European Commission

ICT for a Low Carbon Economy

EEBuilding Data Models

Energy Efficiency Vocabularies and Ontologies

JUNE 2012

Proceedings of the
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EEB Data Models Community
European Conference of Product and Process Modelling (ECPPM) 2012
Reykjavik, Iceland, 25th - 27th July, 2012

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1.1. Ontological Specification for the Model Integration in ICT Building Energy Systems

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Abstract

Integrated analyses and simulations of building energy system performance throughout the whole lifecycle can be efficiently achieved only if a sound integration approach with regard to the needed underlying data is provided. This data is highly distributed and heterogeneous, thereby implying the use of multiple models and resources. In this paper, we present the concept of a suggested multi-model framework that enables the targeted data and ICT tools integration. Described are the development methodology based on the IDM approach, the considered processes and use cases, the overall concept of the suggested framework, the envisaged information exchange on the integration platform and a first implementation prototype. The presented research is performed in the frames of the EU Project HESMOS (2010-2013).

1 Introduction

The European Commission has established a new Energy Performance of Buildings Directive – beginning in 2019 new public buildings shall feature zero energy consumption and Europe will be looking forward to achieve Energy Plus Houses (Directive 2010/31/EU, 2010). This ambitious goal requires application of holistic approaches for radical improvement of the energy performance of buildings through integrated design, monitoring and simulation, while balancing investment, maintenance and reinvestment costs. Our research, performed in the frames of the European project HESMOS (HESMOS, 2010), is directed to close the gaps be-tween existing building, environment and supplier data so that complex ICT-enabled life cycle analyses and simulations can be easily done in all relevant de-sign, refurbishment and retrofitting phases where energy saving potentials exist. However, efficient lifecycle energy performance of buildings is a very challenging inter-disciplinary area. It requires specialist knowledge about the building (architecture, construction), specialist knowledge about the in-stalled building services (HVAC, lighting, building automation etc.), specialist knowledge about materials, their properties and physical behaviour, specialist knowledge about the environment (climate, sunlight, soil) and specialist knowledge about the energy sources and supply networks, together with knowledge about operational and investment costs. For the achievement of ICT system integration it is therefore essential to provide a sound information framework based on a clear, flexible, re-usable and extensible modelling concept.

In our approach, we assume that such a frame-work can be organised on the basis of a standardised building information model (BIM) as developed within BuildingSMART (Eastman et al. 2008). However, while BIM provides the largest part of the needed information and will mark the starting point of the information lifecycle in each future building project, it cannot cover all needed resources alone. Therefore, we suggest *an energy extended BIM specification* (eeBIM), which comprises a multi-model framework with the open BIM schema IFC (ISO/PAS 16739, 2005) being the central schema to which all other information sources are connected. This multi-model concept is selected due to (1) the diversity of the data required in the overall lifecycle processes, (2) the integration of various ICT tools, which already use different modelling standards, and (3) the intention to use existing models on as-is basis thereby avoiding inflating the IFC model with additional classes and properties. Its realisation requires, at the outset, an *ontological specification*, which clarifies the information sources, their existing formal descriptions and semantics and their inter-relationships, as well as the needed links, mappings and model transformations in the energy-related lifecycle processes.

The paper presents the development method for achievement of the ontological specification of the envisaged multi-model framework, explains the principal structuring and content of the information resources, details some specific aspects of interest, describes the principal inter-model links and trans-formations and outlines briefly a first implementation prototype providing proof of the developed concepts.

2 Development methodology

As starting point of the research, the lifecycle pro-cesses are studied and the actors as well as the data exchange and sharing requirements are identified. On that basis, the needed information resources are categorised in an overarching taxonomy. The next step involves the technical specifications identifying data source formats and applications through which the data are transmitted, separating informal from structured (computer readable) data and identifying the inter-relationships. In the last step of the conceptual information framework specification, the trans-formation functions and links between the identified multi-schemas are defined.

In particular, 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 scenarios;
- Determining the respective information exchange requirements;
- Development of the eeBIM concepts, schemas and supporting methods and services;
- Specification of an ICT platform architecture;
- Implementation in CAD/FM software.

This complex sequence of tasks is typically handled in cooperation of end-users, modellers and software developers who all have different back-ground and expertise. Therefore, a grounded methodology that can bring together such multifaceted teams is necessary.

The methodology selected for that purpose is the Information Delivery Manual (IDM) developed in the frames of the buildingSMART initiative (cf. Scherer et al. 2004; Wix, 2007) and later standardized in ISO 29481 (2010a,b). In our approach, it is extended and adapted 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 requirements for the components of an integrated virtual energy laboratory (Liebich et al. 2011).

This information needs to represent requirements to the conceptual schemas that are to be selected and enhanced for the purpose of an energy-efficient BIM. Therefore the exchange requirements are further specified and developed as Exchange Requirement Models (ERM). This is an enhancement of the exchange requirements specification from software point of view as and it provides in addition:

- *The data source*, i.e. the application, service or database where the information is typically stored and to be made available;
- *The data format*, i.e. the data schema, exchange standard or transaction protocol that is typically used to exchange the information;

- *The transformation of raw data to the data format*, i.e. the mapping of the required information to the exact data fields (class/element and characteristic/attribute) within the chosen data format.

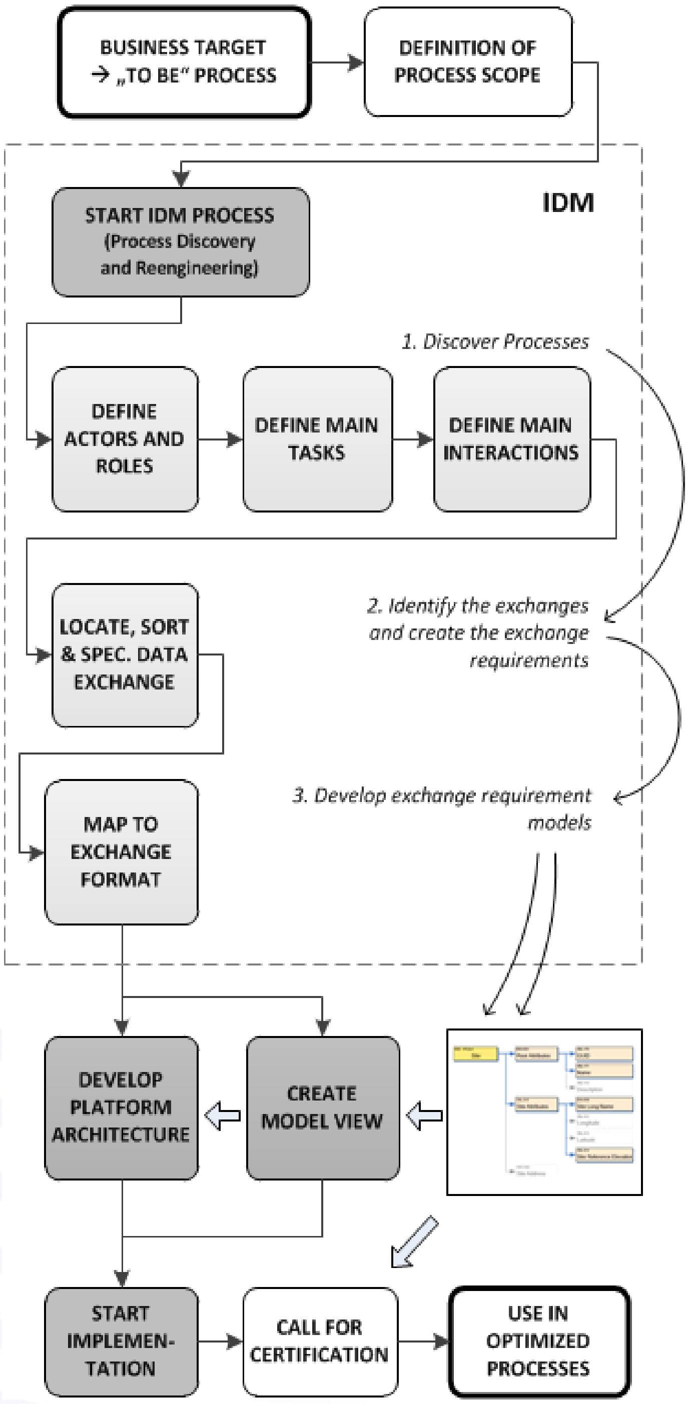

Figure 1. The IDM-based development process

In this way, the exchanges can be sorted, specified and mapped to the data exchange formats in structured manner. The overall process is illustrated schematically in Figure 1 below.

3 Considered Processes and Use Cases

In the HESMOS project four principal use cases are defined for the envisaged improved lifecycle process of buildings developed in PPP projects (Bort et al. 2011). These are: (1) Design Phase, (2) Com-missioning Phase, (3) Operational Phase, and (4) Refurbishment and Retrofitting Phase. In addition, the differences between the current 'AS-IS' situation and the envisaged 'TO-BE' process are elaborated in the form of detailed BPMN diagrams. On Figure 2, the main identified differences and the four principal use cases are synthesized.

The *Design Phase* (Use Case 1) has a key role in the targeted energy optimisation. The right choice of building services equipment in that phase is essential to achieve substantial later reduction of life cycle costs. This phase is best covered by energy analysis and simulation software, compared to all other life cycle phases. However, due to the current poor in-formation integration, available tools only weakly support advanced life cycle considerations. They are used with dedicated specialised models that are not linked with the building information model (BIM) data from CAD. 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* (Use Case 2) is very difficult to manage mainly because the building product must be rapidly put in operation. Here the automation of sequences with continuous monitoring, fast response to malfunctions and adjustment of the Building Automation System (BAS) are in the foreground. Simulation data and tools can be helpful in general but are overall of secondary importance. Primary roles in the process play the client, the building operator and the facility manager.

In the *Operational Phase* (Use Case 3), measured data can be evaluated. As a result, errors can be located and corrected. This is typically done by the operator on weekly basis. However, it is also desirable to assess user behaviour and include that in sub-sequent analyses and simulations. For that purpose, integration of BAS and BIM data is necessary. This is very 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* (Use Case 4) 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. Because of 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 feed-back of analysis results to the designers' BIM.

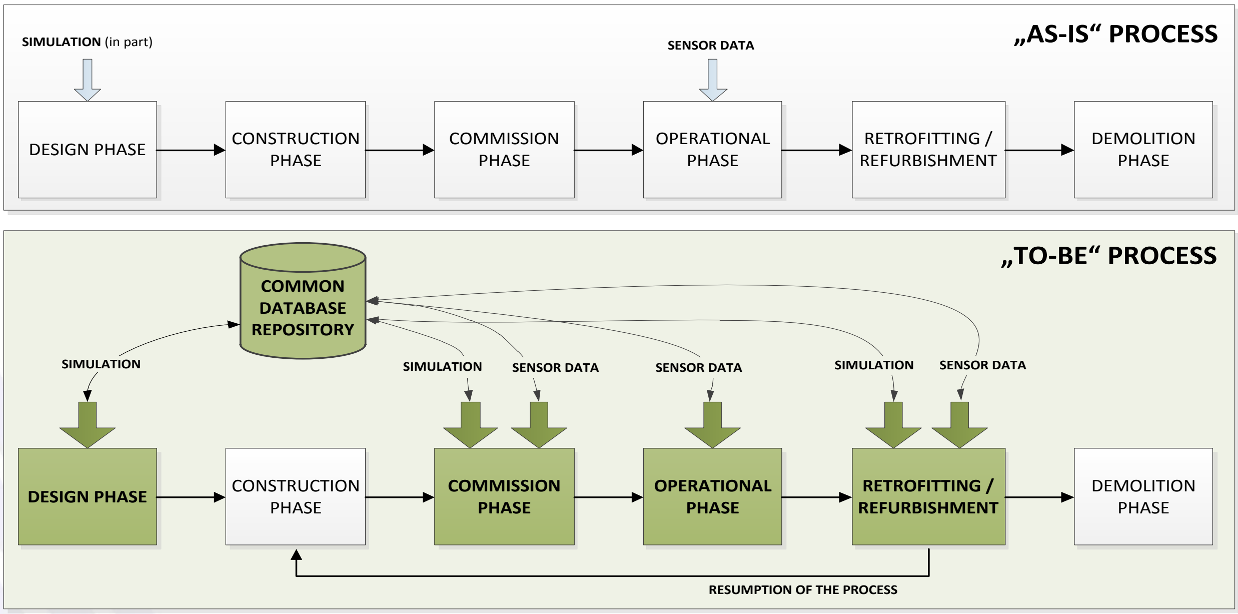

Figure 2. Comparison of the current "AS-IS" process and the envisaged "TO-BE" process in PPP projects

4 Conceptual Schema of the Integrated Mondeling Framework

4.1 Principal Approach

Using the methodology outlined in Chapter 2 above, the identified user and software requirements and the preset high level multi-model concept, a consistent approach with regard to the eeBIM framework of the envisaged integration platform has been developed. In particular, the eeBIM framework comprises a multi-schema architecture with the open Building Information Model (IFC) being the central schema other schemas are *linked* to. This overall concept has been selected because of:

- the diversity of data required in the overall life-cycle processes;
- the public availability of the well-established, standardised open BIM schema (IFC);
- the results of an internal investigation, showing that (1) IFC can serve as the central integrating model, anchoring any additional non-BIM model data, (2) multi-models are more flexible, and easier extensible to adopt for future needs, (3) minimizing changes to IFC is the approach with best chances for industry adoption, and (4) integration with existing software tools appears easier.

Figure 3 presents the main eeBIM component models that are required for efficient ICT building energy system integration in accordance with the use cases presented in Chapter 3.

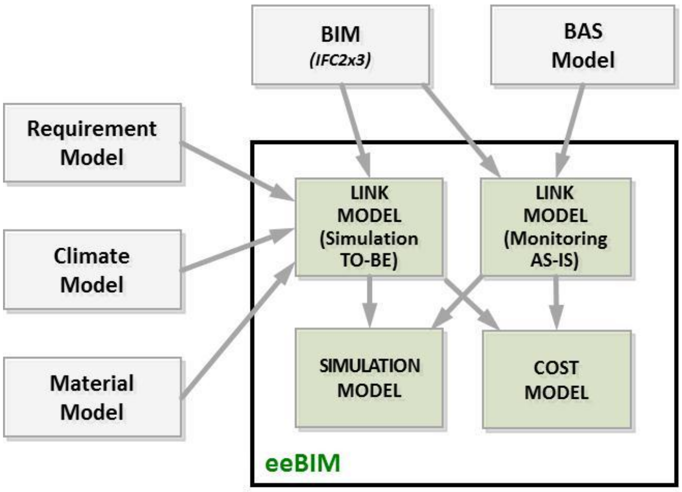

Figure 3. Schema level view of the modelling framework

The models outside the eeBIM box are developed independently of the AEC/FM community and are therefore to be treated as external models to BIM that should be inter-linked but not tightly integrated in the BIM schema. Basically, they provide inputs to the energy analysis, simulation and monitoring tools on building, space or element level. In contrast, the models included in the eeBIM box are more tightly connected because they serve the same process goals. However, it is also not very reasonable to "absorb" these models in the BIM because their specific purposes and the respective data structuring are quite different. The goal is, therefore, to prepare eeBIM in such manner that the needed inter-model links and the simulation and cost model data can be derived largely automatically by means of well-defined model transformation and management functions.

The following Figure 4 shows the main eeBIM component models with the involved model trans-formations embedded in the building life cycle. This figure essentially provides an activity-oriented perspective of the modelling framework, emphasising the needed information flows. 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 decisions 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 fore-cast 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-based integration of all other components in-to a consistent platform is shown.

As already mentioned, one of the main reasons for choosing the multi-schema approach is the diversity of data and data structures. Figures 3 and 4 highlight the various input sources that have to be dealt with. BIM data comes as partially instantiated model from the space program (mainly spaces with properties capturing space use and related client requirements) and is later completed via architectural and MEF CAD, adding building elements (walls, slabs, windows, curtain walls, etc.) and equipment elements (heaters, pump, fan, heat recovery units, etc.) to the building model. Those elements represent highly structured data, well covered in the open BIM standard IFC. 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 formats, 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, e.g. on the basis of the IFD standard (ISO 12006-3, 2007). Finally, in a later stage, data from BAS, such as sensor properties, measured values, configurations 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 for decision makers. All that information has to be pulled together into a coherent framework.

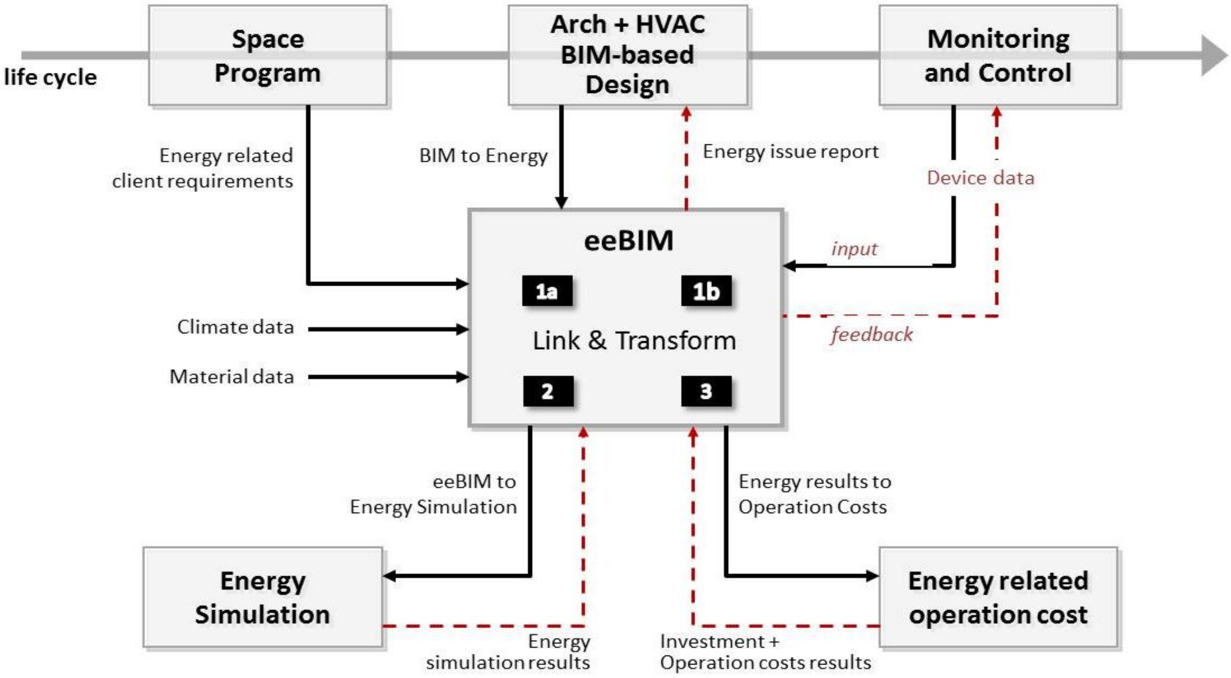

Figure 4. Activity-oriented view of the suggested modelling framework

Considering these multiple information sources, the overall conception of the eeBIM framework is established 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 data sources together and describing the semantics of the established links via added meta data in similar was as RDFS or Dublin Core (cf. 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. We use as baseline the specification developed recently in the German lead project Mefisto (Scherer & Schapke, 2011). It provides an 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 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, external 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 map-ping 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 in-formation 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, pre-diction 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.

