generation. In general any number of providers of flexibility can interact with any number of acquirers of flexibility. However, both the technical as well as the commercial setting may limit the number of providers and/or acquirers. Within the MIRABEL context a probable application context is the balance group environment, c.f. [7]. In this context, an arbitrary number of parties connected to the grid (many providers) offer flexibilities to their balance responsible party (the single acquirer).

Figure 2. Schematic view of provider and acquirer roles

Providers of flexibility control one or more energy resources, either directly or indirectly, which allows control of its power profile. These providers decide what flexibility is offered; based on e.g. technical, financial and/or comfort grounds. Thus the flexibility-provider remains autonomous in its decision making.

Acquirers of flexibility have a use for the ability to control the power profiles of these resources as offered by the flexibility-providers. This includes e.g. the ability for a balance responsible party to achieve the schedules submitted to a system operator as in the ENTSO-E scheduling system [8] with a substantial amount of intermittent energy sources in their portfolio.

Offerings of flexibility need to be accepted (or rejected) by the acquiring party. When flexibility offered is accepted a profile assignment must be provided by the acquiring party to indicate the
desired behavior. This profile assignment must comply with the limits of the flexibility offered; e.g. no higher power output then offered, no temporal shift beyond the temporal bounds offered, etc.

**Role interactions**

Figure 3 schematically shows an example series of interactions between two providers and an acquirer of flexibility. In this sample the flexibility offered by the 1st provider is accepted while the offered flexibility by the 2nd provider is rejected. An assignment is provided by the acquirer to the 1st provider for the power profile within the limits initially offered by the 1st provider.

![Figure 3: Example interactions between two providers and one acquirer](image)

The generic state diagram for flexibility in energy resources used is depicted in Figure 4. Once flexibility is identified, e.g. an electric vehicle is connected to a charging facility and constraints (preferences) for the charging process are provided by the user which allows modifications of the charging process, flexibility may be offered. The offering can either be accepted or rejected. Once accepted, an assignment is provided for the resource (or combined resources) with flexibility; updates of this assignment may be provided.

![Figure 4: State diagram for flexibility in energy resources](image)

### 7.1.5. FlexEnergy Model

Flexibility in consumption and/or generation of electricity is specified in terms of constraints within the MIRABEL approach. These constraints concern temporal, energy related and financial constraints; see table I. This flexibility is offered according to the interactions described in the previous section.
### Profile Assignments

The profile assignment determined by a flexibility-acquirer must comply with all constraints in the specification of the flexibility offered by the flexibility-provider. For this profile assignment a discrete model is used; a visual example is provided in Figure 5.

![Profile Assignment Diagrams](image)

Figure 5: Example profile assignments in increasing amount of detail; d) also includes generation

The profile assignment consists of a set of assignment intervals. The assignment intervals each consist of a start time, end time, duration, average active power demand\(^4\) for the interval, energy amount and tariff. The start and end times are expressed as a point in time, e.g. 12h30 on April 5\(^\text{th}\) 2011. Duration, start time, end time, power and energy amount are related to each other as depicted in Figure 6.

\(^4\) A negative demand indicates supply.
When implementing this model in an actual information system, optimizations may be performed for e.g. efficiency in information exchange.

The tariff is a monetary amount per unit of energy to pay for consumption to the flexibility acquirer. A negative amount indicates a supply of energy and it is the monetary amount received from the flexibility acquirer.

**Constraint Profile**

Flexibility can be expressed as an energy constraint profile which is a set of constraint intervals in the final profile assignment. This energy constraint profile contains temporal, energy related as well as financial constraints. The power and energy values in each assignment interval may in some cases assume only a value from a strict set of values and in other cases a value between a lower and upper bound and potentially combinations of these. The power and energy constraints are expressed as sets of lower and upper bounds. The power constraint set contains tuples of lower and upper bounds in average power demand. Similarly the energy constraint set contains tuples of lower and upper bounds in energy amount.

In Figure 7 an example is provided of a power constraint set with two 2-tuples. Note that in the first tuple the lower and upper bound are equal $pc_1^- = pc_1^+$. 

![Figure 6. Visualization of an energy schedule interval](image)

![Figure 7: Example power constraint set visualization](image)
7.1.6. Examples of FlexEnergy Use

This section describes some concrete examples of FlexOffers for various devices. It shows how flexibility can be expressed for electrical vehicle charging, heat pumps and combined heat power systems.

**Electric Vehicle Charging**

Electric vehicles will typically be used during the day to commute and charged during the night. The charging process is lengthy and consumes a large amount of energy. It would be beneficial for the system operator to have the flexibility to schedule some of the charging load in order to prevent capacity problems on the grid when all vehicles load simultaneously.

An electric vehicle owner can offer this flexibility by expressing the minimal constraints that have to be met. The vehicle is for instance available for charging from 6pm in the evening till 7.30am in the morning. An additional constraint is that the vehicle should be charged to 30% of its capacity before 11pm. The reason for this constraint is that it gives the owner the possibility to use his car for emergency situations; a 30% charge would be sufficient to get for instance to the local hospital. The rest of the charging can be allocated at any time during the night as long as the vehicle is fully charged by 7.30am. Figure 7 shows a graphical representation of this FlexOffer.

![Figure 7: Graphical representation of Electric Vehicle Charging FlexOffer](image)

The figure shows the minimal required energy level for each point in time. Each assignment profile that is above or equal to the minimum level is valid.

**Heat Pump**

Heat pumps draw a lot of power from the grid, up to several kilowatts. The power consumption is usually controlled by a thermostat. By intervening between the thermostat and the heat pump it is possible to shift the heat pump’s demand. Postponing the operation of a heat pump for a small amount of time (0-15 minutes) can already create a considerable amount of flexibility given the large energy consumption.
Figure 9. Example interactions between two providers and one acquirer

Figure 9 shows an example of a flex-offer that makes this flexibility explicit. Please note that the y-axis of this figure represents power and not energy as in the previous electric vehicle charging figure. This figure shows the two extremes; an energy block that starts at 8.00 and ends at 9.00 and another block that runs from 8.15 till 9.15. All other options that start between 8.00 and 8.15 are also valid. The example is a simplification of a real situation in that all blocks have the same duration. In reality a later start time means that the heat pump has to operate for a slightly longer period of time because the start temperature will have dropped a bit further.