4.2 Content of Non-BIM Information Resources

As already mentioned, three types of non-BIM in-formation resources are currently considered in the eeBIM specification, i.e. (1) Climate Data, (2) Material Data, and (3) Device Data from BAS.

In the context of eeBIM, climate data means the collection of climate elements related to a single unique geographical location as a function of time. Normally, climate data sets are stored in time steps of one hour over a period of one year. A climate data set can contain more than one measured data or (statistical) calculated data sets. The related single unique geographical location can be a city, a special place inside/nearby a city (e.g. airport) or a special landmark (e.g. top of a mountain). The climate dataset of such a single unique geographical location can be used as representative climate dataset for other geographical locations nearby or a region around the primary location with similar climate conditions. Climate data elements are, concisely, outdoor air temperature, relative outdoor air humidity, overall solar radiation on a horizontal plane, direct/diffuse solar radiation on a horizontal plane, wind direction, wind velocity, precipitation and cloudiness.

With regard to *material data* no general specifications, data repositories or standardised schemas and exchange protocols currently exist. There exist different resources as stand-alone data repositories, mainly managed by scientific organisations. These resources provide information in a quality that is applicable for the use in building simulation tasks with focus on energy related topics on general level. Examples are the MASEA database (Häupl and Plagge, 2007) and the NIST database (Zarr, 2006). However, if answers to questions related to building physics and building climatology like moisture transport are needed, material data on a more detailed level are additionally required to be linked to the eeBIM framework. The needed material data elements include the material name (used as key for the link to BIM), constant scalar values such as mass density, specific heat capacity and thermal conductivity, and a number of functional data tuples used as initial values for the generation of spline functions for the approximation of needed intermediate values. Such data tuples include sorption isotherm (relative humidity – water content), water retention (capillary pressure – water content), liquid water conductivity (water content – water conductivity), liquid water diffusivity (water content – water diffusivity), water vapour diffusivity curve (water content – vapour diffusivity), thermal water conductivity curve (water content – thermal conductivity), air permeability curve (water content – air permeability) and so on (Grunewald et al. 2011).

Device data from BAS are described on the basis of the suggested ontological concepts by Dibowski and Kabitzsch (2011). They include:

- Device name – used as key for the link to BIM;
- Functional profile - describing a typed set of inputs and outputs, e.g. Light Switch, Temperature Sensor, Occupancy Sensor etc.;
- Operation mode - defining possible different semantic meanings of a functional profile (e.g. a temperature controller running as PID or as two-point control);
- Parameterization Data – a set of configuration parameters used by a specific operation mode (this is useful since the configuration parameters of different operation modes of the same functional profile may differ).

Here it is important to distinguish between component *types* and their *instances*. Information about the component types can be stored in a central repository that can be used in the same way in different projects. In contrast, information about component instances (i.e. the real devices in a specific building) should be handled in a separate database for each project (Ploennigs et al. 2011).

4.3 Multi-Model Links and Model Transformations

We saw that in our approach the eeBIM specification is based on a *Link Model* of confederated data schemas with IFC as the main underlying schema. The elements of the other specialized schemas (climate data, material data, device data, occupancy schedules, etc.) are linked to components of the IFC data schema using the suggested link model approach. On Figure 5, the principal bidirectional data flows within the eeBIM framework and the involved model transformation types are shown.

The model links, binding all elementary models with the IFC model, comprise:

- *BIM ↔ Climate data*

Link to the IFC model via the high-level spatial structure objects site or building, represented by instances of the classes IfcSite and IfcBuilding;

- *BIM ↔ Material data*

Link to the IFC model via the corresponding material names provided as material characteristics to the relevant building elements that define a thermal zone, represented by instances of classes like IfcMaterial associated to IfcBuildingElement;

- *BIM ↔ Device data*

Link to the IFC model via the corresponding building services elements carrying the BAS de-vices, or via the space objects in which the devices are located, represented by instances of sub-classes of IfcDistributionElement or of IfcSpace respectively;

- *eeBIM ↔ Energy reports*

Link to the IFC model via the high-level spatial structure objects building and space, or via construction elements, aggregated groups of objects or reports (cf. IfcDocumentReference), depending on the context;

- *eeBIM ↔ Cost reports*

As for energy reports, link to the IFC model via the high-level spatial structure objects building and space, or via construction elements, aggregated groups of objects or reports, depending on the context.

The main model transformations that need to be supported are:

- *Spatial requirements to eeBIM*

Early energy-related requirements are typically provided in the form of spatial requirements definitions listing the spatial, functional, comfort and equipment requirements for each functional area. Such spatial requirements form a very early, conceptual building information model and are also available as IFC data. Particularly the comfort and equipment requirement information is needed by eeBIM for the early design phases.

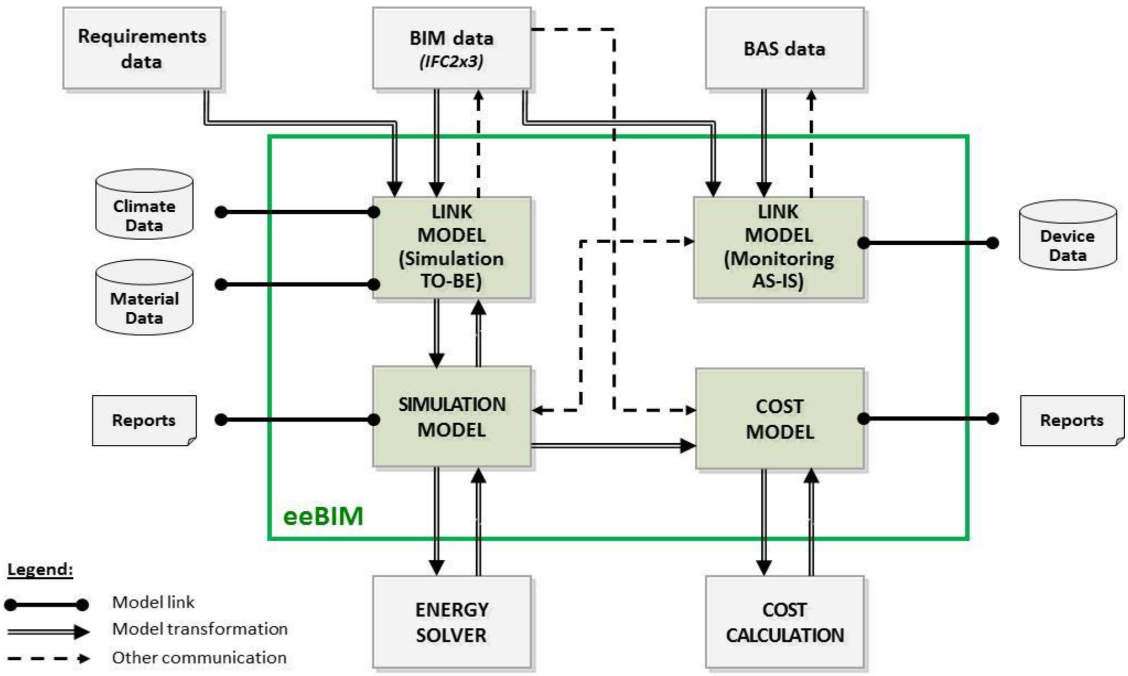

Figure 5. Principal model links and transformations in the eeBIM framework

- *BIM (CAD or FM) to eeBIM*

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 de-fines them on what is known as Level 1 representation. 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 (Weise et al. 2011).

- *Monitoring to eeBIM*

As indicated above, BAS data can be linked to BIM on the basis of the provided locational and typological information. However, the difficulty is to provide first a suitable BAS description, containing the needed metadata in neutral format. This requires a BIM-BAS ontology that defines concepts generalizing the data from the various used BAS standards today, i.e. LON, KNX, Bac-Net, EnOcean etc. (cf. Reinisch et al. 2008).

- *eeBIM to Energy Solvers*

Energy simulation models essentially employ the same data values that are already contained in the eeBIM, but structured completely differently. Therefore, here a typical mapping transformation 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 an 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 the data to it, thereby achieving higher level of interoperability on medium term.

- *eeBIM to Costs*

This transformation is in spirit the same as the described transformation of eeBIM to Energy Solvers. 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 of the overall life cycle can be worked out, such as the automated creation of single-zone simulation models from architectural BIM.

The mapping of IFC classes to eeBIM ontological specifications is straightforward whereby only a small subpart of the IFC schema is needed. The principal structuring is shown on Figure 6 below.

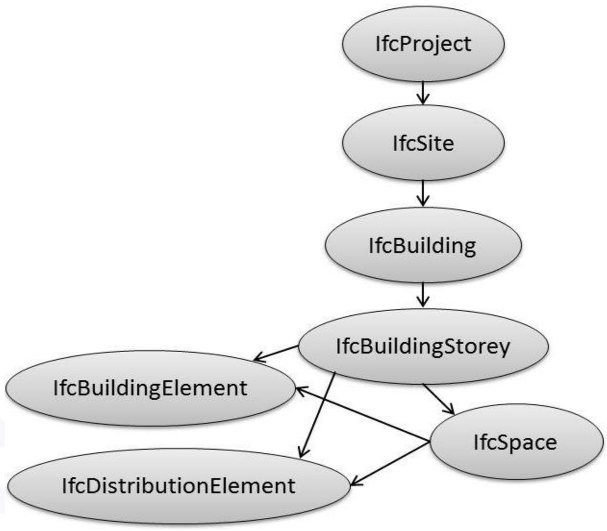

Figure 6. BIM ontology part

5 Information Exchange in the Integrated Mondeling Framework

5.1 Basic Issues

One of the most important criteria for selecting suitable exchange formats is the availability of open standard interfaces. Especially for public authorities it is important to be able to tender BIM-related services without enforcing specifications of proprietary software solutions. Recognising this fact, the public authorities in Finland - Senate Properties, Norway - Statsbygg, the Netherlands - Rijksgebouwendienst, Denmark - DECA, and the USA - GSA jointly gave a statement of Intention to Support Open Standards for Building Information Modelling (cf. GSA 2008, 2009). Following these considerations, the IFC data exchange formats SPF and IfcXML are suggested as the main data formats for exchanging building in-formation. However, since not all relevant data can be structured in a single super schema, our approach is to take existing models as they are and treat them as one interoperable multi-model space. Advantages of that approach are as follows:

- *Existing* and accepted data models can be used further without modification;
- IT *coverage* of building process information can be extended by alternative data models, as suggested, or by data models created in the future.

This shifts the paradigm from BIM-centred information management to a federation of coequal multi-models, thereby aggregating model instances of unmodified existing data schemas of possibly orthogonal domains and allowing explicit relations be-tween the instances by linking their elements.

The suggested generic multi-model approach in (Fuchs et al. 2010) aims at *exchanging linked domain models relevant to a particular task* of the entire information process. However, producing these links can be complex and expensive work. The resulting data structures represent special domain knowledge and should therefore be accessible for further information processes. Nevertheless, the suggested approach is not intended to give a single point of access to a construction project´s complete information resources. Rather than that, linking is intended to work on instance level, expressing the user´s intention and need to describe the relations between real world objects that are represented by different data models. Since such relations have a task-specific semantic and may allow different interpretation without further context information, the sender´s original intention must be recognizable by a multi-model receiver to facilitate correct further pro-cessing. Hence, the overall concept can be seen as a *semantic coupling* of elementary models. In that context, clear definition of the ontological concepts *Elementary Model*, *Multi-Model* and *Link Model* is essential.

An *Elementary Model* (EM) is an exchangeable instance of a data model with a delimited domain and clearly assigned semantic. It does not require a corresponding explicit schema, but the meaning of the data must be known to sender and receiver.

A *Multi-Model* is a serializable composite of a set of EMs and a set of Link Models having elements of the EMs as subject.

Finally, the *Link Model* is a serializable instance of a data model with a schema that stores references between elements of different Elementary Models.

5.2 Proposed Structure of a Generic Link Model

Links are the explicit externalization of references between the EMs. As most of the existing construction information models have identifiers for their elements, we choose an ID-based linking. In this way, links can be easily held outside of the domain models in analogy to relational database technology. In the suggested link model structure (Figure 7), the class *LinkModel* represents the idea of task-specific linking - each instance stands for a distinct combination of some of the EMs. Each contained link is expressed by an instance of the class *Link* where the narity of a requirement as well as the ability to have a higher cardinality is implemented by a collection of contained *LinkedElements*. Each instance of that class represents one EM element by using its ID in the attribute elementID. For convenience, the class *LinkModel* provides a reference to *ElementaryModel* having all the EMs which are subjects of the contained links. Therefore, an application does not have to inspect all *LinkedElement* instances to discover whether a *LinkModel* is relevant to it.

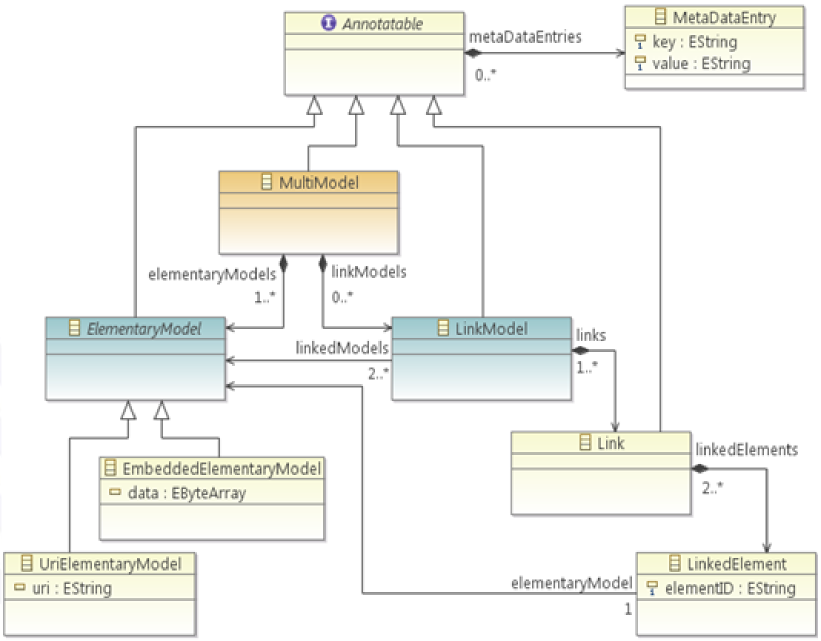

Figure 7. Principal class diagram of the Link Model schema

5.3 Elementary Models

After taking the different criteria such as format availability and openness into account, the following formats are selected for the specific exchanges in the targeted use cases.

The preferred format for exchanging data derived from an architectural BIM is the current state-of-the-art IFC 2x3 format and for extensions the soon to be published IFC4 (Liebich, 2010).

Climate and Material data transport is realized via HTTP using the transport/exchange layer TCP/IP. For writing the corresponding messages SOAP is selected, and for the interface WSDL. The preferred data format is XML, which is widely supported by various industry applications. Such XML documents comprise two sections: (1) meta-data, and (2) the actual content data as described in Section 4.2. Climate meta-data are the site address, the geographical position, availability and access rights information, data quality, available climate elements, available time periods and information about allowable or not data manipulation. Material meta-data include the material name, aligned with the IFD standard (ISO 12006-3, 2007) and the material category, if present. This type of data is especially important for a future realisation of an integration ontology for eeBIM, which will be able to reason about the data, thereby supporting intelligent queries, system suggestions and decision-making.

For Device data an approach independently of existing technologies like BACnet, KNX or LonWorks is suggested. As explained in Chapter 4, not the measurement data itself but data about the BAS devices has to be stored in the eeBIM. Basic information about this data is already available in IFC2x4 (e.g. *IfcSensor*), but it is not sufficient for evaluation purposes. Real devices are complex objects, which can combine functionality of several sensors. Also, existing device description languages like FDCML (FDCML, 2002) or EDDL (Riedl & Naumann, 2011) cannot be used because of their insufficient semantically defined vocabulary for automatic evaluation. Therefore, an ontology-based approach is suggested. The basic structuring of the device information is shown in the following figure.

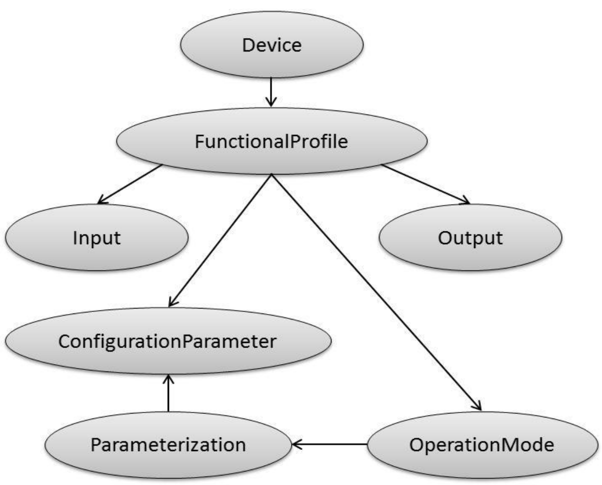

Figure 8. Basic structure of the exchanged device information

One device can contain several functional profiles, each having own inputs, outputs and configuration parameters. Sets of parameters for a given operation mode are united into parameterizations. This approach is independent of concrete technologies like BACnet, KNX or LonWorks and allows to be prepared for upcoming BAS technologies in the future. In addition to the data shown above, information about the access to the measurement data (a reference parameter) is stored, containing information about the network and the “way” to get the information. As with all other non-BIM data, the device information is exchanged in the form of XML. The link between the building geometry data (IFC) and the BAS devices is provided by connecting BAS devices to spaces or building elements, enriched by their exact position (coordinates). This information is needed for evaluation of the meaning of measurement data and for automatic finding of appropriate sensors for a given purpose.