**Combined Heat Power System**

A Combined Heat Power (CHP) system consumes gas and produces heat and electricity. Like the heat pump the CHP is also temperature driven. The operation of a CHP can be postponed or advanced in the same manner as the heat pump. In addition to the shifting operation in time it is also possible for certain CHP’s to operate at partial (70%) or full power (100%). This can be exploited by offering two flexibility options; one to run at 100% (producing 1kW) and one that produces 700W of power but that runs for a longer period of time (otherwise the target temperature will not be reached). This is depicted in figure 10.

The CHP produces electricity hence the negative energy consumption. The CHP can also be shifted in time but this figure focuses only on the different power output levels. The surface of the two blocks are more or less equal depicting the fact that the same amount of energy is required to raise the temperature to the required level.
7.1.7. Flex-Offers and Building Energy Management Systems

From a consumer point of view, the concept of flexibility is only one of many aspects to be considered when managing energy in a household or larger building. A building usually contains many devices that require or produce electricity. A Building Energy Management System (BEMS) is able to take care of monitoring and control of the entire use of energy in the building. A BEMS takes input from various sensors in the building and controls devices in order to achieve an optimum between various objectives, such as:

- usage of resources to minimize the import of electricity from the smart grid,
- maximize the use of the building’s own energy generation,
- maintaining the comfort level within the desired limits,
- reducing the cost of energy consumption.

When considering the flex-offer concept to be applied in a BEMS, i.e. using flexibility for matching demand and supply in the smart grid, a new objective is added. This objective is to further reduce cost of energy consumption through offering and negotiation of flexibility to be utilized by the smart grid such that smart grid balance is improved and penetration of intermittent renewable energy sources can be increased. Obviously, offering flexibility in return for a cost-reduction has to be weighted by the BEMS with the other objectives and constraints of building energy management.

In order to incorporate a flexibility objective, a BEMS must know the flexibility characteristics of the various types of devices that are present in a building. We can distinguish between the following four types of devices that have possibilities in flexible energy consumption or production [10]:

1. **Shiftable operation devices:** batch-type devices whose operation is shiftable within certain temporal limits\(^5\), for example (domestic or industrial) washing and drying processes. Processes that need to run for a certain amount of time regardless of the exact moment, such as assimilation lights in greenhouses and ventilation systems in utility buildings. The total demand or supply is fixed over time.

2. **External resource buffering devices:** devices that produce a resource, other than electricity, that are subject to some kind of buffering. Examples of these devices are heating or cooling processes, whose operation objective is to keep a certain temperature within an upper and lower limit. Instead of applying the standard thermostat-driven, the flexibility which exists can be used to provide flex-offers in exchange for cost-reduction. Building energy management systems must obviously ensure that technical and user constraints are met. Devices in this category can both be electricity consumers (electrical heating, heat pump devices) as well as producers (combined generation of heat and power).

3. **Electricity storage devices:** grid-coupled electricity storage is widely regarded as a future enabling technology allowing the penetration of distributed generation technologies to increase at reasonable economic and environmental cost. Grid-coupled storage devices can only be economically viable if their operation is reactive to a time-variable electricity tariff.

\(^{5}\) E.g. deadlines for process completion may exist.
4. **Freely-controllable generators**: devices that are controllable within certain limits (e.g., a diesel generator) but have no immediate secondary effect, i.e. the generation of electricity is their primary function. A BEMS can use the flexibility in this type of devices for flex-offers as well.

In order to leverage this flexibility, the user has to set his preferences to be used for each of these devices in the BEMS. An example element of such a preference could be a minimum and maximum level of an environment variable such as temperature that can be used as set-points for the control of a heating device. Another example preference could indicate whether or not a washing machine can be interrupted at certain fixed points within the washing programme, e.g. between washing and centrifuging. Obviously, it is the producer of the washing machine that has to make it possible that the washing machine can be interrupted at the various steps of these programmes.

Based on the entire set of devices in a building and the various flexibility profiles, the BEMS should then be able to generate flex-offers that adhere to the MIRABEL FlexEnergy model in Figure. 11. This figure presents the highest level of the model and gives a nice example. The entire datamodel for flex-offers can be found in [11].

![Figure.11: MIRABEL FlexEnergy data model that forms the basis for flex-offer generation.](image)

In various national and international projects data models are being developed out to incorporate energy consumption and production information into existing Building Information Models (BIM). One interesting example is the data model produced by the FIEMSER project in which various information elements that can be used to express flexibility are defined [12]. For instance, elements like HomeUsageProfiles, Scene, Comfort Setting and Load (which is shiftable) can be used to generate flex-offers towards the smart grid. The further integration of BEMS data models, like the one in FIEMSER, and the FlexEnergy data model of MIRABEL is an important topic for future investigation.
7.1.8. Incentives for Use and Pricing Mechanisms

In the previous sections, the flex-offer concept has been described in detail and some examples have been given about its usage. The next question that comes to mind is which financial incentives can be offered to the various actors in the energy domain in order to start offering and scheduling flexibility in demand.

As mentioned in section III, the main goal of incorporating flexibilities is to decrease imbalance between demand and supply of energy. Flexibilities in demand can be used to match as best as possible with the uncertainties (due to RES) in energy supply. Thereby, the demand and supply curves will resemble each other as much as possible and thus the balancing problem is minimized. When we try to map this onto day-ahead scheduling, we can conclude that it is not exactly known which demand flexibilities and RES supply will be offered the next day. Nevertheless, forecasts of flexibilities based on e.g. history, weather prediction and time of day can be used to produce a day-ahead schedule in which flexibility is taken into account as best as possible.