6 Implementation Prototype

Using the described model integration approach a first implementation prototype has been developed as proof of concept and guidance for a further, more comprehensive realisation of the envisaged ICT platform. It is based on the SOA approach and is fully web-enabled. The GUI, accessible via a standard Web Browser is subdivided in four areas, as shown on Figure 9 below:

- a tree-like file browser (top left);
- a presentation area reserved for external applications launched through the platform, e.g. for viewing building information or simulation results (top right);
- an area for support information like geographical and climate maps (bottom left);
- an input area where the user can specify or modify certain properties (bottom right).

These GUI parts can be displayed within a single window or as separate (detached) windows on the platform. The second option is more appropriate when the results of an external application with an own complex GUI need to be shown. With this visualisation approach, it is possible to integrate flexibly various other applications into the main presentation area shown on Figure 9.

Currently, the following part of the identified eeBIM subprocesses has been realised:

- Level 1 to Level 2b space boundary conversion of the BIM data - an extension of the BSPro library (Karola et al. 2002) with full IFC support;
- Automated material mapping and linking;
- Automated model generation for the simulation of the thermal behaviour of rooms via the energy solver Therakles (Nicolai 2009, 2011);

- Principal linking of BIM and energy results and their presentation at the prototype platform.

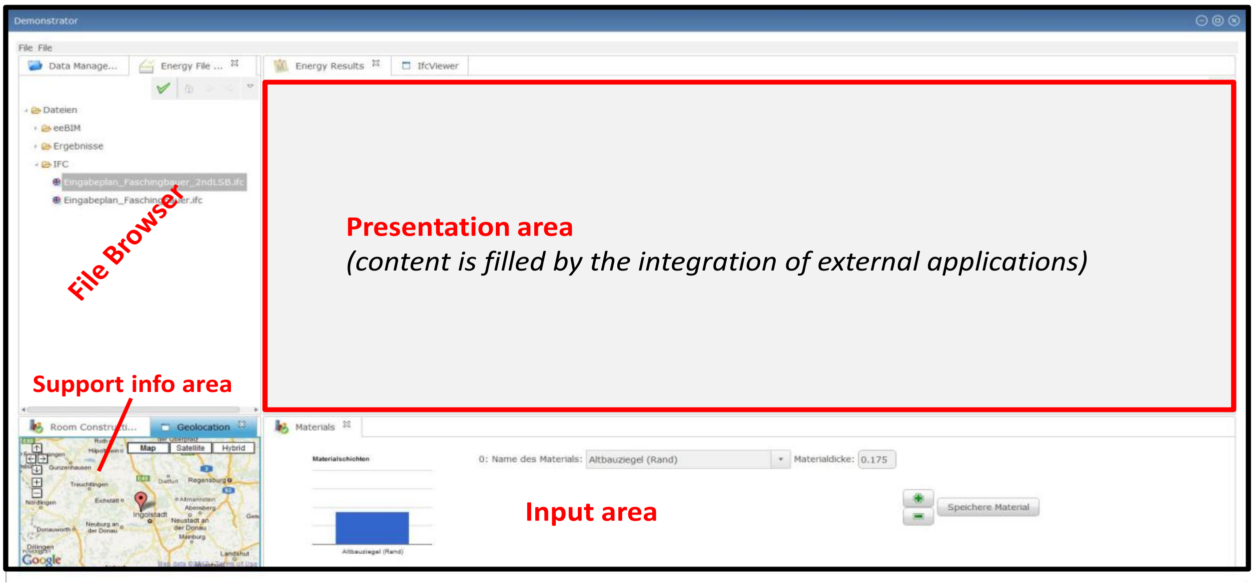

Figure 9. Graphical user interface of the prototype platform implementation

The whole process, starting with the BIM input from CAD up to the presentation of the obtained results is completely integrated and almost fully automatic. The user needs only to indicate the rooms that he wants to be examined and to select the type of result presentation. In the current prototype, we have implemented only basic presentation views where the user can inspect simulation results by diagrams returned from the energy solver (s. Figure 10). In the final platform, a comprehensive nD Navigator with considerably extended functionality and capabilities to present aggregated results will be used for improved decision-making.

After inspection of the obtained results, the user may modify some parameters of the building to run an alternative simulation. This is especially important when different design or refurbishment options need to be quickly checked and compared, regarding for example the use of different materials, different thickness of insulations, different glazing and so on. Currently it is possible to change, add or remove material of the building elements (walls, slabs, windows, doors) and set the thickness. In the future, broader possibilities to alternate the design will be provided, such as assignment of individual properties or property templates to groups of objects selected by various means (e.g. via zone definition, type of use, thermal response etc.). However, geometry changes and final change of the model will only be done in the BIM-CAD or the FM system at the responsibility of the respective actor in the process (designer, facilities manager, owner) in accordance with the defined use cases.

Web technologies used include WSDL, external communication via SOAP or REST and transaction management on the basis of the Spring framework (SpringSource, 2012). More details in that regard are provided in (Laine et al. 2012).

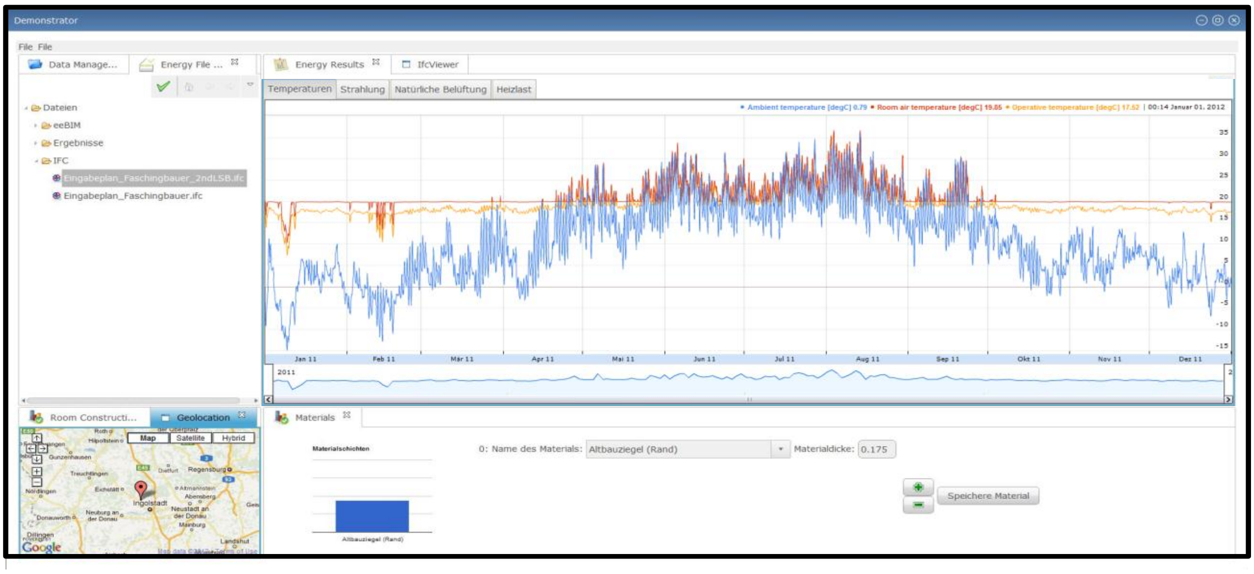

Figure 10. Visualisation of energy results on the prototype platform

7 Conclusions

In the preceding chapters of this paper we presented the major aspects and principal specifications of a suggested energy enhanced building information modelling framework (eeBIM) that is being developed for the HESMOS Integrated Virtual Energy Laboratory, but can also be used in other systems beyond HESMOS and is intended to be forwarded for standardisation (Liebich et al. 2011). The frame-work is based on an innovative multi-model concept comprising a consistent set of elementary models, with IFC-BIM as central integrating part and a Link Model to bind the distributed model data together. In addition, the adopted IDM development approach was extended and adapted for the needs of energy efficient ICT support in the whole building lifecycle. A clear development roadmap was worked out that not only serves the HESMOS project, but can be applied in many related research areas and application domains as well. Thus, a sound basis for technical formulation of the eeBIM and its software implementation was achieved.

Further work regarding eeBIM includes:

- Consideration of software developer and end user feedback including, in particular, as-needed revisions and extensions of eeBIM details with regard to energy simulation, device data from BAS, as well as viewing, inspection and navigation;

- Elaboration and harmonisation of the conceptual eeBIM framework to technical specifications for implementations;
- Realisation of the core Link Model in the OWL ontology language (OWL 2009), including model management and decision support extensions;
- Full integration and testing of the framework on the HESMOS platform and its validation in real-life pilots.

Acknowledgments

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1.2. Ontology-based Building Information Model for Integrated Lifecycle Energy Management

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Abstract

The growing application of the BIM (Building Information Modelling) methodology shows that the BIM (Building Information Model) needs some agreed limitations in its universe of discourse in order to remain manageable and to solve the interoperability with other worlds, like the Building Automation System (BAS) modelling. The fast developing domain of energy-efficient design and operation of buildings has put strong pressure on such developments because the vast quantity of information and data models not originally belonging to the AEC/FM domain need to be made interoperable with the BIM model. We propose an interoperability method based on description logic ontology whose core is provided by a Link Model containing rules and constraints, not only to connect dynamically any kind of models, but also to allow sound quality control of the links by supporting knowledge-based management methods protecting the end-user from possible errors by the exponentially growing possible links with the increase of the level of needed detail.

1 Introduction

Buildings are very individually designed and very individually configured compared to many other products of our daily life. Consequently, there is no overarching Building Information Model (BIM) covering all facets of a building product, but several complementing models over which the overall in-formation is distributed. These models may even be represented in different data structures and formats (Scherer & Schapke 2012). The question is: does that reflect only the status of an intermediate development step in the evolution of building data models or does it reveal an important fact, marked by the particular kind of information management possibilities and demands in the AEC industry? The AEC modelling community is currently at a corner point where it has to decide upon the future direction: to-wards development of one homogeneous data model with hard prescribed constraints for the interoperability of the various sub-models like STEP does (ISO 10303), or towards a more liberal federal approach of independent models, loosely coupled by some linking mechanism. With the introduced term BIM (Building Information Models, resp. Modelling) buildingSMART seems to go the second way.

The domain of lifecycle energy management is one of the application areas which strongly demand new ideas and methods to solve this dilemma. In this domain, the building cannot be treated as a complex, yet passive product, where information is continuously added, but not so much interacting. Rather, it has to be seen as a complex active product that is capable to adapt to its context, namely the timely climatic conditions on one hand and the timely user demands on the other hand. This means that the building is continuously changing its state and has a very dynamic behaviour. Moreover, the building energy system is redundant and should be timely optimized according to cost and environmental terms. It is also not an autonomous system, but a system interacting with its local neighbourhood systems as well as with the global energy supply system. We can therefore distinguish between additive information models, interacting internal information models and interacting external information models. They can be grouped together in BIM (building information model), BAS (building automation system model), BES (building energy system model) and BPM (business process model), just to name a few, but the most important of them.

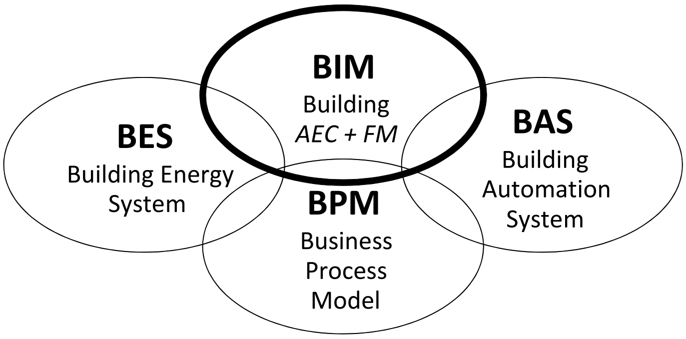

Figure. 1. Main interacting models in lifecycle energy management

2 Structuring OF BUILDING INFORMATION MODELS

BIM and in particular IFC (ISO/PAS 16739, 2005) was successively developed in the past two decades and the IFC model has grown from about 300 classes in version 1.0 (Kiviniemi, 1999) to meanwhile 775 classes in the current version 2x4 (Liebich, 2010). In parallel, research and proprietary extensions have suggested new classes, summing up to over 1000 classes today. Thus, while in earlier times the whole instantiated BIM model was exchanged between software application in a file exchange pro-cess, the request for the exchange of views has arisen and the IDM methodology for the definition of processes (ISO 29481, 2007) together with the MVD approach (Hietanen, 2006) for data view definition and the IFD approach for the definition of a common vocabulary (ISO 12006-3, 2010a,b) have been developed to reduce the amount of data to be exchanged and to avoid distortion of information by the application programs, which can happen for non-supported information.

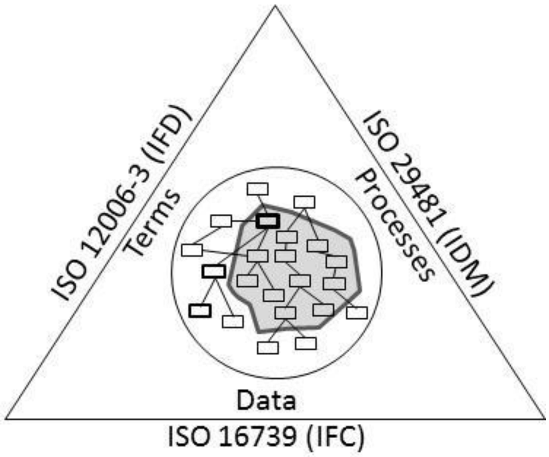

Figure. 2. Interoperability through standards

(adapted from: buildingSMART.org 2012)

By examining the current IFC data model one can already recognize various embedded domain models, which are made statically interoperable via the IFC interoperability layer. The overall BIM schema is sub-divided in a kernel model, i.e. the basic structuring objects of a building and several extension models such as the architectural domain model, the structural system domain model, the building services domain model etc. Implicitly, there is also a defined topological model, namely the room (space) model with its hierarchical aggregation in building storeys, building, site and project. However, the room defining instantiations, namely the grouping of building element to rooms, a gap free room model and the definition of functional zones are not mandatory and are not readily supported by CAD and FM systems. Hence, this very important aspect with regard to lifecycle energy analyses and simulations is left over to the end-users or their downstream tools.

Analysing the information content of these BIM models as defined in IFC, we can distinguish be-tween tangible object-defining models, like the core IFC model defining the basic building objects, additional tangible object-defining models, like the furniture model or the building services model, intangible object models, like the room model or the climatic zone model, and additive information models, like the structural system model or the thermal system model, which add new information to existing building elements and group them to new meaningful systems with specific functionality and goals. This is often connected with a re-arrangement of some building elements, resulting in a different geometrical definition, in the sub-dividing of existing building elements into smaller pieces and sometimes their grouping into new elements as already pointed out by (Scherer & Katranuschkov, 1993), which we now call the *Integer Problem of Object-oriented Modelling*. In the energy modelling domain, such sub-dividing appears in the form of the well-known space boundary problem (Bazjanac, 2010; Weise et al. 2011), with boundary levels from 1 up to 4. Another sub-model of this class of models is the façade system, which is for instance necessary for the energy efficient investigation with regard to solar radiation or for the wind-structure interaction (Windisch et al. 2012).

A first attempt for structuring of these information (sub)models is given in Fig. 3. This kind of structuring will be very important for the interoperability demands and the determination of interoperability information needs and related methods.

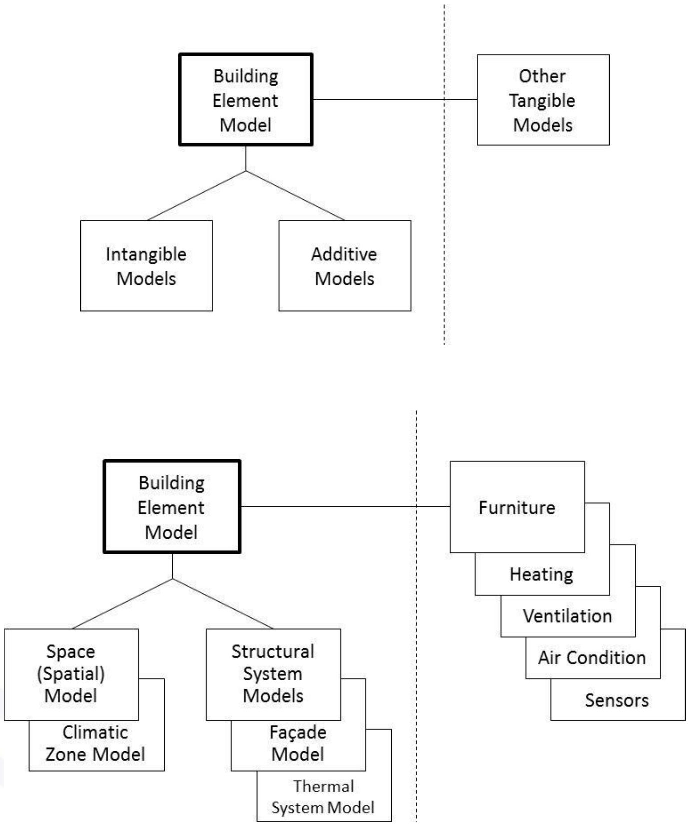

Figure. 3. Classification structure of the BIM domain models – classes (above), model examples (below)

3 Application Models

Domain models are rarely used alone (of course together with the kernel model), and there is seldom a need to use them always as a whole. The usual application is a combination of several views of different domain models. This is immediately recognisable when the building lifecycle is considered. Fig. 4 below shows the lifecycle information path of application models against the two axes Level of Detail (LoD) and Domains. In this figure, each black dot represents a view from a different domain model with an individual level of detail. The sum of all domain model views at an instant of the lifecycle represents an application model.

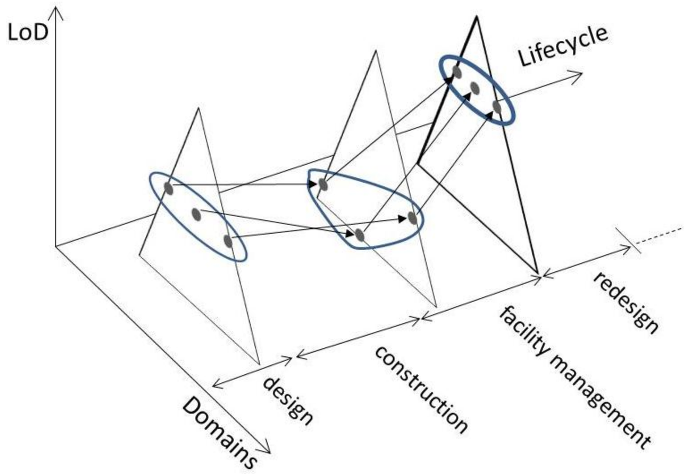

Figure. 4: Lifecycle information path of application models

At the very beginning of the design process, the information used from the different domain models is on a very general level, i.e. at a high level of detail, because the flexibility and variability and the focusing on the main topics, like costs, usability, energy efficiency, maintainability are the most important aspects. Later on in the progress of the life-cycle, the information is more and more detailed, which does not mean that the detailing is a deterministic process occurring in all domain models in a coordinated parallel way. It is on demand, i.e. the LoD requested from some domain models is higher than the one of others; hence instantaneous application models usually consist of a mixture of different LoDs of the domain model views. To keep track, i.e. to have the application models under control, interoperability methods between the objects of the different domain models in a different LoD status constituting one instantaneous application model are needed as well as the interoperability between the different LoDs in one and the same domain model.

Instantaneous application models are the result of an activity, e.g. the preliminary design or only the principal energy system mixture in the preliminary design, or the cost estimation for the total energy over the life-cycle from the perspective of preliminary design. This means that the process model of the life-cycle is determining which application model is needed and when. This was already extensively elaborated for the construction phase by (Scherer & Schapke, 2011) where several domain models and their structuring into an overall framework have been defined and the methods for multi-model management have been developed. The information needs and a suggested multi-model framework for integrated lifecycle energy management are ad-dressed in (Guruz et al. 2012), where the generation of an energy simulation model from a set of distributed information resources (BIM, user requirements model, climate model, element material and construction templates) is discussed. In these works, first suggestions for the solution of the interoperability and integration issues regarding the use of multiple information models for a specific design, construction or facility management tasks are made on the basis of a *Link Model* relating the unique identifiers of object instances in two or more models with each other. However, many interoperability problems require more detailed semantics and management methods to be successfully resolved.

4 Interoperability of BIM and Related Information Models

The different BIM (sub)models constitute the BIM multi-model. These sub-models are not put together side by side but interlinked by constraints and relationships in order to properly tackle the information interoperability. In IFC, this is achieved via a whole set of classes specialised from the kernel class IfcRelationship and a number of constraint defined via EXPRESS WHERE rules (Liebich, 2010). The problem becomes considerably more complicated when a multi-model framework of BIM and other external models have to be considered, such as a climate model or a BAS model in the energy domain. In principle, each instantiated object of each of these models can be interlinked with any other object in the other models. Therefore, theoretically, the maximal possible overall link model is the cross product between all sub-models, i.e. it is an exponential problem, which can never be managed by hand. First developments towards multi-model integration with the help of a link model were undertakenen in the German Mefisto project, where the basic link model structure and the information exchange via multi-model containers have been investigated (Scherer & Schapke 2012). However, the exponential problem has not been addresses there but the definition, representation and exchange of multi-models have been in the focus of research. In Mefisto, a link is still simply defined as a relation between any two objects belonging to two different models, i.e. a link is technically a tuple containing two IDs.

5 Ontology-based Link Model

In accordance with the above considerations, the link models have to be kept minimal for the multi-model approach to be efficient. Hence, a link has to be described in generic way and the specialisation of its instantiation on different levels of detail has to be derived largely automatically, selecting the appropriate objects in the inter-linked models by means of knowledge-based and model management functions with the help of generic templates, rules and constraints using OWL DL (OWL, 2009) and SWRL (Horrocks et al. 2004) technology.

To create an integrated view for the needs of a specific application or task, both the related domain models and the level of detail have to be taken into account. As an example from the area of lifecycle energy management, consider the inter-linking of BIM and BAS data. Fig. 5 below shows the dependencies between a certain sensor and the building object that is monitored. At the abstract level of both object representations the relation between the sensor and the corresponding building element can be identified as mandatory because of the tangible character of the sensor model. This dependency is responsible for the influence detailed information has on both objects. Details about the type and the functional profile of the sensor (room temperature sensor, room humidity sensor, occupancy sensor etc.) restrict not only its attributes range like the geometric arrangement (hidden sensor, area sensor, etc.) and the exact function (thermistor, resistance temperature detector, etc.), but may also reduce the needed attributes of the corresponding building element.

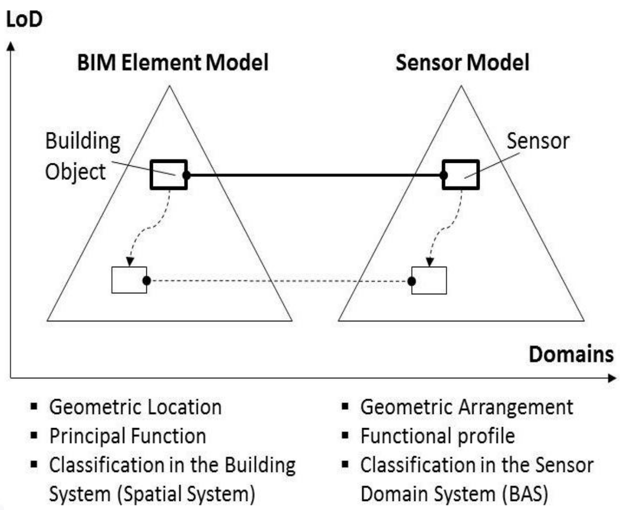

Figure 5. Schematic presentation of the Link Model concept

Overall, the process of linking two or more do-main model elements requires identification of the correct dependencies, which can be quite complex in certain situations. It is possible that a link has to be set from one object in the first model to a group of objects in the second model, where such a group may even not yet exist. As an example, the solar radiation (as element of a climate or weather model) on the south-west façade (group of building elements, which is usually not defined as such in the architectural BIM) may be required for a specific energy simulation task. Inversely, several sensor devices from the BAS model may be associated to one space (or even subspace) in BIM. Examples of M:N relationships with additional rules and constraints al-so exist and have to be taken into account. There-fore, in order to adequately support the creation and the validation of link models, an approach based on description logic is proposed. It provides a method for developing a *link model ontology* by applying three steps of formalization. They are described in the following sections along with an alternative method, optimizing development work.

5.1 Step 1: Ontology-based formalization

The idea of the ontology based link model definition is to offer a method for describing and analysing link types on class level. Following the approach of the application model information path (Fig. 4), the starting point for the formalization of the link types is formed by identification of relevant domain model combinations for a concrete lifecycle phase and pro-cess. Each combination of model classes represents a certain link type annotated with the corresponding lifecycle phase. This definition of link types is equivalent to the definition of templates and can be applied for describing and validating aspects of combined domains. Link types can be characterized as mandatory, optional and transitive. The latter can be derived via available additional relationships, thereby reducing the amount of information that has to be stored in the ontology.

5.2 Step 2: Interdependencies among model views

The resulting link model after the first step describes all possibly appropriate relations on domain model level. By identifying relevant views for each model, even without the concrete information of the included classes, the previously identified model dependencies can be concretized for these views. The combination of domain views represents the resulting new link types and - from programmers' point of view - the resulting new templates. For the selection of a new link type and filtering unneeded model dependencies out, a second selection criterion has to be applied. It is formed by examining the targeted application model(s).

5.3 Step 3: Interdependencies among element types

In this step, the content of the domain model views has to be considered in the ontology to get a more detailed definition of the link types. Therefore, identification of the so-called domain core concepts becomes necessary. Core concepts are classes representing the relevant content of each domain model on an abstract level (e.g. storey, wall, column, etc. for the BIM element model). They form the basic linking points for a lean global schema integrating the underlying different domain model schemas. Similar to the previous steps, the link types are de-fined in detail by identifying the appropriate dependencies using the detail level as criterion.

5.4 Using link types as building blocks

The identification of the necessary link types needed for each formalization step is a process, which can be only partly supported by computer-based methods. Many of these methods are rule-based methods, as e.g. the selection processes, which use semantic web technology to derive the correct combinations automatically. However, many links must nevertheless be specified manually. Providing a method for the reduction of this manual work would not only make the creation process but also the process of combining different link models more efficient. Therefore, as alternative modelling method, the definition of link types as building blocks is suggested. In contrast to the previous approach of a facet taxonomy (Lifecycle –Application Domain – LoD) forming the starting point for the link model development, here a set of *preconfigured link types* which are only partially instantiated is used. The definition of such types is based on the idea that for most applications only a small amount of changes to such preconfigured types will be necessary to adapt the ontology link model.

6 Conclusions and further Work

In the previous chapters, an attempt was undertaken to define a visionary concept for multi-model information management based on description logic ontology. The ontology approach has been chosen to:

- provide for interoperability regarding domain-external information;
- allow federative arrangement of domain-internal information, distributed over several interacting, but independent data models with different data structures and formats;
- support the flexible specialisation and instantiation of inter-model links;
- support the quality management of the interoperability links (not discussed in this paper).

The proposed approach is currently under development. First results have been demonstrated in the German Mefisto project with regard to multi-model management, multi-model information exchange via multi-model containers, multi-model linking of arbitrary cardinality using ID-based links, and multi-model filtering and visualisation through generic services based on a developed filtering toolbox, BIMfit (Schapke & Fuchs, 2011). This research is now being extended in the European FP7 projects HESMOS (2010-

2013) and ISES (2011-2014) in the direction of a multi-model energy enhanced BIM framework (eeBIM) and an overarching ontology for meta information management and interoperability (OntoBIM) respectively. The outlined ontology approach will be intensively further investigated, elaborated and validated in the frames of the ISES project. Additional research and development support is provided also by two other projects, where the focus is on different engineering applications of a virtual engineering laboratory based on the multi-model approach, namely the EU project SARA dealing with wind-structure interaction and the German project GeoTechControl, dealing with the intelligent identification of geotechnical systems. In all these projects, the balance between description logic support and performance is seen as a critical issue. Therefore, in ISES a hybrid solution aligned with the suggested conceptual approach is sought on technical level, where description logic (OWL DL) will be used predominantly for the lean Link Model, whereas the overall information framework is represented by standard object-oriented data structures (BIM), databases (climate, detailed material descriptions) and XML product catalogues (prefabricated elements, templates etc.).

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1.3. From BIM to BEMS, covering the Design- and Operational-Phase Interoperability Gap

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Abstract

This paper deals with the FP7 EU project "Building as a Service" (BaaS). The BaaS project is a research initiative which aims at providing a generic solution for delivering standardization and interoperability concepts for building data and open middleware platform covering the Design- and Operational-Phase In-teroperability Gap in the application domain of "non-residential buildings." There are two important phases in the building life-cycle: the design phase and the operational phase. Development and integration of ICT tech-nologies can help best coordinate the building design and operation phases. Overcoming interoperability gaps between both phases so as providing a way of integration to use existing and future tools and services would help to enhance building operations and controls. Better design, standardization and interoperability can con-tribute themselves to the goals of improving energy efficiency. Interoperable components working as services at the building level, will lead naturally to the concept of the Building as a Service ecosystem. This paper aims at analyzing some of the BaaS project topics: (1) building data management and interoperability: data warehouse to collect, organize, store and aggregate static and dynamic data from various in- and out-of-building sources; an IFC-based BIM will act as a central repository for all static building data, and a data warehouse will be used for dynamic data, both schemes mapped using a unique vocabulary. (2) Integration of building energy management Services using Open Service Middleware Platform technologies. A service middleware platform to abstract the building physical devices, support high level services on the cloud and facili-tate secure two-way communication between the physical and ICT layers (building) with high level services (cloud).

1 Introduction

The discussion on energy-efficiency in the building sector has become ubiquitous, as has become the ef-fort of achieving improved operational performance along with a lower lead time from building design to commissioning, and the development of tools to support facility management and operation. The de-velopment and integration of ICT technologies can help best coordinate building design and operation and thus contribute to achieving energy performance objectives. Still despite significant advances there exist no tools that are capable of streamlining the whole process and achieving in a systematic and well-defined way design objectives.

There are two important phases in the building life-cycle: the design phase (along with subsequent retrofitting phases) in which design decisions signif-icantly affect subsequent performance; followed by the operation phase where the Building Energy Management System (BEMS) ensures a parsimoni-ous and effective use of the available resources. Achieving energy efficiency requires mitigation of both design-phase and operational-phase inefficien-cies.

In the design phase, issues of collaboration and in-formation interchange are crucial (Shen, 2010) for the successful orchestration of the different teams (including architects, engineers, contractors, owners, site planners etc.) and for achieving many, – often conflicting, – requirements and constraints imposed by the different teams involved. In current practice, during the initial phases of design, different tools are utilized with little or no connect between them (Van-lande, 2010), (Singh, 2010): ineffective communica-tion (of files and documents) and lack of standardi-zation between the various teams involved along with incomplete information incur significant delays to the design and construction phase, and design er-rors are easily introduced (and overlooked) that re-quire retroactive actions

In the operation phase, designing the building monitoring system and also incorporating decision strategies is a laborious task requiring expert knowledge. Buildings viewed from a systemic view-point are becoming increasingly complex: they have a wealth of energy systems that have to operate har-moniously together; they have to respond to signals from the grid; the atypical availability of energy through Renewable Energy Sources (RES) has to be effectively utilized; and graceful degradation of per-formance has to happen in case one or more of the building subsystems fails or goes offline. More to that, changes on the building components (through refurbishing, installation of new systems and/or sen-sors etc.) and characteristics (degradation of perfor-mance) during the operational life-time of the build-ing present formidable problems in reconfiguring and updating the BEMS. And last but not least, building users largely stay out of the loop and their actions inside the building can have detrimental effect on energy efficiency and building performance.

The fact that the BEMS is configured once during the initial installation along with possible reconfigu-rations during subsequent retrofitting phases repre-sents a very static (and limited) view. Even more, the separation and discontinuity between design- and operation-phases seems unnatural. The availability of BIM description during the initial phases is essential for effective information interchange; but in the operational life-time of the building this description can be updated and can evolve dynamically, to de-scribe and reflect actual changes in the building.

This paper deals with the FP7 EU project "Build-ing as a Service" (BaaS) < http://www.baas-project.eu >. The BaaS project is a research initiative which aims at providing a generic solution for deliv-ering standardization and interoperability concepts for building data and open middleware platform covering the Design- and Operational-Phase In-teroperability Gap.

2 Building Data: interoperability and standarization.

Current building environmental and energy man-agement systems are focused on building control and automation. As long as building energy management systems (BEMS) succeed in maintaining set envi-ronmental conditions (e.g. temperature, relative hu-midity), the client has shown little interest in access-ing/analyzing the environmental and energy data being utilized by the BEMS and associated data log-ging meter equipment (Maile, 2007). Monitoring and targeting (M&T) software tools attempt to address this situation when a client/facility manager requires this data. This tools 'communicate' with a variety of data streams from stand alone and/or multiple building management systems and data loggers usually in the form of ASSCII and/or CSV text files (Keller, 2008). This has resulted in ad-hoc fragment-ed systems development of building environmental & energy management systems.

All designs of M&T systems are reactive to exist-ing installed BEMS infrastructure. Also, clients are not encouraged to retrofit such systems to effect bet-ter energy management because of the prohibitive costs of these systems. The limitations of current en-vironmental & energy management systems lie in their infrastructure (cost restrictions) and in the unre-liability and inaccessibility of the environmental and energy related data across a fragmented BMS infra-structure. The emerging EU directives relating to energy (EU EPBD and the EU Directive on Emis-sions Trading) now places demands on building owners to rate the energy performance of their build-ings. This creates demand for integrated and reliable building environmental and energy data.

2.1 Building Automation Systems

Building Automation Systems (BAS) have made tremendous strides in recent years toward embracing connectivity and interoperability standards. These efforts have given building owners more freedom to choose among manufacturers for both products and service support. Even greater benefits await an or-ganization whose BAS is seamlessly merged with its information technology architecture. The synergy created by sharing infrastructure and data reduces operating costs and creates new service opportuni-ties.

Building automation system manufacturers have accelerated the rate of open protocol device devel-opment to BACnet® (www.bacnet.org) or Lon-Mark® (www.lonmark.org) interoperability, or both. In the new world of convergence, systems that claim to provide interoperability and conform to industry standards also must provide connectivity to a variety of equipment that integrates seamlessly into the net-work. Neither BACnet nor LonMark alone provide a complete answer for the vision of total enterprise information compatibility. A better solution is to apply the new standards for interoperability, such as XML-based communications applications, in order to achieve all of the benefits that each protocol offers individually. In general, systems that require in-teroperability on a broad basis will be best served if they support multiple protocols.

eXtensible Markup Language (XML) is the uni-versal language of Internet data exchange, and can be called across platforms and operating systems re-gardless of programming language and offers an op-portunity to use web-services. The Web Services model provides information to diverse requestors of information. This opens the floodgates for a new class of information-rich applications to be delivered anywhere, anytime across a network that is in place and inexpensive.

With true convergence, stakeholders are empow-ered to obtain more information on a by-request ba-sis and in a manner that is more easily understood by any technology system within the building or by the stakeholders. This integration level opens opportuni-ties for stakeholders that were not technically or economically feasible in the past.

2.2 Building Information Model and DataWarehouse

Building Information Modeling (BIM) presents a vi-able solution for information inter-change by estab-lishing, through accepted standards, a common lan-guage to describe architectural, structural and energy concepts in the building. It can therefore help estab-lish a stronger (and more direct link) between various stakeholders. The Industry Foundation Classes (IFC) (currently ISO/PAS 16739 and with the new version IFC2x4 destined to become ISO/IS 16739) provides consistent frameworks, of sufficient granularity, capable of describing all pertinent details (www.buildingsmart-tech.org).

Often, the failure of the operation and performance of buildings is a result of insufficiently integrated representation for building products, process and control resulting in an inappropriately defined build-ing performance criteria (Wong, 2005) and because an information loss regarding the intended building operation strategy as the building progresses through the building lifecycle (NIBS, 2011).

3 Building energy services integration: open middleware platform.

IT systems for Building Management (BMS) control and monitor the building's mechanical, electrical and energy equipment (e.g. HVAC, lighting, power). Their functionality might include links to Facility Management Systems (Schach, 2004), Enterprise Management Software (Malatras, 2008), and offer web services (Malatras, 2008), (Wang, 2002), (Wang, 2007), (Jang, 2008). BMS are usually com-plemented by fire, and security systems. They con-sist of an interface layer to the usually Ethernet-based network backbone using management layer protocols like BACnet, OPC, SOAP, etc. (Malatras, 2008), (Wang, 2002), (Jang, 2008), to communicate with gateways connected to the field level network protocols (BACnet, LON, EIB/KNX, EnOcean, ZigBee).