When making such a day-ahead schedule, the price of imbalance is not yet known exactly, because this price is based on the entire, real-time demand and supply the next day. Therefore, it is hard to take this price of imbalance into account during day-ahead scheduling. Nevertheless, the day-ahead schedule is used by the balance responsible party to indicate to the system operator what energy demand and supply can be expected.

Looking at intra-day level, the exact, real-time situation can however slightly differ from the situation predicted the day before. This is due to the uncertainty of RES supply and the flexibility of the consumer in using his/her equipment and thus energy demand. For instance, new energy demand can be raised at any time, e.g. because of an electrical vehicle to be charged or a washing machine that is put on.

Therefore, at intra-day level, flexibilities can be used by the balance responsible party to shift energy demand such that the actual schedule fits the promised day-ahead schedule as much as possible. Thereby, the consumers that have offered these flexibilities should have a benefit, because the imbalance is kept to a minimum thanks to their flexibilities.

By minimizing the imbalance, the balance responsible party can also minimize the amount of reserve power to be activated by the system operator to balance the system. Thus, this is a financial gain for the balance responsible party and usually also for the system operator, because both have to pay less for the activation of reserve power.

Having identified this initial financial profit, the next question is what kind of “pricing mechanism” can be used to transfer (part of) this profit from the balance responsible party to the consumer so that the issuing of flexibilities is made attractive. We distinguish three types of pricing mechanisms: one based on real gain per flex-offer, one based on real gain per time period and one based on fixed gain for a bundle of flex-offers.
**Real gain per flex-offer**

The real gain per flex-offer mechanism is based on the fact that flex-offers have a pricing field that indicates the price that the consumer is willing to pay for the energy demand or the amount the consumer wants to get for its flexibility. The price indicated in a flex-offer is the maximum price the provider wants to pay for the amount of energy in this flex-offer. We assume that this price is a reduced price based on the flexibility in energy level or time interval. Thus, it is lower than the usual price for the time-interval involved.

Now, one possibility for this mechanism is a so-called “single offer/acceptance cycle”. Thereby, the flex-offer is either accepted for the price asked for or rejected. Thus, directly after the acceptance of the flex-offer the price and profit is known. As a consequence, it is up to the balance responsible party who has to accept/reject the flex-offer, to decide whether or not this maximum price is realistic or not. The exact gain is thus based on a kind of educated guess of the actual price at intra-day level and a requested reduction based on the amount of flexibility offered.

Another possibility of a real gain per flex-offer mechanism can be based on the entire set of flex-offers for a certain scheduling interval. In this case, once a final schedule is made for a set of flex-offers, the overall gain of this schedule based on the use of flexibilities has to be calculated with respect to a schedule without flexibilities. This gain has then to be distributed between the providers of the flex-offers. This means that a measure per flex-offer for the use of its flexibility in the scheduling process has to be defined. These measures can then be used as weights for the distribution of the gain.

**Real gain per time period**

The real gain per time period mechanism assumes an overall decision on the gain per consumer over a certain time period, e.g. every month or year. Thus, this mechanism is not based on the price indications of each flex-offer. At a monthly level, the gain of using flexibilities is calculated and redistributed over the consumers who offered these flexibilities. Obviously, this mechanism has to use a default situation in which flexibilities are not used. Otherwise, the gain based on these flexibilities can not be calculated. This can be done by calculating at intra-day scheduling level, which flexibilities are used to shift energy demand such that the imbalance is minimized as much as possible.

**Fixed gain for a bundle of flex-offers**

The fixed gain for a bundle of flex-offers mechanism assumes a fixed gain for those who offer flexibilities against no gain for those who do not. In more detail, the mechanism can be based on a bundle of flex-offers the consumer is required to offer. In addition, the level of flexibility in these flex-offers can also be part of the required bundle. Based on the flexibility in the bundle, the consumer can get a certain reduction on the monthly price for his/her energy. Thus, the challenge is to define a fixed incentive per month to attract consumers to provide a minimum amount of flex-offers or a minimum amount of flexibility in time or energy level per flex-offer.
Each of these mechanisms has advantages and disadvantages depending on the particular situation of consumers and electricity providers. This for instance depends on the business goals of electricity providers towards gaining consumer market share. It also seems that a more simple pricing mechanism like the real gain per month or the fixed gain for a bundle of flex-offers is a good starting point, while a more comprehensive mechanism like the real gain per flex-offer is more suited once the flex-offer approach is already in place. We are currently discussing the flex-offer approach with various electricity providers to find out in more detail which pricing mechanism fits best to their needs.

Conclusions and Future Work

In this paper, we have presented a model for flexibility in electricity demand and supply that can be used for the information exchange between consumers and balance responsible parties to negotiate this flexibility. In addition, we have described high-level business advantages and some pricing mechanisms with incentives for consumers and balance responsible parties to use flexibility in balancing the electricity system. This model is currently being used for deriving scheduling algorithms that make use of the flexibility model. These algorithms also use forecasting and aggregation techniques on flex-offers in order to decrease the complexity and increase the chances of matching the electricity of demand and supply. Furthermore, we are discussing the pricing mechanisms with various stakeholders in the electricity domain in order to make these mechanisms suit their actual situation as best as possible.

References

[5] ENTSO-E harmonized role model
7.2. Paper: Prosumer interactions for Efficient Energy Management in SmartGrid neighborhoods

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Abstract

The introduction of distributed energy generation has among other things the power to enable traditional consumers to also produce energy (called prosumers), which they subsequently may make available on the network. The emerging SmartGrid relies on the active participation of these prosumers, and their interactions may have a significant impact on its core operations. The NOBEL project investigates these interactions by considering the local context of the users and their behaviour in a neighbourhood within a smart city. The aim is to provide an information and communication driven infrastructure for the users to interact and e.g. buy and sell energy on online marketplaces. Such an envisioned infrastructure may pose significant opportunities as well as challenges for all involved actors, however it bears the potential to enable us to better manage the energy in the highly dynamic electricity network of the future.