The Building Management IT systems require to access and to utilize heterogeneous resources of dif-ferent devices, subsystems and external resources. The systems often need to process, filter and route emerging data in a scalable manner, given the other challenges, such as volatility of network and mas-siveness of volume of data.

3.1 Service Oriented Architecture concept for System Integration

Service Oriented Architecture (SOA) is a core con-cept for middleware platforms in order to organize IT resources and data collectively, to enable integra-tion between different technologies and to allow for standardized data interaction (Bell, 2008), (Valipour, 2009). SOA focuses on interoperable, robust, reusa-ble, and composable services that abstract the appli-cation functionality and data of each technology (Fowler, 2002).

Two important aspects of implementing a success-ful SOA are Web Services and their ontology (data models).

While Web Services (Malatras, 2008), (Wang, 2002), (Wang, 2007), (Jang, 2008) are partially inte-grated in Building Management Systems, there is currently not yet a consistent Service Oriented Ar-chitecture approach available for building control systems (Malatras, 2008).

The middleware solutions are often tailored for individual applications. There are also some solutions that adopt "programming abstractions" that have been successfully used for many years in distributed computing.

Since the emergence of Web Services and their wide area of applications, the SOA- and Web-Service-based technologies are also utilized to de-velop middleware solutions for various areas.

The SOA-based middleware solutions allow to re-duce the complexity and to offer high-level service-specific interfaces to access the data. While the cur-rent middleware solutions introduce flexible and loosely coupled methods, there are issues such as in-teroperability, efficiency, scalability and aggregation of service and the emerging data from Internet Con-nected Objects that require further research and de-velopment.

3.2 Connectivity to Building information Model

The BIM encompasses building geometry, spatial re-lationships, material specifications, properties of building services components, etc. However, current BIM's capabilities are limited regarding their man-agement and control functions or their performance analysis of buildings. On the other side, features of Service–Oriented computing, such as standard pro-tocols, loosely coupled components; ontology-enabled dynamic discovery and composition of SOA seem to be capable to address these deficits of soft-ware systems in the building construction and build-ing controls domain. The potential gains of applying SOA techniques have not really been discovered.

4 BAAS solution

The BaaS approach is considering three layers archi-tecture: the data layer which is used to collect, store and aggregate all static and dynamic data regarding the building; the middleware layer to abstract the building and its subsystems and allows transparent two-way communication between the physical and the ICT layers; and the service layer where high-level services could be provided. A "separation of concerns" approach is adopted to help manage the complexity and provide a generic and widely appli-cable solution.

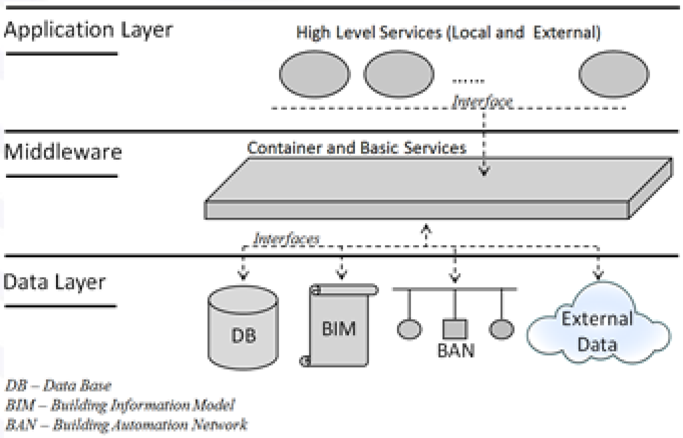

Figure 1. Components and global architecture in BaaS.

In that sense the BaaS system is not just a Build-ing Energy Management System but rather a next-generation holistic interactive multi-player extensible enterprise building management system capable of providing access-to and integrating most aspects of building operation in a harmonious and effective manner.

In addition, special care will be taken that the BaaS platform ensures secure interaction between all stakeholders and enables privacy protection where appropriate.

4.1 Data Management Layer

At the data layer, the use of Building Information Modeling (BIM) using the open soon-to-be-standard IFC (Liebich, 2010) will be used as a central reposi-tory for all building-related information. The upcom-ing IFC2x4 specification has new and consistent definitions for building systems, services and controls that we intend to fully utilize.

A "BaaS view" of the data model will be created with all pertinent to our system information and ap-propriate interfaces will be created for interacting with the BIM. In addition to static data, all dynamic-data (i.e. ones obtained through sensor measurements) are to be stored and aggregated in a "data warehouse" (Ahmed, 2010) that will be automatically generated from the BIM sensor information descriptions, and will be able to obtain data through the middleware layer of the building, and will make them available to the high-level services in almost real-time.

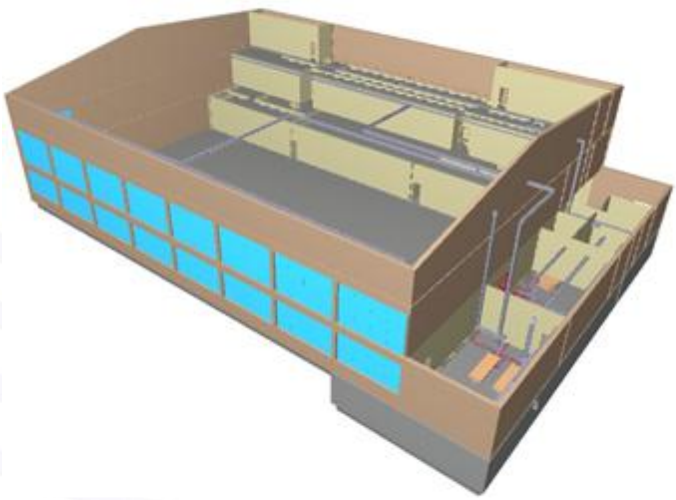

Figure 2. Building Information Model.

BaaS will develop a standardized central BIM that acts as a 'one-stop-shop' for acquisition & stor-age of data from standard and non-standard sensor networks and provision of that data to upstream data warehouses that aggregate the data to support best practice facilities management. The BIM will be de-veloped using standard engineering definitions of sensors (e.g. temperature), energy components (valves, pumps etc) and energy systems (Air han-dling units, heat pumps etc.) as stipulated by recog-nized professional engineering institutions such as CIBSE (www.cibse.org) and ASHRAE (www.ashrae.org). The BIM will be developed using an industry data standard data model (Industry Foundation Classes – IFC). The IFC data model will have to facilitate interoperability with multiple data warehouses.

The use of an extended BIM to describe building-related information and to generate all components aspires to deploy a generic widely-applicable tool to a wide range of building typologies.

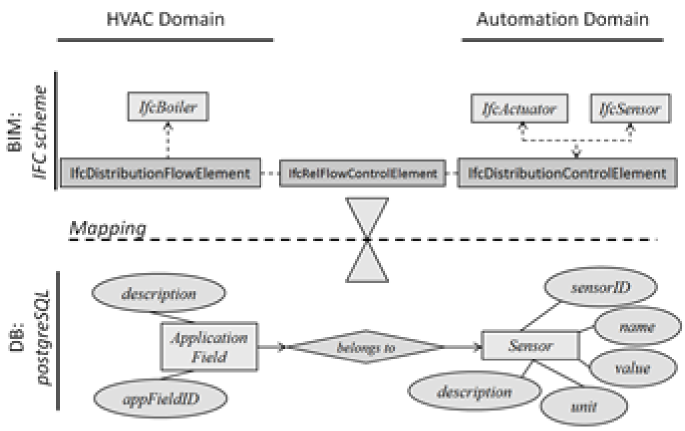

Figure 3. Mapping data schemes between both, BIM and data-base.

BaaS project proposes the development and test-ing of an integrated data management technology platform capable of capturing both energy and envi-ronmental data by utilizing sensor networks and an integrated database management system that struc-tures this data to support the management activities that underpin building energy and environmental management.

BaaS addresses the problem of inconsistently and incompletely stored and managed building perfor-mance data by establishing an integrated Data Warehouse Platform. The project will develop a Data Warehouse to support facilities management relating to environmental & energy performance activities in the first instance. This will involve formal data mining and analysis of the data contained in the BIM and the creation of multiple representations and views of the data to support activities that include Inspection & Maintenance, and Control and Config-uration of building management systems.

4.2 Middleware Layer

The middleware layer will be a set of services to provide transparent two-way communication be-tween the building and the high-level services. It acts as a building gateway (BGW) in the individual buildings which abstracts from the BMS particulari-ties and provides a generic and well-defined inter-face for the communication platform to interact with those BEMS which implement standards building automation protocols.

This project will progress beyond the state of the art with respect to the way how a communication platform can interface with the individual BEMS of different buildings: this project introduces a building gateway (BGW) in the individual buildings which abstracts from the BMS particularities and provides a generic and well-defined interface for the commu-nication platform to interact with a wide range of BEMS, for sending configuration settings to the BGW, and for propagating commands from the plat-form through the BGW to individual BEMS as well as passing data from BEMS (e.g. sensor data such as in-building temperatures) through the BGW to the communication platform. Additionally, more dy-namic ways of interaction between the communica-tion platform and the BGW such as the aforemen-tioned Web Services will be considered for applicability and extended if needed to carry data relevant for BEMS.

The BaaS project will focus on identifying the best gateway service and building service architecture to allow best tools for building control ICT system in-tegration and interoperability with different systems. Integrating tools will be developed that support easy of communication and open interfaces. This project proposes the development of ontology-based service composition framework for integration of internal and external ICT-systems hosted in an open cloud-based environment. BIM should be extended to in-clude function requirements and service specifica-tions targeting for a holistic Building Energy Man-agement and Control including a Performance Moni-toring system.

An important point for creating the data models and shared middleware platform is privacy and secu-rity, it is clear that any new technology has to look at privacy and security for having an impact. First ideas of privacy-preserving energy management systems and suitable data aggregation were developed recently (Bohli, 2010).

4.3 Application Layer

The service layer will provide building character-istics (as available from the BIM), and measurements (as available from the DW) for high-level services which, for instance, could intelligently perform building management operation. During normal op-eration the middleware platform will abstract build-ing devices, the data warehouse will be the central data repository.

5 Expected result

Based on the concise analysis presented above, BaaS attempts to fill a number of methodological, techno-logical and practical gaps for the development of a vertically integrated building energy management solution for integration of multiple trusted and un-trusted cloud-enabled services; this solution will have to be able to support:

- *Data management in charge of aggregating static and dynamic data from building (BIM, Data Warehouse and BEMS) and external sources in a harmonized way, and make them available in near real time,*
- *Communication interfaces between the communi-cation platform, external ICT systems (e.g. weather services on the Internet) and the building systems in a secure manner (Building Gateway).*
- *Current IFC scheme and extension about proper-ties regarding building dynamics, mapping the data schemes between both, the data warehouse and the BIM,*
- *Implementation of high-level services (models, simulations and algorithms) for energy saving and operation optimization.*

6 Conclusion

In summary, the crucial points for interoperability are harmonized data models, interactive communication protocols and architectures respecting privacy and security and accompanied with a certain level of open standardization.

Hereby vertical standardization of data represen-tation to enable communication between standard data models within each associated industry will greatly benefit the market for integration of diverse systems.

The reliance on BIM for building description en-sure that the system will be generic and usable to the whole building lifecycle enabling information from previous phases like design and retrofitting phases to operational phases.

Overall better interoperability and standardiza-tion, and integration of the high level services will make the BaaS system a generic ICT-driven enabler of energy efficiency.

7 Acknowledgments

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2. Session: eeBEMS

2.1 Energy and Behavioural Modelling and Simulation at Facility Management

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Abstract

ABSTRACT: The main objective of the EC-funded FIEMSER project is to develop an innovative energy management system for existing and new residential buildings that optimizes the use of energy resources, and increases the overall building energy efficiency, by anticipating energy demand and improving user behaviour. In this paper we present the work achieved to build the FIEMSER Data Manager. We detail the methodology used to elaborate the Data Model, starting from the analysis of the various data exchanged in the use cases. We present how these data have been categorized and structured in a global data model, interoperable with standard BIM representations like IFC or gbXML. Finally we illustrate how this data model underlies the implementation of the Data Manager, which interfaces with other system components through Restful web services. The FIEMSER system will be tested in two locations to assess the energy savings compared to more traditional energy control systems.

1 Introduction

The rarefaction of natural energy resources and the global warming have led governments to define new energy policies implying the achievement of more energy-efficient buildings for the coming years. Amongst possible technical solutions, more energy-efficient buildings can be achieved by means of ICT and advanced Building Energy Management Systems (BEMS) that can optimize the use of energy resources by taking care of user behaviour, forthcoming weather conditions, and energy prices.

In this context, the main objective of the EC-funded FIEMSER project, launched in February 2010 for a duration of three years, is to develop an innovative energy management system for existing and new residential buildings (single family houses or multi-dwelling building blocks) that increases the overall building energy efficiency by anticipating energy demand and improving user behaviour.

In the following pages, after a brief introduction to the architecture and technical choices for the FIEMSER system, we present the work achieved to elaborate the FIEMSER Data Model that supports communication and interoperability between the different system components, and we illustrate how this data model underlies the implementation of the FIEMSER Data Manager.

2 The FIEMSER system

The FIEMSER system is an innovative BEMS for existing and new residential buildings, which increases the efficiency of the energy used and reduces 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. In case of flexible hourly energy pricing (which is not yet available for residential customers but should become standard with the development of smart grids), and shortfall in local energy production to satisfy all the needs, a second-level optimization strategy would consist in scheduling the shiftable loads (like washing machines or dishwashers) at the cheapest possible energy 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.

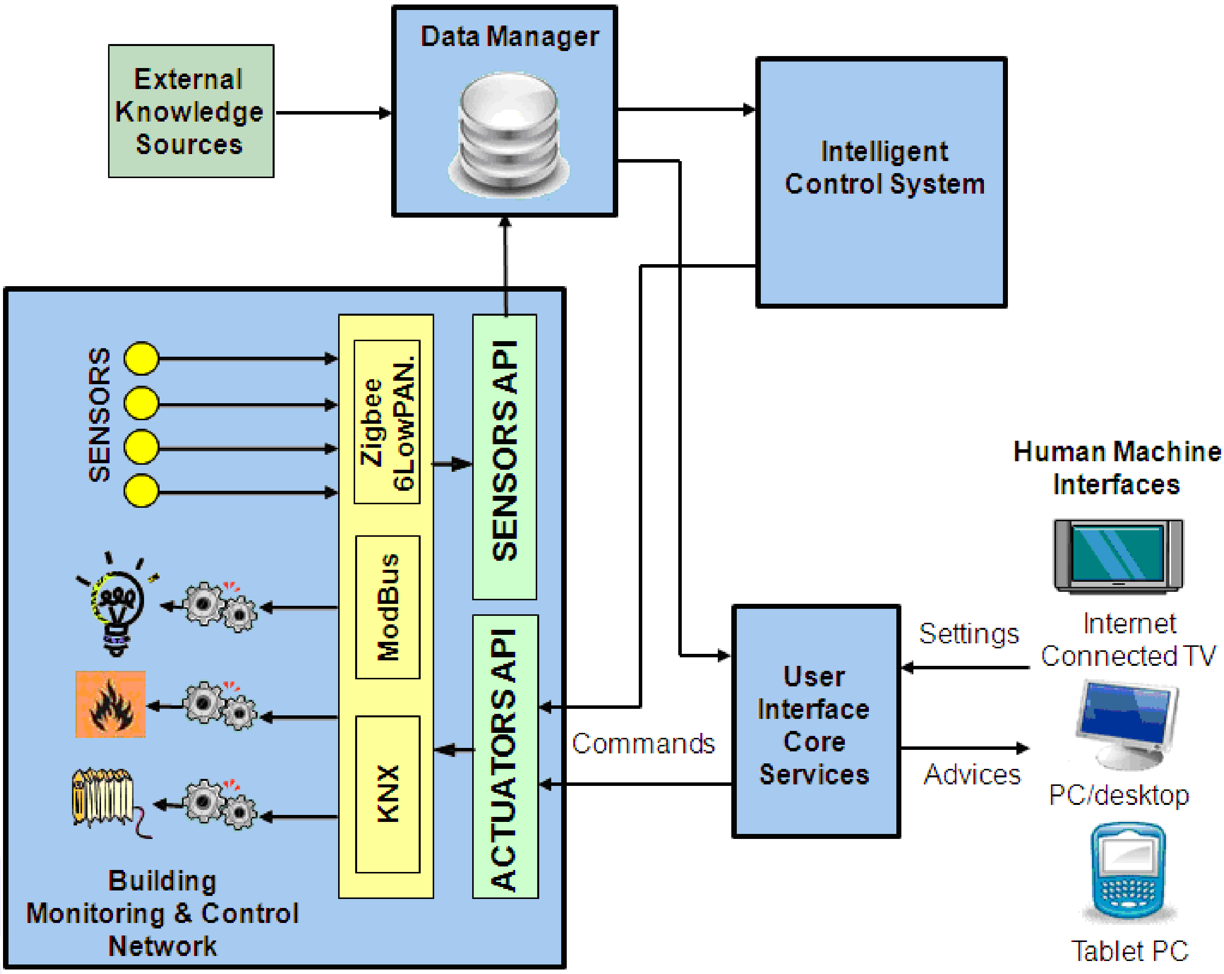

Figure 1. Overview of FIEMSER functional architecture

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).

The Building Monitoring & Control Network (BMCN) has an IP-based infrastructure (6LowPan), and ensures interoperability with existing control communication systems like KNX and ModBus.

The Intelligent Control System (ICS) provides holistic, predictive and optimized energy management strategy, by taking care of planned user activities, forthcoming weather conditions and flexible energy prices.

The system interacts with end-users depending on their role (occupants or facility manager); for occupants, internet-connected TV is one of the privileged user interfaces.

The database plays a central role in this functional architecture. It contains not only descriptive "static" data on the building (spatial layout, envelope, components, equipments, etc.), but also "dynamic" data on the building usage and operation, collected from a set of sensors, and environmental data coming from external sources like weather forecast and energy prices. Storing all data in the same database guarantees their consistency and allows interoperability between system components.

3 Data modelling

The methodology chosen to elaborate the so-called FIEMSER Data Model is based on 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 2:

1. Categorization of data: several categories of data have been identified, starting from the description of use cases, each category corresponding to a specific functional view of the system.
2. Modelling of data in each category: this was achieved by following the UML class diagram methodology, including the use of a tabular template 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.