Keywords: Energy efficiency, public lighting system, energy brokering, enterprise services.

7.2.1. Motivation

Europe has set ambitious goals towards increasing energy efficiency and sustainability in order to tackle the emerging energy needs of its citizens. Additionally there is a strong movement towards distributed energy resources and decrease in dependence from traditional, environmental unfriendly ones. Distributed generation of energy coming from various vendors, even private homes, is a big challenge for tomorrow's power management systems that, unlike today, will not dispatch energy centrally or under central control. In the emerging infrastructure of SmartGrids the production, distribution and management of energy will be a reality, and taking into consideration local conditions and data one might better locally optimize its operation. The SmartGrid is a complex system of systems that will undergo a significant change in the next decades, and as any distributed system, it will be challenging to design, deploy and manage it in a traditional centralized way.

The NOBEL project (Marqués et al. 2010) envisions that market-driven interactions at local (neighbourhood) level may motivate energy to be traded locally by the producers and consumers and
(i) better cover the local energy needs (increase efficiency), and (ii) assist the DSO to better assess the situation and plan its actions. Hence, via the local market, individual as well as groups of prosumers (Karnouskos 2010) can communicate their energy needs directly. The last brings market concepts to the business transactions among the users, which might introduce new opportunities as well as new revenue sources to the participants. A typical such example investigated within the NOBEL project is the ability to use public infrastructure (e.g. the public lighting system) as a flexible balancing market actor. This would enable the community to investigate an additional source of revenue by offering its flexibility to consume (e.g. by turning lights on) when too much production is available as well as to lower its consumption (e.g. by turning lights off) when it is needed.

Figure 1: Towards Energy Efficiency in Neighborhoods

A significant problem is the balancing of energy production and consumption even at local level due to the highly nonlinear and very dynamic system. It is hard to predict disturbances and undertake counter measures on time. This is expected to get even worse with the introduction of Distributed Energy Resources (DER) such as Combined heat power (CHP), Fuel cells, Micro combined heat and power (MicroCHP), Microturbines, Photovoltaic Systems (PV), Small Wind power systems etc. As we can see in Figure 1, there are ongoing efforts to map production to consumption; however today this is mostly done by relying on static historical data and often to human intelligence (and many times feeling/expertise) to procure the envisioned energy from national energy market. However, the introduction of very dynamic energy resources such as DER may not be adequately tackled with these approaches.

As depicted in Figure 1, NOBEL aims at minimizing the electricity excess on the network while managing also DER. For neighbourhoods today the electricity is procured e.g. at a national market, however whatever is not really used is “wasted” (as depicted in the upper left part of Figure 1) although it was paid for (e.g. because the needs were falsely predicted). To minimize the losses,
procurement of energy is done by experts who rely on historical data as well as prediction algorithms. They then buy the necessary energy in national markets in an optimized way (as depicted on the lower left part of Figure 1). However, the introduction of DER is hardly considered and difficult to be predicted. NOBEL aims at creating an infrastructure where the information among the users can be shared and where e.g. energy produced within the neighbourhood can also be used locally, resulting to more efficient internal management in the neighbourhood (as depicted on the right side of Figure 1). Our vision is to achieve this in a market-driven way by enabling interactions among the prosumers. Hence NOBEL invests in realizing a cross-layer and open information flow among the different actors involved, so that they can transact and via these transactions to be able to make better tackle the system dynamics which may lead to better energy management and achieve better energy usage.

The ultimate objective is to achieve higher energy efficiency and optimise its usage. This can be achieved by analysing and continuously monitoring not only the components in the distribution network, but also the prosumer interactions, gathering the appropriate data and, finally, identifying on-the-fly situations where energy can be saved. This will allow NOBEL to create a highly dynamic system where the amount of electricity in the network follows more closely the current demand. Excess energy is monitored and managed to make the energy available in other parts of the network or to intelligently make use of it via demand side controlling. To achieve this goal, the energy that comes from the local network operator as well as the prosumers will have to be monitored, analysed, and decisions will need to be made in a timely manner. The objectives of the NOBEL project are in-line with the vision and the strategic deployment agenda set by the SmartGrids European Technology Platform (2010).

The key to NOBEL’s efficiency improvement is that prosumers become sources of both energy and information that can be exchanged. The information allows the energy system to better adapt the amount of electricity in the network to the real time demand. The performance of the entire system is enhanced by exploiting the locality of the processes in monitoring and control that normally do not consider the detailed behaviour of the actual consumers.

7.2.2. The neighborhood in a Smart City

A neighborhood is a geographically localized community within a larger city, town or suburb sharing a common service infrastructure. In some countries, neighborhoods are often given official or semi-official status, serving to represent administrative division found immediately below the district level. In the context of NOBEL, a neighborhood is a group of households and public services served by a same electricity local Distribution System Operator (local DSO) and geographically localized in the same area. Thus, the neighborhood unit within the project refers to the capability to manage electricity related services. In this way, usually a local DSO will always manage at least one neighborhood, but there are also cases where a single local DSO manages several neighborhoods, as it happens nowadays in most cities. In this context, the NOBEL project proposes a way to bring together the various prosumers and the DSO in order to maximize energy efficiency; the approach is
market-driven and interactions are facilitated in an online marketplace where brokering of electricity can take part.