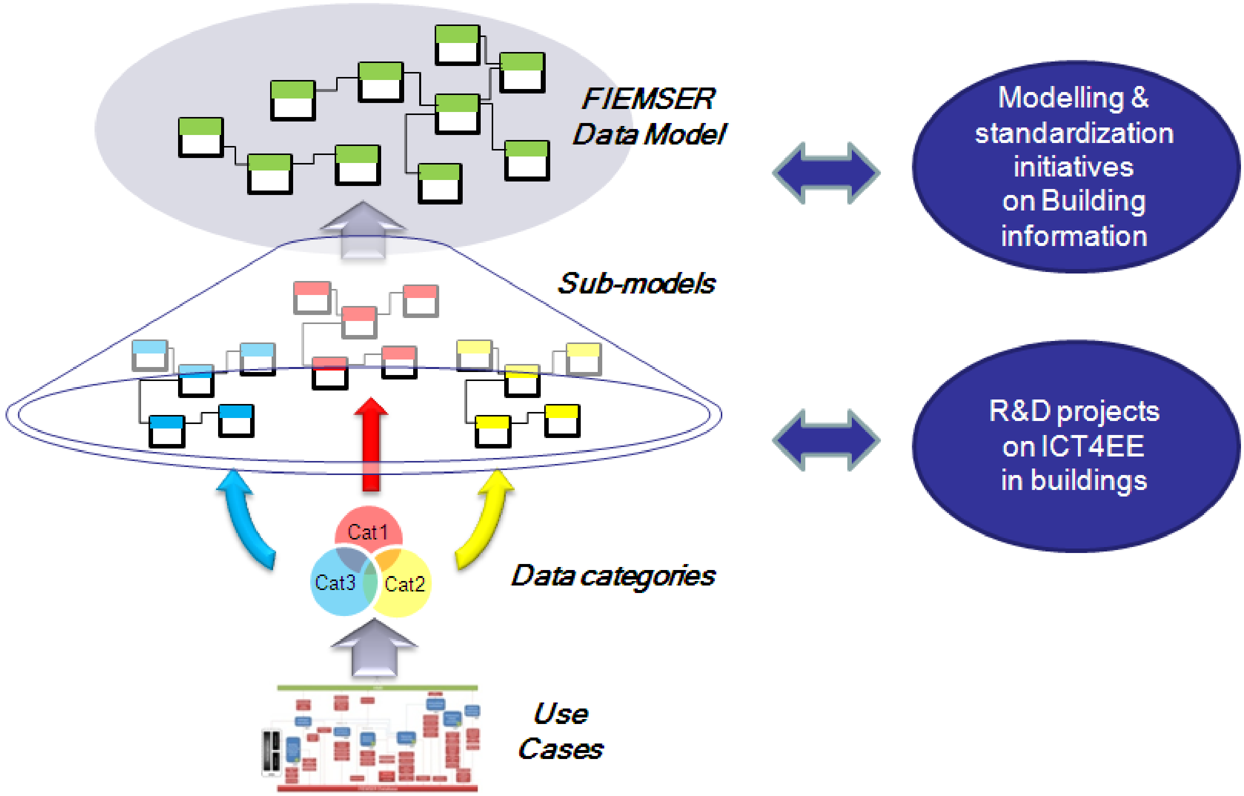

Figure 2. Methodology for data modelling

3.1 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 in 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 1. FIEMSER data categories

Data Category	Content
Environment	Location, climate zone, shadowing, building orientation, etc. Weather, energy prices, etc.
Monitoring & control network	Sensors & actuators (location, characteristics, configuration data, etc.)

	Data collected from sensors (equipments operation, building usage) Log of activations (control orders sent to actuators)
User preferences	Usage profile, definition of scenes, including comfort set-points and use of appliances Control rules and energy strategy
Resources scheduling	Scheduling of resources
Advices	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
Energy performance indicators	Log of consumptions Performance indicators
Energy-focused BIM (Building Information Model)	Space organisation / Envelope & partition (characteristics) Home equipments like appliances, generators, and storages (location, type, characteristics…)
User Access Rights	User rights regarding the access to FIEMSER functionalities

3.2 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 describe some parts of the model that are of specific importance for FIEMSER as an advanced building energy management system.

3.2.1 MONITORING & CONTROL NETWORK

This part of the model represents the interface to the building sensing and actuating 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 ControlComponents (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, the model maintains an estimate (CtrlDeviceEnergyConsumption) of the energy consumed by every ControlDevice.

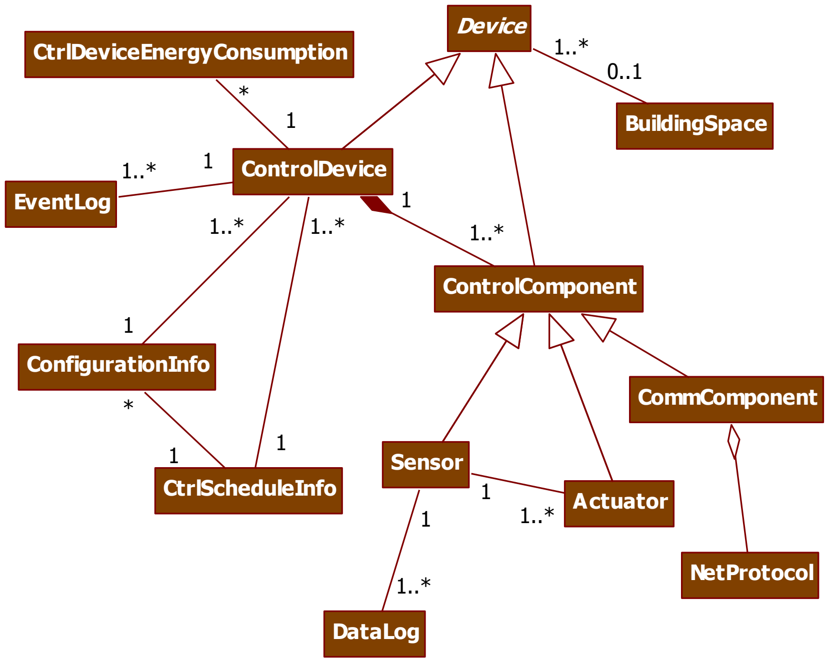

Figure 3. Simplified UML diagram for Monitoring & Control Network

3.2.2 USER PREFERENCES

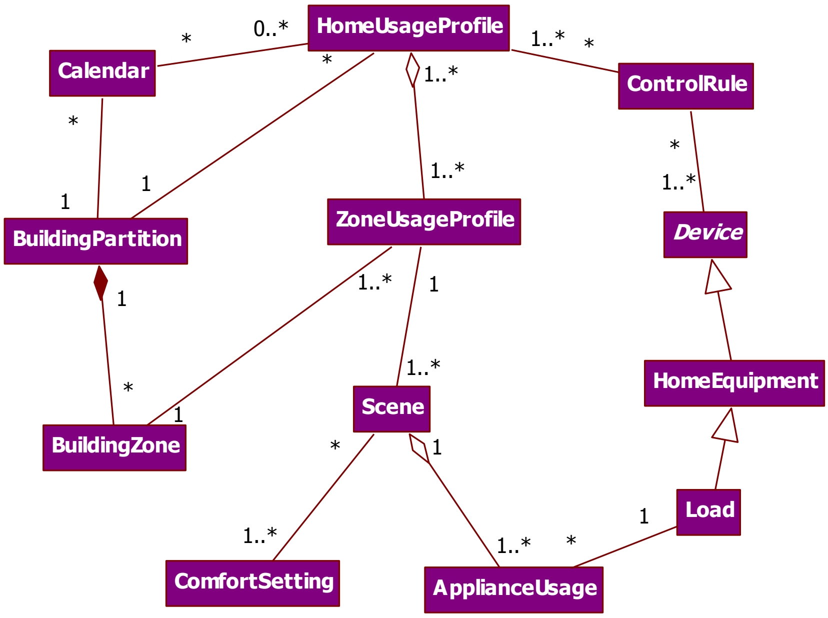

Figure 4. Simplified UML diagram for User Preferences

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 describes a 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 BuildingZone.
- Scene class: This class allows defining usage scenarios, i.e. specific usages of the building, in terms of comfort set points and use of appliances.

3.2.3 BUILDING PHYSICS - INTEROPERABILITY WITH BIM

Special attention has been paid to the interoperability with architectural CAD tools and energy simulation tools. The two main standard data models usable for 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. This model, 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 provides flexibility and extensibility, and data can be easily processed by XML parsers which are available in all modern programming languages. 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.

In a typical FIEMSER system configuration process, a basic gbXML file, exported from a CAD tool, and containing only architectural data, is enriched with settings and installations information in a tool like Green Building Studio (GBS), then parsed to populate the database with needed building and equipments characteristics.

3.3 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 disambiguisation 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 software was chosen to support this modelling work.

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

4 FIEMSER data manager

The FIEMSER Database, which relies on the data model introduced above, is made accessible to other system components by the FIEMSER Data Manager.

Figure 5 shows the architecture of the Data Manager.

The FIEMSER Database is a relational database implemented with MySQL, which is one of the world's most used open source relational database management system. Hibernate is a widely used tool that provides an object relational mapping library for the Java language. It provides a framework for mapping object oriented domain models to traditional relational databases (MySQL in our case). Hibernate solves object-relational impedance mismatch problems by replacing direct persistence-related database accesses with high-level object handling functions.

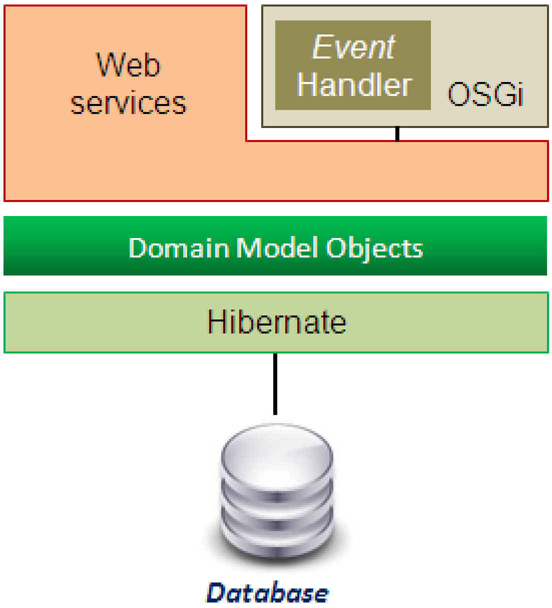

Figure 5. FIEMSER Data Manager architecture

4.1 Synchronous communication

Generally speaking, the FIEMSER system follows a Service Oriented Architecture (SOA). In particular all accesses to the database by other FIEMSER components are realized through a Web Services layer (see figure 5). The REST communication architecture style has been chosen preferably to the more classical SOAP because it is a lighter and more extensible solution. Contrary to SOAP, which follows a method-oriented model, REST is resource-oriented. The focus is on interacting with resources, rather than messages or operations. So, unlike SOAP-based Web Services, RESTful Web Services (i.e. Web Services using HTTP and the principles of REST) do not require the definition of a service API by means of WSDL (Web Services Description Language). Then a RESTful Web Service is a collection of resources, with three defined aspects:

- The base URI for the Web Service.
- The internet media type of the data supported by the Web Service. In our case XML has been chosen to describe the resources data returned by the RESTful Web Services developed in FIEMSER.

- The set of operations supported by the Web Services. Applications use simple HTTP requests to post data (create and/or update), read data (e.g. make queries), and delete data (CRUD=Create/Read/Update/Delete).

Below is an example of HTTP/REST request to get the description of a building partition:

http://fiemser.cstb.fr/fiemser/BuildingPartition/view?id=20

The first part of the request (http://fiemser.cstb.fr/fiemser) represents the URI of the Data Manager Web Services.

In response the following XML file (simplified view) is sent back to the application making the request.

```xml
<fiemser>
  <message>View building partition</message>
  <modelObject id="20" className="BuildingPartition">
            <properties>
            <property name="creationDate">Thu Feb 16 14:49:59 CET 2012</property>
            <property name="name">second</property>
            <property name="idGBXml">1X02</property>
    </properties>
    <references>
      <reference name="building" classNameAndId="Building.21"/>
      <reference name="users" classNameAndId="User.7"/>
      <reference name="spaces" classNameAndId="BuildingSpace.30"/>
    </references>
  </modelObject>
</fiemser>
```

Figure 6. Simplified example of XML file sent back by the Data Manager in response to a http/Rest request

4.2 Asynchronous communication

For event notification, the OSGi events publish/subscribe mechanism has been chosen. Since the FIEMSER architecture is distributed on several computers (in a typical multi-dwelling building, there will be a main server and one "box" for each Building & Monitoring Control Network (BMCN) installed in each flat), the distributed OSGi extension R-OSGi has been chosen to pass events between remote OSGi platforms. Contrary to other dis-tributed extensions of OSGi, R-OSGi can be deployed in minimal OSGi implementations, such as Concierge, targeting computationally constrained devices.

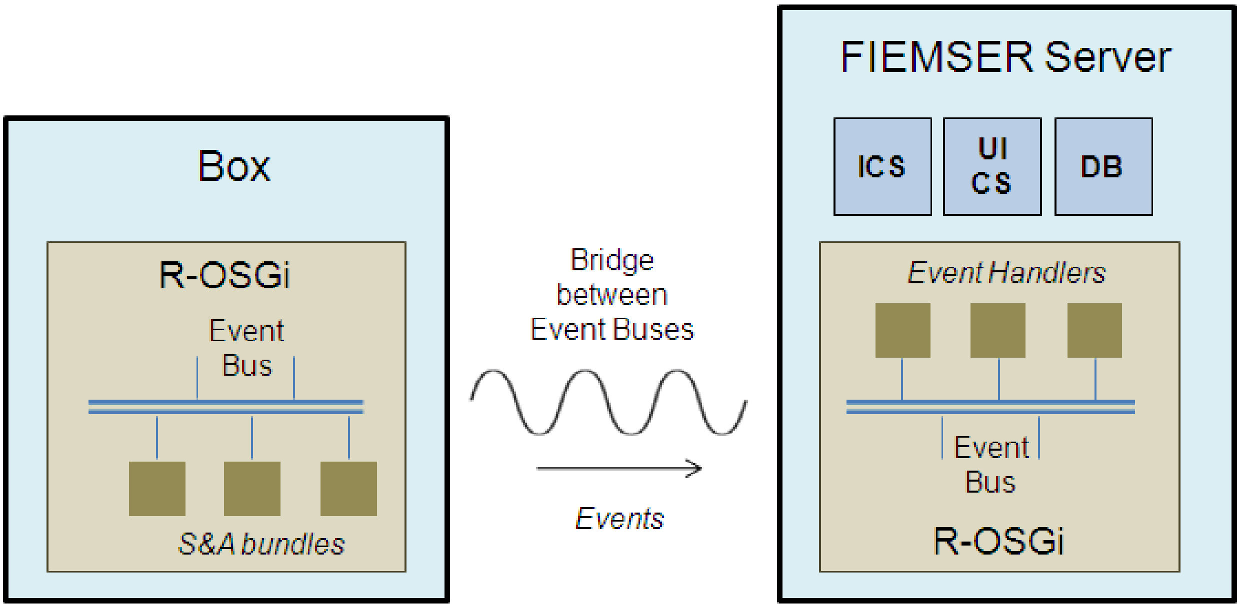

Figure7. Event notification with distributed OSGi (R-OSGi)

R-OSGi provides a bridge that allows seamless communication of events between distant computers. As a consequence, all events that are published on one machine are seen on the remote one as if they have been produced locally. On each box side, OSGi bundles are in charge of publishing the events that occur on the BMCN network (e.g. a light is switched on). These events are automatically published on the Event Bus of the remote OSGi framework installed on the distant computer hosting all other FIEMSER components (Intelligent Control System, User Interface Core Services, and Data Manager). Component-specific bundles (named Event Handlers) are to be written to subscribe to those events that the components are interested in, and call the relevant Web Services in response to these events. There is typically one Event Handler per FIEMSER component. In case of the Database Event Handler, any event occurring in the BMCN network needs to be subscribed in order to store the related information in the FIEMSER Database.

The following figure 8 sums up how the Data Manager interfaces with other FIEMSER components.

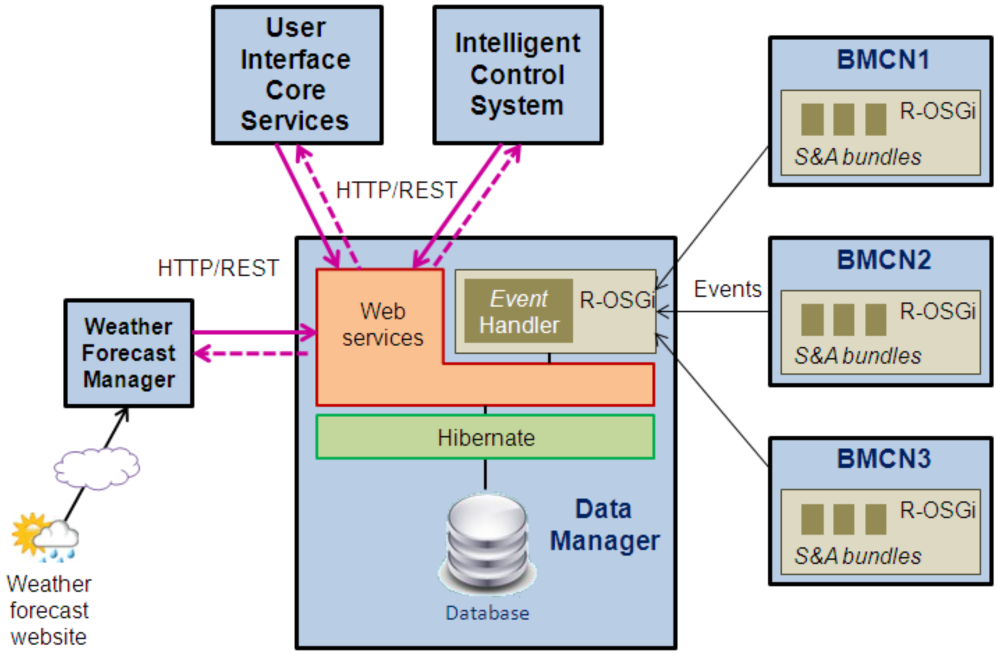

Figure 8. Communication schema between the Data Manager and other FIEMSER components

4.3 External data sources

External information useful for FIEMSER is two-fold:

- The weather forecast for the upcoming 24 hours at the building location, hour by hour, including temperature, humidity, wind speed, and solar irradiance;
- The evolution of the energy price for the same period, hour by hour.

4.3.1 WEATHER FORECAST

One of the main challenges of advanced BEMS is to estimate the expected energy production and consumption 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 their expected evolution, which depends on the weather forecast and the scheduled home usage profile for the day ahead.

In the FIEMSER system, a specific software component, the Weather Forecast Manager (WFM), is in charge of retrieving weather information from external weather forecast services.

Many free services are available, but few of them are providing means to retrieve data through a machine-to-machine process (e.g. ftp or web services), with a regular and frequent update of the weather forecast. Several services have been tested, including the use of free software tools like zyGrib that allows download of data from Grib file servers. Grib is the format used by the meteorological institutes of the world to transport and manipulate weather data and is the foundation of the forecasts we can see around us in our daily life. One of the shortages of these free services, however, is that they do not commonly provide solar irradiance values, which are needed in particular to estimate the generation profile of the PV system possibly installed in the building. Only cloud cover (like clear or sunny, mostly sunny, mostly cloudy, cloudy, etc.) is available. This is why a specific tool has been developed in FIEMSER to predict hourly solar irradiance from cloud cover, by using the Zhang and Huang prediction model (Zhang 2002).

In parallel the FIEMSER consortium is also investigating the possibility to conclude a special agreement with a weather information provider in order to get forecast data, including solar irradiance, at both test branches of the FIEMSER pilot system (Bilbao in Spain, and Holzkirchen in Germany) for the duration of the experimentations.

4.3.2 ENERGY PRICES

Concerning energy prices, residential customers do not usually access the prices of the wholesale market. They get the price from their retailer and according to different types of contracts. Depending on the chosen contract, tariffs may vary from one day to another one and/or from one time slot to another one (e.g. day and night tariff), but hourly prices are not used today in the residential sector.

With the development of smart grids, however, this situation will certainly change in a next future, by introducing a more dynamic pricing of energy for all customers.

In order to take account of flexible energy prices in the FIEMSER optimization process, it has been decided to simulate this evolution by referring to the wholesale market data provided by one of the existing "power spot markets" like EPEXSPOT (European Power Exchange), which covers France, Germany, Austria and Switzerland markets, or Red Eléctrica de España, dedicated to Spain and Portugal. Both markets provide historical data as well as future hourly prices for the day ahead.

Of course, a corrective factor will have to be applied to convert these wholesale market prices into prices potentially applicable to residential customers. Indeed, those prices are for "the energy bought" only. They don't include additional costs to be paid by the end-users, e.g. for using the distribution and transmission network, or for contracted power. Finally the wholesale energy market prices may get increased by 2 or 3 times, or even more, depending on the operating conditions.

5 Conclusions 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 is an important foundation to ensure the interoperability between the different functional modules of the system. 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.

The database built upon this data model is a core component of the FIEMSER system since it holds all data needed or produced by other system components. A Data Manager implements the interfacing mechanisms to collect data, store them in the database, and make them available to other components. It provides a Web Services layer to interoperate with those components, and integrate an OSGi Event Handler that listens to all events occurring on the monitoring and control network, and populates the database accordingly.

Further project steps will consist in achieving the full system integration, and validating the system in two testing facilities in Spain and Germany, with two different climatic conditions.

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2.2. Occupancy and Business Modelling

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Abstract

Analysis of building energy efficiency at the early stages of the design process has been viewed in the past few years with increasing interest by key stakeholders such as architects, designers and mechanical engineers as well as by the research community. Early design products comprise features that determine to a large extend energy performance and thus can provide critical evidence to simulation and analysis tools for thorough evaluation of design alternatives. Capitalizing on the actual effect of building occupancy (human presence and movement) in the overall energy consumption during the early design phases of a building, this paper addresses the need for a common set of reference models definition for correlating the two disjoint worlds in the building domain, the building information models and the business processes models of an organization that will be housed in the building. The paper introduces a set of domain semantically enriched models that can express occupancy using spatio-temporal information and incorporate space utilization definitions taking into account enterprise-related information at various levels. To cope with interoperability with existing simulation tools, a provisional extension to the green building schema (gbXML) is examined towards incorporating the necessary information needed for realistic and accurate evaluation and optimization of alternative energy efficient building designs.

1 Introduction

1.1 Motivation

Energy Efficiency is considered to be a key component of the European energy policy underlying the fundamental objectives of the European Union's (EU) 2020 strategy. Buildings are a major constituent of the urban ecosystem accounting for almost 40% of the overall energy demand in Europe (European Parliament 2010, European Commission 2011). Urban Sustainability heavily relies on building operational and space utilization characteristics as well as the behaviour of their occupants.

Past and recent studies on energy efficiency in buildings indicated that appropriate design improvements, tailored with the support of building performance simulation software, could reduce energy use in both existing and in new building envelopes (Clarke 2001, Kim et al. 2011). With enriched simulation results in hand, planners, designers and architects will be able to analyse the future performance of a building envelope with sufficient accuracy-cy and granularity, taking into account both descriptive data on the building (material, components, equipment's, space layout, etc.) and information related to the dynamic behaviour of the building due to its usage and operation by humans. Focusing on the early design phases of a construction product, there is lately an increasing emphasis on delivering simulation tools and methods that improve the prediction of the building energy use by analysing also the performance in connection with the space utilization of the building by its occupants (Zimmermann 2008, Tabak 2008, Hoes et al. 2009, Goldstein et al. 2011).

Focusing on the early design phase and attempting to deliver a holistic building performance simulation framework that fully captures the dynamic behaviour of buildings operations addressing the various features underlying the organizational pro-cesses and respective spatiotemporal occupancy and control behaviour patterns, this paper presents a thorough analysis of the shareable information that needs to be modelled and proposes a set of provisional reference data models.

The models and the vocabularies proposed can be considered as a further extension of BIM in the do-main of commercial premises, towards incorporating business process modelling (BPM) elements regarding organizational structure and respective business processes performed by its occupants. The appropriate-ate utilization of the respective models would allow further enhancement of Building Performance Simulation (BPS) tools with advanced capabilities such as i) the more robust and accurate analysis of the performance of a facility under design regarding its space usage at an early stage and ii) the optimization and balancing of often conflicting building performance aspects, namely energy efficiency, business performance and comfort, taking into account the in-formation from the later “real” behaviour of the building due to its occupancy.

The rest of the paper is organized as follows. Initially, section 1.2 provides a literature review on the current approaches used for modelling the building occupancy as well as the human activity behaviour in buildings. Section 2 presents data models related to the user behaviour as a building occupant. Next Section 3 investigates the delivery of a flexible set of data schemas for incorporating organizational aspects such as actors, roles, enterprise units and other information related to business process models, whereas Section 4 exploits the interaction of the user behaviour models with the enterprise ones. In Section 5, the proposed XML schema for space utilization simulation is presented, whereas Section 6 concludes with an overview for the use of such models in building performance simulation frameworks.

1.2 Related work

Construction products are designed and delivered to accommodate user's organizations and respective assets, and eventually to enable its occupants to utilize its spaces (Ekholm et al. 2000) by performing every day activities. As of today, several methods and modelling techniques have been investigated towards analysing and predicting the building occupancy that can serve as input to building performance simulation tools for predicting and evaluating its performance in terms of space usage and energy consumption.

Abushakra et al. (2001) proposed a well-established method that represents occupancy in a building via a time-variation model, which is de-scribed through schedules and diversity factors (Davis 2010). Daily or yearly schedules can be estimated using onsite survey or through individual experience. Then these schedules can be applied to building spaces with similar characteristics for calculating the energy consumption due to the impact of human presence in internal heat gains and cooling loads. In addition, diversity factors were proposed to correct average heat gain estimations from the aforementioned schedules, but in general they can-not elucidate the stochastic variations of building occupancy in the spatiotemporal domain. Overall, diversity profiles offer a cost effective "black-box" modelling approach of the average occupancy, how-ever they fail to capture many of the underlying relations between features and critical evidence affecting occupancy variations.

To cope with occupancy dynamics and human presence in time and space, Wang et al. (2005) pro-posed a probabilistic method to estimate the occupancy schedule in a single person office. The method proposed, assumes that building occupancy and vacancy intervals during working hours are independent and sequential random variables and models the durations of presence and absence during business hours with exponentially distributed random variables. The coefficients are estimated through measurement data, whereas indicative time-dependent parameters such as arrivals and departures in the single office are modelled with normal distributions towards simulating the occupant pattern. The specific approach addressed single person offices which is not always the case in real life situations. Furthermore, intermediate periods of presence and absence during the working day were treated as exponential distributions with a constant coefficient over the day. This hypothesis was confirmed in the case of absence but not in the case of presence.

A more comprehensive occupancy model was proposed by Zimmerman (2007) for the aim of improving the building control system (lighting, heating and cooling system), which investigated the modelling of user activities over time taking into ac-count user groups, their roles in functional units and the tasks that they may perform.

In addition, Tabak (2008) presented a sophisticated framework for simulating the human behaviour in buildings for any given organization. He investigated thoroughly the activities performed in office-based organizations and tried to make a taxonomy of tasks executed by building occupants as well as to analyse the factors (individuals, organizational) that influence the interactions occurred between individuals (e.g. attend a business meeting, give a presentation, etc.).

In his study, Tabak (2008) categorized activities in three different ways depending on i) the nature of the activity (social, physiological or business related; ii) the number of occupants involved resulting in solo or group activities, and iii) the type of the activity such as planned or unplanned. His approach to the human activity behaviour simulation was based on the definition of activity schedules, which were linked with the employees of the analysed organization. An activity schedule contains a time ordered set of activities consisting of primary (skeleton) and secondary activities, whereas each activity is per-formed in a building space (location) and can involve, depending on the nature of the business pro-cess, one or more enterprise resources (e.g. occupants or facilities).

Skeleton activities as defined by Tabak reflect actual business processes, which eventually increase the level of complexity and degree of granularity of the models. As a result, the approach requires a high number of input parameters related to organizational structure and operations. A sensitivity analysis indicating the statistically significant input features that influence the occupancy variations is lacking. Furthermore, a higher level, abstract modelling of activities could provide equivalent simulation performance while at the same time minimizing the necessary user input parameters.

A similar approach for generating fictional occupancy in buildings was proposed recently by Gold-stein et al. (2010). A hybrid approach was proposed to produce more realistic patterns of human behaviour in buildings, in which information found in statistical occupancy schedules was combined with optional parameters supplied by the user in the form of personas attributes (e.g. arrival/departure times per occupant, probabilities for office meetings, offsite break, etc.).

In a recent study from Shen et al. (2012), a framework is introduced, namely Building Information Modelling-based user activity simulation and evaluation method (UASEM), whose ultimate goal is to conduct pre-occupancy evaluation of buildings under design and to provide via user activity simulation better understanding of the design solutions in terms of space layout utilization.

The above overview indicated several on-going developments and research studies that aim at demonstrating various modelling techniques with the capacity to realistically reproduce significant proper-ties and attributes of human presence and movement in buildings under design. Results have mainly been used as input to building performance simulations tools (Zimmerman 2008, Hoes et al. 2009), towards improving the energy use predictions of the building under design.

2 Activity Based and Behavioural Based Occupancy models

Accurate analysis, prediction and simulation of occupant behaviour in the early building design phases can significantly improve the predicted performance of the buildings, while simulation tools can further assist designers, planners, architects and engineers to reduce uncertainty at early design phases due to occupancy.

The ultimate goal for the delivery of a detailed occupancy model in buildings is to provide the necessary information related to occupants' presence and movements in the building spaces, to define user-related activity schedules with high level of granularity (sub-hourly, hourly, daily, weekly, monthly, yearly, etc.) and to analyse with mathematical methods the spatiotemporal correlation between the occupant and the locations (*spaces* or *zones*) in which the human activities take place.

Combined approaches that incorporate both occupant's presence and movement with occupant's control actions (behaviour) into a single model, pre-sent significant limitations and weaknesses. We pro-pose a modular approach consisting of two separate models: a) an activity based occupancy presence model, subsequently followed by b) an occupant control behaviour model. This approach presents several obvious advantages. Firstly, we significantly reduce the model dimensionality problem during training and calibration. The two models can be trained and calibrated independently focusing only on a subset of the relevant contextual evidence. Secondly, both models can be used independently providing flexible input to other building performance simulation tools, covering alternative aspects of building design (lighting, windows, etc.) that re-quire input of varying granularity. Finally, the overall approach is considerably more flexible and more parameterised towards addressing alternative building and domain alternatives.

The term activity schedule is used in the literature to encapsulate an individuals' schedule in a temporal manner, composed of various series of activities per-formed during his/her presence in the building. The complexity of each *task* is highly correlated to the occupant's role (*actor*) in the organization and is partially depended on his/her role in respect to the enterprise (visitor/guest, employee, etc.). Further-more, business-related tasks depend on the building static layout (space adjacencies and locations) as well as from additional key factors (enterprise assets, equipment type and locations in the building spaces) that are mostly provided via BIM models.

A provisional schema for the building occupant (actor) is illustrated in Figure 1. The schema correlates the building occupants with an enterprise department (e.g. actor belongs to a unit and has a specific set of roles), with user preferences (schedules, optional parameters for absence durations, breaks, etc.) and associates an actor with business tasks due to its position to the enterprise.

The data schema is semantically enriched with concepts (classes), has a formal representation (ontology data and object properties), and can be seen as a basic generalized model for defining a building occupant correlated with the enterprise domain model.

A more detailed schema view for modelling the user activity behaviour is provided in Figure 2. The proposed activity modelling schema further elaborates on the groundwork presented by Tabak (2008), where both activity and workflow modelling approaches are integrated to enable mimicking the behaviour of real human beings when scheduling activities in an enterprise building.

It supports the division of users' activities in "*skeleton*" and "*intermediate*" activities (Figure 1), where the former are related to direct enterprise workflow dependent activities (e.g. "give a presentation", "perform health check-up on a patients' room", "do research", "attend a meeting") and the latter are strongly depended on the social or physiological needs (e.g. "get a drink", "smoke", "have a break", "walk to enterprise asset", "receive visitor/guest").

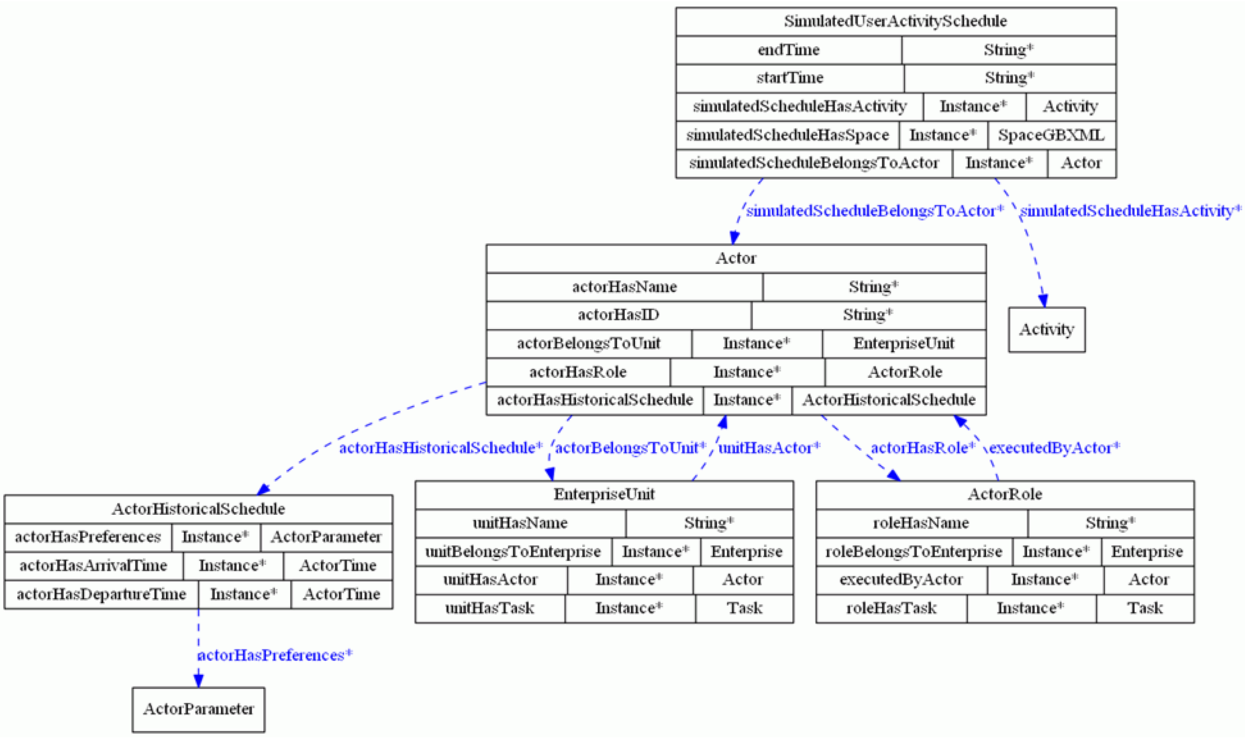

Figure 1: Semantically enriched data schema for the definition of actors (occupants of a building) and correlation with activi-ties/business processes, equipment utilization through human presence and movement in building spaces.