While a universally agreed definition of a smart grid is not clearly stated and varies in focus in different countries; Hoang (2008) has already identified a number of typical components that should be considered:

- **Intelligent appliances** capable of deciding when to consume power based on preset customer preferences.
- **Smart power meters** empowering bidirectional communication between consumers and power providers for better data collection, maintenance, outage detection etc.
- **Smart substations** that include monitoring and control of critical and non-critical operational data such as power factor performance, breaker, transformer and battery status, security, etc.
- **Smart distribution** that depicts self-* features such as self-healing, self-balancing and self-optimization.
- **Smart generation** capable of “learning” the unique behavior of power generation resources to optimize energy production.
- **Universal access** to affordable, low-carbon electrical power generation (e.g., wind turbines, concentrating solar power systems, photovoltaic panels) and storage (e.g., in batteries, flywheels or super-capacitors or in plug-in hybrid electric vehicles).

In the context of NOBEL the relevant components for a neighborhood-oriented system include from the intelligent appliances to the smart distribution at a local level. The scope of the project, however, does not consider the intelligent appliances or the hardware developments as main topics of research, because other EU research projects and initiatives such as BeyWatch (www.beywatch.eu), OpenMeter (www.openmeter.com), AIM (www.ict-aim.eu), DEHEMS (www.dehems.eu), BeAware (www.energyawareness.eu), MIRABEL (www.mirabel-project.eu), ENERSip (www.enersip-project.eu) and SmartHouse/SmartGrid (www.smarthouse-SmartGrid.eu) already cover such topics. On the contrary, NOBEL tackles the use of information coming from Smart Meters (SM) and end users through proactive consuming/producing profiling to adapt the operational behavior of a local network, introducing brokerage capabilities and providing improved monitoring and control tools to distribute and move the decision making to a local level whenever it is possible.

Additionally the NOBEL project gives a significant focus on the business side and specifically on the enterprise services that would empower its concepts. Figure 2 depicts the overall project vision, where enterprise services integrate almost in real time information coming from highly distributed smart metering points, process it and take the necessary decisions. Data is collected from existing monitoring devices such as the smart meters are communicated via wired and wireless channels either directly to a service or via the usage of in-network intelligent data processors. The goal is to be better able to manage complexity and high distribution at the point of action and not at centralized systems. In our case the fully customized data capturing as well as processing is done by the respective NOBEL developed modules, while the integration of hardware and multiple communication channels is hidden.
The enterprise system is comprised of several Internet-accessible services, which in their turn can be used to create mash-up applications. Additionally, following a software-as-a-service (SaaS) model, we expect the rise of new applications (as well as feature enhancement) simply by rapidly combining cross-enterprise services to deliver customized functionality. This is the case for the energy management system portal (from which the DSO can get an overview of the network) as well as the mobile front-end (BAF), which is expected to be provided to the smartphone of the users and enable them to interact with the NOBEL infrastructure.

NOBEL aims at creating mash-up applications that use Internet services to create dynamically customized applications at the end user side, whether this is a simple user, a standard prosumer or a senior prosumer. This is a significant change for the energy domain, as we move away from heavyweight monolithic applications towards much more dynamic, up-to-date and interactive ones utilizing local capabilities. By increasing visibility via near real-time acquisition and assessment of the energy information, providing analytics on it and allowing selective management, NOBEL will provide a new generation of customized energy efficiency services. Typical Energy Enterprise Services envisioned include: Energy Brokering, Energy Monitoring, Energy Prediction, Energy Optimization, Energy Info Services, Energy Pricing, User/Profile Management, Energy Management, Energy Service Catalogue, Asset Management etc.

7.2.3. Market Interaction

In the future smart city, several of its neighborhoods will be supplied by different local Distribution System Operators (DSO) who coordinate with a few Transmission System Operators (TSO). The local
DSOs are in charge of providing the last mile infrastructure, distributing the electricity to the end users according to the contracts they have with the different suppliers. Each local DSO is controlling and monitoring a number of neighborhoods (as depicted in Figure 4).

Each neighborhood is expected to have an Electricity Monitoring and Control System (NOEM) developed within NOBEL, assisting the DSO in having the overview by providing analytics as well as enabling the management of the energy (as depicted in Figure 2). The information that such services will process and depend upon, come from the network (smart meters, local distribution equipment, concentrators, network analyzers, etc.), the prosumers interacting with the network through a brokerage agent front-end (BAF), or the relevant local DSO. NOEM is a mash-up application composed by various enterprise services provided within the project and are expected to be cloud-hosted (as depicted in Figure 2).

Another mash-up application is the Brokerage Agent Front-end (BAF). This application is targeting mostly modern mobile devices, is again depending on a mash-up of several services to provide it with real-time data, and fosters direct interaction with the user who can not only receive info e.g. energy consumption, but also can connect e.g. to the online marketplace to buy and sell electricity. Of course similar functionality will be available via a web portal accessible also by normal desktop and laptop computers. The objective of BAF is the design and development of a tool for standard prosumers to interact with its brokerage agent. This tool provides to the STandard Prosumer (STP) a user-friendly and easy to use front-end to interact with the brokerage system managing the efficiency of its electrical demand. The front-end enables the active communication between the energy management system and its end users. In typical examples, the local Distribution System Operator Transmission System Operator may interact with the users and provide incentives in order to affect the behaviour of the consumers e.g. multiple tariffs. The Brokerage Agent Front-End is accessible from a wide variety of wired and wireless devices - PCs, smart phones and PDAs – in order to achieve access to the energy data anywhere, anytime, in any form easily and effectively.
The Neighbourhood Oriented Public Lighting Monitoring and Control System (NOPL) is the example of a Senior Prosumer interacting with the NOEM. Senior Prosumers require internal energy management processes, which impose some constraints not necessarily observed by normal STPs, but also provides new capabilities to improve the energy efficiency of the target neighbourhood. In the case of a public lighting system as the one used in the NOBEL project, the main constraint would be the need to respect at any time the contractual obligation of providing a public service: major disruptions on the service could affect not only the well-being of citizens but also its security and safety. In this way the monitoring capabilities should be highly robust, which may limit the number of feasible energy-saving solutions. The NOPL will make available to the NOEM information related to consumed energy through the Data Capturing and Processing service, as an STP would do. Alarms on the behaviour of the lighting grid will be treated internally, and only the ones affecting the neighbourhood grid performance will be propagated to the NOEM – e.g. an unexpected demand due to heavy rain requiring more electricity than planned is an event of interest for the local DSO.

Market driven interactions lie in the heart of the emerging SmartGrid infrastructure. The bidirectional information exchange will put the basis for cooperation among the different entities, as they will be able to access and correlate information that up to now either was only available in a limited fashion (and thus unusable in large scale) or extremely costly to integrate. From the business side new, highly distributed business processes will need to be established to accommodate these market evolutions. The traditional static customer processes will increasingly be superseded by a very dynamic, decentralised and market-oriented process where a growing number of providers and consumers interact (as depicted in Figure 3). Such an infrastructure is expected to be pervasive, ubiquitous and service-oriented. However the biggest issue to be tackled for all of these to be made a reality would be the development of open interoperable approaches (NIST, 2010). Various roadmaps such as the one drafted by the SmartGrids European Technology Platform (2010) as well as the Federation of German Industries (2010) provide an insight on the challenges and directions.
NOBEL explores the importance of local energy markets to enable better energy management at neighborhood level; which implies the horizontal interactions among the prosumers (via a brokering system) and the ability to provide analytics at local DSO level. The concepts are expected to be trialed in 2012 in the city of Alginet in Spain. We plan a number of prosumers to be able to use the brokering capabilities provided and buy and sell electricity in the local marketplace (also provided by NOBEL). The interaction is expected to be mainly done via mobile devices i.e. smartphones and tablets. Besides the normal residential customers in the trial entities controlling the public infrastructure will be present. As such the public lighting system of the city will be used to act as a balancing partner twofold: (i) at the first stage by offering its flexibility to better balance the local energy needs, as a result of management from the NOEM, (ii) and later experiment by having it offering this functionality over the neighborhood market.

Conclusions

NOBEL uses state of the art technologies to dynamically obtain and process information from current available installed equipment. This is achieved by implementing bidirectional communication with all involved entities, process the information with respect to consumption and production and automate decisions to be made network-wide. The project also develops a service oriented framework that will allow easy flow of information among the prosumers and the enterprise systems in order to foster more energy efficient processes. This implies the development/extension of a middleware – i.e. a set of application independent services – that enable the distributed capturing, filtering and processing of the energy related data. The same services will ease enterprise wide inclusion and allow for better cross-layer collaboration which will lead to holistic optimization strategies. NOBEL fosters cooperation approaches for all entities involved. Once the basic infrastructure supporting real-time monitoring and management, as well as the respective brokering services, then scenarios demonstrating how energy efficiency can be achieved will be realized. NOBEL will try out these concepts in the city of Alginet in Spain in 2012 and assess the results from a real-world trial.

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References


8. Session: eeB Data Models collaboration space


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Abstract

ICT4E2B Forum project aims to bring together all relevant stakeholders involved in ICT systems and solutions for Energy Efficiency in Buildings. Moreover the project has the objective of identifying and reviewing the needs in terms of research and systems integration as well as at accelerating implementation and take-up. ICT4E2B Forum bases its roadmapping activities on the outputs of REEB project that has already developed a high-level roadmap on ICT for Energy Efficient Buildings. Starting from this expert-based work, ICT4E2B Forum intends to promote, through community building activities, a better understanding, a closer dialogue and a more active cooperation between researchers, end-users/practitioners, building owners, technology-suppliers, and software. By accomplishing these objectives, ICT4E2B Forum is mapping the sector-specific priorities into a common view and vocabulary, thereby enabling communication and understanding between experts in different sectors that need to join forces in order that fundamental improvements in energy efficient buildings can be achieved. All this coordination work will support in defining future research directions as well as in channelling efforts, while favouring consensus buildings on the roadmap itself. Within this framework a relevant aspect is covered by Data Models, which represents an enabling infrastructure for the actual implementation of future ICTs in the EeB context and that covers all relevant priority areas identified by the project. Considering this important aspect ICT4E2B Forum created a specific collaboration space for sharing relevant results and discussion about EeB Data Models, in order to foster the discussion and extract relevant future scenarios and prioritization for the roadmap from this relevant area of research.

Keywords: ICT4E2B Forum project, REEB project, Strategic Roadmap, Stakeholder-based, Collaboration Space.
8.1.1. Introduction

Nowadays it is widely recognized that the great energy savings potential of the introduction of ICT technologies should be considered along the whole life-cycle of the built environment. On the other hand, the large set of potentially exploitable ICT technologies and the wide possible use-cases that can be considered in the whole building life-cycle, make necessary a prioritization of the efforts, identifying the most promising technologies and the most effective use-cases in order to efficiently direct the R&D efforts on the upcoming years.

There are several examples of such technology roadmaps developed or under development by field experts, but in most of the cases the presented visions lack, even if they are very relevant from a technical/scientific point of view, a consistent contribution from the stakeholders involved in the whole value-chain. There is a need to provide a wider vision not only from the technical point of view, but also from societal, economic, market, end-user and several other perspectives.

ICT4E2B Forum project aims to fill the above mentioned gaps by bringing together all relevant stakeholders involved in ICT systems and solutions for Energy Efficiency in Buildings, and the project aims at identifying and reviewing the needs in terms of research and systems integration as well as accelerating implementation and take-up.

It is important to underline that ICT4E2B Forum bases its roadmapping activities on the outputs of REEB project. This project has already developed an high-level roadmap on research and technology development in the area of ICT for Energy Efficient Buildings, therefore ICT4E2B Forum starting from this expert-based work, intends to promote, through community building activities, a better understanding, a closer dialogue and a more active cooperation between all the players of the building sector.

With reference to the above objectives, ICT4E2B Forum is identifying the building sector-specific priorities, organizing these into a structured classification, thereby enabling communication and competences/knowledge sharing between experts in different sectors that are joining their forces in order that fundamental improvements in energy efficient buildings can be achieved.

All this coordination work will support in defining future research directions as well as in channelling efforts, while favouring consensus buildings on the roadmap itself.

Within this framework an important emphasis shall be devoted to Data Models for Energy Efficient Buildings (EeBs), since they represent an enabling infrastructure for the actual implementation of future ICTs in the EeBs context. Data Models actually influence all the priority areas identified by the project, and, in particular, they are directly involved under “Tools for Energy Efficient Design and Production Management” and “Integration Technologies”.

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Considering this important aspect ICT4E2B Forum created a specific collaboration space for sharing relevant results and discussion about EeB Data Models, in order to foster the discussion and extract relevant future scenarios and prioritization for the roadmap from this relevant area of research.

The aim of this paper is to present the approach proposed within the project and show how the EE Data Models collaboration space can contribute to fostering future technologies roadmap. In Section 0 there are details on the main results of REEB project that will constitute a baseline for following activities. Section 0 shows the proposed approach for the ICT4E2B roadmap preparation is outlined. Section 4 details how the EE Datamodels Collaboration Site can contribute to the discussion.

8.1.2. Results from REEB as a baseline for ICT4E2B Forum

This section is based on the REEB project. The REEB coordination action (European strategic research roadmap to ICT enabled Energy - Efficiency (EE) in Building and Construction) was an initiative to identify the current state-of-the- research and best practices. The objective was to provide a vision in form of a strategic research agenda (roadmap) with supporting implementation recommendations for ICT supported energy efficiency in construction. During the REEB project, following items were covered:

- State-of-the-art and best practices related to the subject
- Gap analysis of research and technology development initiatives
- Structured roadmaps based on industrial priorities
- Recommendations for different innovation stages: policy, coordination, research and development, take-up, standardization, and education and training

In order to understand the transformation of focus from the initial construction cost to whole life performance, 12 key best practices, as described in table 1, were developed based on lessons from more than 80 case studies.

<table>
<thead>
<tr>
<th>✔ Simulation based energy design</th>
<th>✔ Early energy design</th>
<th>✔ Smart grids</th>
</tr>
</thead>
<tbody>
<tr>
<td>✔ Smart metering for energy consumption awareness</td>
<td>✔ Building Management Systems</td>
<td>✔ Wireless Sensor Networks for energy performance monitoring</td>
</tr>
<tr>
<td>✔ Standards based energy performance assessment software</td>
<td>✔ Energy performance audit solutions</td>
<td>✔ Integrated Modeling solutions based on Building Information Modeling</td>
</tr>
<tr>
<td>✔ Websites for collecting and disseminating energy-efficiency</td>
<td>✔ Standards-based solutions for building life-cycle management</td>
<td>✔ Standards-based energy data exchange solutions</td>
</tr>
</tbody>
</table>

Table 1: Key Best Practices described as a result of REEB
During gap analysis of research and development initiatives, five main categories of research were identified based on ICT trends and a review of more than 270 relevant projects of which 52 were more intensively analyzed. The identified research areas are as presented in the following Figure 1.

![Integrated RTD areas for ICT enabled Energy Efficiency in Buildings](image)

**Figure 1:** Key RTD areas for ICT enabled Energy Efficiency in Buildings

For each of the five areas, detailed roadmaps were developed as illustrated in Figure 2. The roadmaps covered a vision illustrated by exemplary business scenarios, drivers, barriers, impacts and short, medium, and long term research priorities.

To guide towards realization of the required actions identified in the roadmaps, several implementation actions were recommended covering policies, coordination of activities, research and technology development, dissemination and awareness creation, standardization, education and training. Implementation of these recommended actions are envisaged to lead to key industrial transformations within the construction sector through the role of ICT for energy efficiency in buildings.

The results obtained by REEB have been validated by key stakeholders from ICT, energy and construction sector. However, there is a need to extend this to a much larger stakeholder forum for refinement, endorsement and implementation. This initiative has now been launched through the ICT4E2B Forum (European stakeholders’ forum crossing value and innovation chains to explore needs, challenges and opportunities in further research and integration of ICT systems for Energy Efficiency in Buildings).
8.1.3. A proposed approach for Roadmap design

As mentioned before, the current work continues from results obtained in the previous roadmap work. Following Figure 3 represents the roadmap approach in ICT4E2B Forum. The gray items represent external contributions beyond the consortium.

**REEB roadmap:** The ICT4E2B Forum project engages experts and stakeholders from the ICT, construction and energy sectors to update and validate the Research and Technology Development (RTD) roadmap that was issued by the REEB project in October 2010.

**E2B roadmap:** This roadmap was prepared by the E2B Association in 2009. It broadly addresses RTD priorities for construction. The ICT topics were mainly provided the partners of the REEB project which was then ongoing. ICT4E2B Forum will suggest updates to the roadmap.

**Taxonomy of RTD areas:** Classification of research areas into five main categories (Table 2), each divided into three to four subcategories. The taxonomy is essentially unchanged from REEB.
The roadmap is being developed through following eight steps:

### Figure 3: Summary of the Roadmap Approach

<table>
<thead>
<tr>
<th>Main category</th>
<th>Subcategory</th>
</tr>
</thead>
</table>
| 1. Tools for integrated design and production | Design  
Production management  
Modelling  
Performance estimation |
| 2. Intelligent & Integrated Control | Automation & control  
Monitoring  
Quality of service  
Wireless sensor networks |
| 3. User awareness & decision support | Performance management  
Visualisation of energy use  
Behavioural change |
| 4. Energy management & trading | Building energy management  
District energy management  
Smart grids and the built environment |
| 5. Integration technologies | Process integration  
System integration  
Knowledge sharing  
Interoperability & standards |

Table 2: Identified five main categories and related subcategories
**State-of-the-art:** Identification of ICT solutions that are already been used by the industry and main results from recently completed research.

**Current RTD topics:** Topics and main expected results of currently ongoing research. Up to 100 European and national initiatives are analyzed.

**Vision of future ICTs & usage scenarios:** Extrapolation of future ICTs beyond the state-of-the-art based on current research, industry needs and ICT trends. Visionary stories how new ICTs could be used in 2010 and beyond. Scenarios are developed with external experts in workshops using template presented in Figure 5.

![Figure 4 Template used for scenario work](http://forum.ict4e2b.eu:8080/share/)

**ICT gaps:** Identification of required progress from the state-of-the-art to the envisioned future ICT.

**Prioritized RTD topics:** The vision and gap analysis is presented to experts and stakeholders. They are offered the possibility to prioritize the topics at workshops and via polls, questionnaires and discussions on the web forum.

**Initial roadmap:** The initial roadmap is based on the REEB roadmap. Prioritized RTD topics in short, medium and long term are highlighted and further elaborated.

**Final roadmap:** The roadmap is finalized based on validation workshops with experts and feedback from stakeholders. Recommendations will be made to update the ICT-related topics of the E2B roadmap accordingly.

### 8.1.4. A Collaboration Space for EEB Data models

The previous section has clearly underlined how the involvement of relevant stakeholders is fundamental for a common and shared vision on what are the future developments of ICTs in the EeBs context, to foster this agreed approach ICT4E2B Forum project set up an on-line collaborative environment ([http://forum.ict4e2b.eu:8080/share/](http://forum.ict4e2b.eu:8080/share/)) able to make available to stakeholder a virtual discussion arena where to share technical documents and paper as well impressions and comments.

On the other hand, Data Models represent an enabling infrastructure for the actual implementation of future ICTs in the EeBs context. In fact, there is an urgent need to merge (or at least ensure interoperability) data models and semantics of the different systems in order to allow a seamless and
agreed model able to operate through the whole building life-cycle. More in general, Data Models actually influence all the priority areas identified by the project, and, in particular, they are directly involved under "Tools for Energy Efficient Design and Production Management” and "Integration Technologies”.

For these reasons ICT4E2B Forum project decided to dedicate a separate collaboration space inside its collaborative environment. The aim of this space is twofold, on the one hand, ICT4E2B has the chance to gather in one single discussion context all the relevant stakeholders with the possibility of easily get their visions and priorities for the sake of the roadmap updating; on the other hand all the stakeholders interested on EeB Data Models have the chance to share in a common repository the outputs of their research activities, with particular regard to the developed data models. This will foster on-line discussion on formalization of the data models with the final aim of developing a (potential) harmonized data model.

Figure 5: User dashboard of EeB Data Models Collaborative site

ICT4E2B Forum EeB Data Models collaborative site offers different tools to allow an easy collaboration among the different stakeholders. All these tools are reachable from the user dashboard (see 5), namely:

A Wiki tool providing a shared knowledge base of issues related to Data Models for Buildings. It is worth to underline that the process of creation such a knowledge base is even more important of its final creation. To this aim the editorial policy of the Wiki is at the service of the goals of the site. The
minimum quality of a page is reached when the page is the result of the contributions agreed by at least three projects, or research teams or independent experts. Until then, it is declared as provisional, calling for more contributions. Changes to the content have to be agreed with the previous contributors, the “owners” of the page. In this way a consensus process is promoted;

A Blog tool where to announce relevant events and discussion topics;

A Document Library tool where all the different stakeholders can share and edit the outputs of the different research projects, with special regard to schemas and formalized ontologies, to this aim it also important to share them with agreed standard coding languages, as such RDF, OWL and similar;

A Links tool where links to websites containing relevant information are provided;

A Discussion Forum tool where discussion threads with respect to relevant topics can be launched.

Furthermore, different participation roles are considered, in order to provide different levels of rights on accessing the site. This has been done in order ease user participation without losing the scientific credibility that such a collaborative site has to maintain. The different roles are the following:

Manager, this role allows full control over site and it is allowed only to founding members and technical support providers;

Collaborator, this role allows uploading documents, adding wiki pages and launching discussions. The participants of relevant research projects on the topic can assume this role;

Contributor, this role allows participating to the discussion, and any stakeholder can access with this role after a screening procedure;

Visitors, this role is only for site reading without any write permission. Some defaults login visitor users are set up for the site visit.

Conclusion

ICT4E2B Forum project aims to produce a technology roadmap on ICT for Energy Efficient Buildings able to show a clear, shared and agreed vision of the different stakeholder involved in the whole value chain. In this paper the relevant reference elements and the proposed approach to reach the final goal of the project are presented.

REEB project results are relevant since they consider all the relevant issues coming from the technical stakeholders in the different fields involved in the topic of ICT for Energy Efficient Buildings. Together with an updated review of the Industrial State-of-the-Art they represent the baseline for the next activities of the project.

Starting from this reference base, the proposed methodology has been designed to actively involve relevant stakeholders in all the relevant phases of the process, they will be involved in fact by providing their vision and prioritization during the set-up of the roadmap, but also providing a continuous assessment of the project results during the iterative process of roadmap updating.
Since EeB Data Models represent an enabling infrastructure for the actual implementation of future ICTs in the EeBs context, ICT4E2B Forum project decided to dedicate a separate collaboration space inside its collaborative environment; in order, on the hand to gather in one single discussion context all the relevant stakeholders with the possibility of easily get their visions and priorities for the sake of the roadmap updating, on the other hand to give to all the stakeholders interested on EeB Data Models the chance to share in a common repository the outputs of their research activities.

The final ICT4E2B Forum shall therefore provide a high-level and wide-horizon vision of what will be the future challenges of research and technology development in ICT for Energy Efficient Buildings and what will be the most effective instruments to tackle these challenges.

References


Links

To visit the space as a visitor use:
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