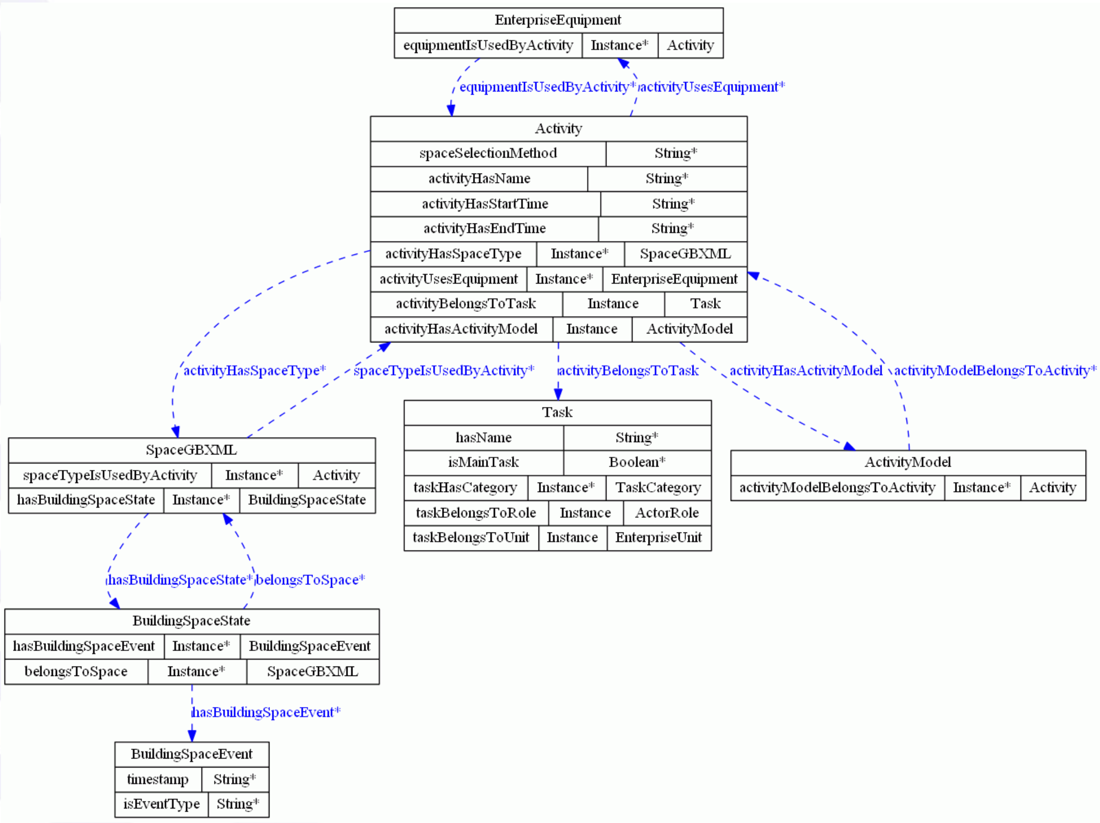

Figure 2: Detailed schema view of the activity modelling and provisional correlation to the building spaces and resources (equip-ment, material, etc.

The efficient management of continuous time series of recorded sensor and meter data poses significant challenges. To this end, our framework proposes the pre-processing and normalization of low level data and decoupling of input/sensor data of different time and spatial granularity. This way we reduce the spatiotemporal dimensions of the various learning models while also delivering more semantically abstract, robust and flexible models, applicable to different variations of similar building spaces (e.g. When we move from one office to another, even though retaining similar sensor settings and topologies, low level data acquired by sensors present variations that are handled at the lowest level, before entering input data to the occupancy models).

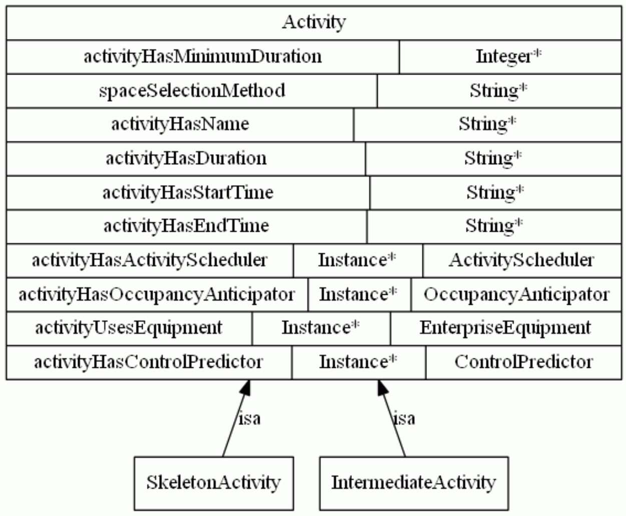

Figure 3: High level schematic representation of an activity and instantiation via skeleton or intermediate activities.

After the pre-processing and normalization of in-put data, feature vectors are extracted, consisting of features that present the highest Information Gain. Low level building space events (*Building-SpaceEvent*) are extracted based on these, reflecting the basic changes in the contextual environment of each building space (*BuildingSpaceState*). Higher level events related to activity based occupancy and control behaviour, will subsequently be extracted and composed based on these low level events.

The schema provides a basic reference to activity types such as skeleton (primary) and intermediate activities (secondary) and links them with mathematical methods (*ActivityModel*) that can analytically describe their scheduling prediction method.

The basic schema is notable for its flexibility as different levels of detail can be instantiated depending on the design phase of the building (level of development - LOD). For instance, in the schematic design phase, the building models would contain geometry and functionality of building objects, including spaces, base, walls, decks and roof, which are essential for the early analysis of selected systems in terms of sustainability, structure and space utilization.

Focusing on the energy efficiency and space utilization simulation, the provisional enterprise behavioural model (imported from a knowledge share repository) in this phase, could contain information for the actors, their roles and the business tasks they can perform in the enterprise. Then, behavioural patterns could be reproduced in a simulation (space utilization) based on various attributes described in the mathematical models used for the activities, such as the frequency, duration, number of occupants involved (solo or group tasks) depending on the probabilistic method used for modelling each activity.

In case the level of design and development progresses (BIM is also enriched with precise quantities of materials, equipment, etc.), the human behavioural modelling can be further elaborated with more information about user preferences (in terms of "personas" with different attributes such of presence time, duration of breaks, involvement in business tasks based on their role to the organization, number of occupants in business processes, etc.), towards providing a more realistic simulation for the building under design. The additional characteristics and at-tributes of "personas" are encapsulated within the concept "*ActorParameter*", as illustrated in Figure 1.

The additional parameterization would support key stakeholders involved in the design process with customized occupant behaviour simulations towards assessing the building energy use and overall performance, taking into account the specific requirements set by the building tenants and property owners.

3 Business Models

One of the key ambitions for the near future in de-signing and constructing energy efficient buildings is to capitalize on the synergy between the collaborative use of two correlated models, the building in-formation models (BIM) and the business process models (BPM) defining the organizational structure of an enterprise. As of today, architects, designers and engineers 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, including one of the most important factors, that of occupants' behaviour.

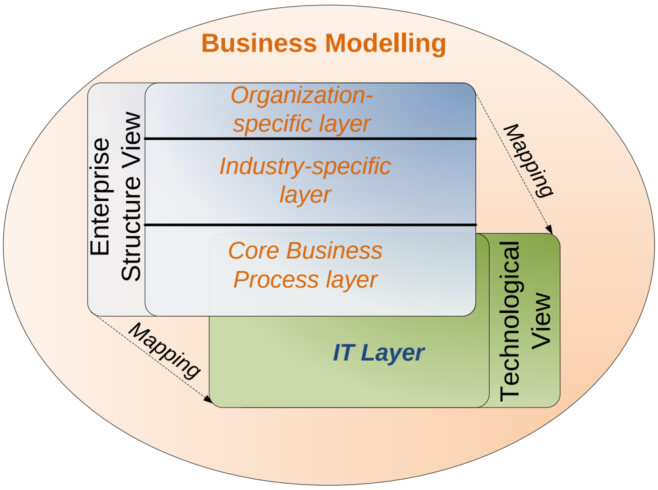

Figure 4: Semantically enabled three dimensional layers for business process modelling and management.

The last generation of business process management tools provide an integrated view on business aspects (actors, activities, events, processes) and ac-cording to Saravanan et al. (2011) the enterprise view can be conceptualized, as illustrated Figure 2 in into three semantically enriched layers: i) the core business layer, ii) the industry-specific layer and the iii) organization-specific layer.

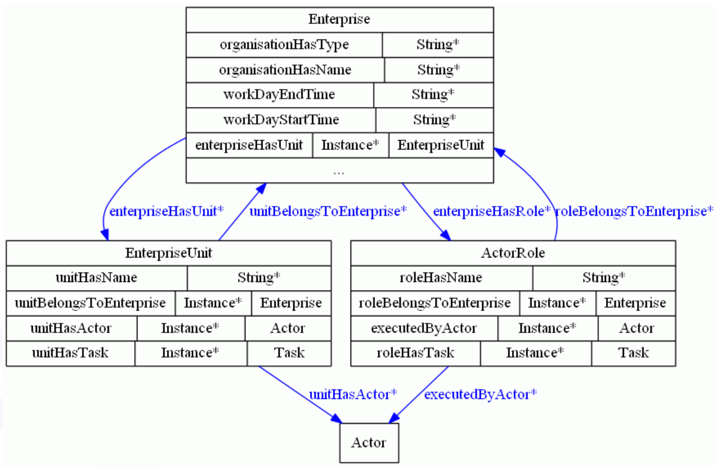

Figure 5: Schema for enterprise modelling and utilization in frameworks for analysing building occupancy.

Depending on the purpose of use, different business models can be instantiated having as main scope to accommodate the context of use. In this paper, focus is given on the specific view of an organization model that is “housed” in a building envelope and targeting one of its main catalysts factors, the building occupants. The ontological schema defined for modelling an organization for this purpose is illustrated in Figure 3.

An *enterprise* typically consists of many individuals (actors), who have diverse roles (*ActorRole*) and belong to different organisation units (*EnterpriseUnit*). As already described in Section 2, the behaviour of building occupants (as individuals) is highly dependent on their assigned roles, their individual preferences and other factors correlated with their social and physical needs.

The core business layer (Figure 2) can be used to define the generic role concepts (actors, units) of an enterprise, while the organization-specific layer would extend these concepts by defining roles that are specific to that particular organization. At the very end, the IT Layer represents the translation and mapping of the business knowledge (business flows, events, etc.) into a "technical" representation.

The conceptual model (ontology) of an enterprise presented in Figure 3 is a provisional set of classes and corresponding properties that need to be inter-changed between the BIM and the BPM models. The exchange of the information shall support both import and export functionalities, focusing mainly on the data imported in BIM model during the design phases of a building. Data integrity (Eastman et al. 2008) is still an open issue in the AEC industry, thus the contribution on this part will be on enhancing the so called Virtual Building Modelling (VBM), in which more informative models are delivered for utilization in diverse but complementary domains (Eastman et al. 2008), such as building structural de-tail, energy-use analysis, cost estimation, business performance analysis, etc.

The incorporation of business modelling in the BIM process will foster the optimal collaboration between project stakeholders through the whole life cycle of a building. Moreover, their utilization in the early design phases will enrich current practices in space usage analysis and energy consumption, by delivering new services and tools to planners, de-signers and engineers to understand the building performance from different perspectives, including the dynamic performance of the building due to the human presence and movement.

To cope with dynamic building occupancy, the incorporation of static and descriptive data of an enterprise is not enough. The actual business flows (tasks, processes) encountered in an organization shall be modelled and certain parameters that may affect the building performance models shall be investigated.

Furthermore, even though business activities and respective tasks are different in scope, however the contextual information describing these business events is often quite similar. Spatiotemporal data acquired by building sensors will not always provide sufficient evidence to differentiate between the activities. Therefore, appropriate analysis of the under-lying business models in conjunction with statistical data acquired from pilot premises must be combined in order to identify the most representative and in-formative contextual evidence (actors, artifacts/equipment per zone and activity). Moreover, incremental processing and parsing of these data will be required in order to establish robust and accurate correlations between activities and contextual evidence.

Next paragraphs introduce the necessary schema definitions towards correlating the building descriptive data (spaces, resources, material, and equipment) with the business processes (tasks, activities) that will encounter in the building under design during its operational phase, having as main catalyst the building occupants. By analysing the relationships in spatiotemporal domain (spaces, activities, occupant schedules, etc.) of a building under design, key stakeholders will have the opportunity via parameterization of the models, to easily and rapidly simulate the building space utilization, towards supporting their decisions in both optimal space planning and energy efficiency of the buildings at the early stages of the design.

4 Combining Activity and Behavioural Occupancy Models with Business Models

Existing building energy modelling and performance tools primarily focus on the building envelope itself and rarely use detailed information for the building users and the activities that they may perform (e.g. organization and business processes).

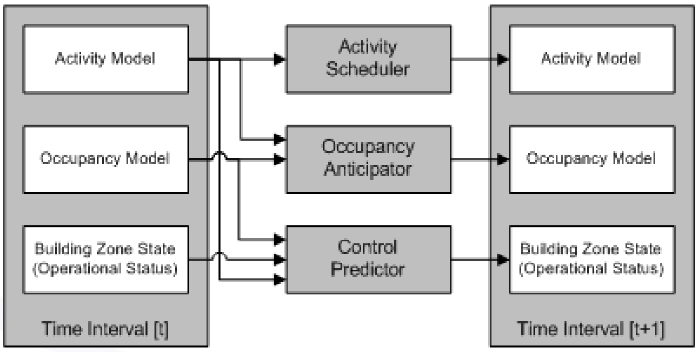

Figure 6: Activity-based occupancy and Control Behaviour Prediction

Specifically, current tools use detailed information for building spaces when evaluating the energy performance such as the envelope material, HVAC systems, lighting systems, etc. However, de-signers and engineers utilize only limited data about the business organization and the processes that the building under design will “house” during its operation phase.

For example, current tools use information about the single usage of a building space and static historical occupancy schedules that may not provide an accurate prediction of the real energy performance of the building under design. To cope with this, the correlation between the two disjoint worlds is needed, the one that contains information for the building spaces and resources in terms of material and equipment (BIM) and the one that provides detailed information on the most frequent business flows (BPM). The exchange of information among these two models is essential towards better supporting the AEC industry in delivering energy efficient buildings fully respecting the building construction standards and its occupants.

Towards delivering new tools and methods for building simulation frameworks that supports both space utilization and energy use analysis of design alternatives, there is a need to define reference schemas (data models) that will allow the decision-makers to easily share, generate and compare several design scenarios.

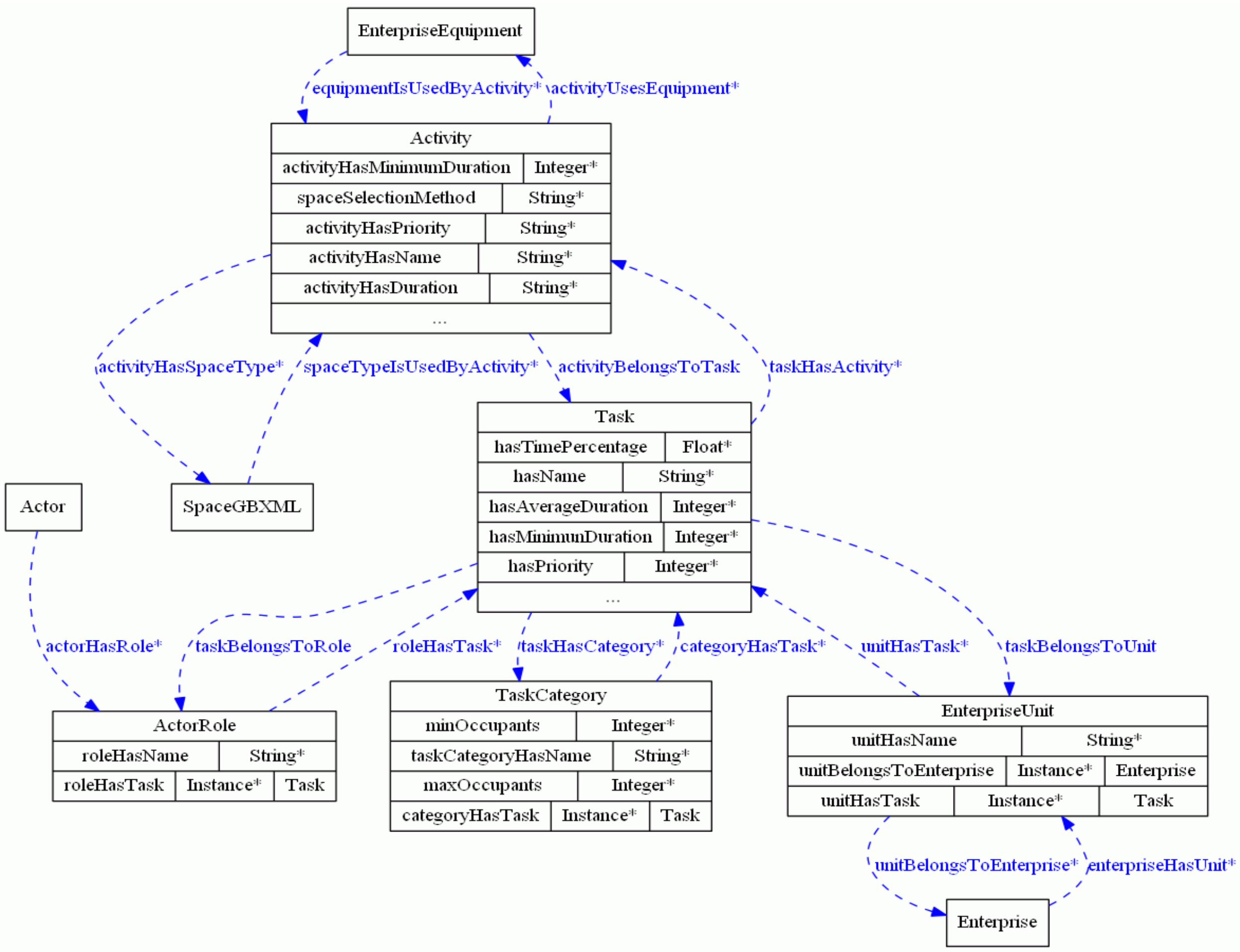

Figure 7: Schema for business processes (tasks, activities) encountered in a building and correlation to occupants and building mate-rial and equipment

Figure 4 presents the proposed occupancy prediction framework for a single building zone, between consecutive time intervals. The Occupancy Anticipator is responsible for the occupancy prediction for the next time step, based on the current activity and occupancy data. The Building Zone Control (on single space level) operations on the next time step are governed by the Control Predictor based on the existing Occupancy data and Zone status (environmental conditions and equipment operational status). Activity flows are estimated by the Activity Scheduler based solely on Activity statistical data.

Moreover, Figure 7 illustrates the definition of a cornerstone hierarchical conceptual model that will enable building simulation engines to support space utilization simulation, which is one of necessary steps for delivering fictional and parameterizable occupancy schedules for building performance evaluation and assessment.

The schema is capable enough to represent the basic interactions among the building, the enterprise and the occupant's domain. Particularly, a set of business processes (*Task*) can be defined and correlated with enterprise units (*EnterpriseUnit*) and subsequently with the actual individual employees (*Actor*).

Capitalizing on the definition of a business pro-cess, which involves a sequence of several processing steps (*Activity*) to accomplish organization related objectives, each actor can be assigned according to its role in the organization in several tasks during a working day.

Going one step further, as already described in section 2, tasks are associated with primary and secondary activities (*SkeletonActivity*, *Intermediate-Activity*) and can occur at certain locations of a building envelope (*SpaceGBXML*). Depending on the level of development of the building, the BIM may contain detailed information on technical systems (*EnterpriseEquipment*) such as lighting and HVAC systems. In such as case, the model is flexible enough to accommodate such concepts, fully interoperable and shareable with the definition of corresponding models in the BIM domain (e.g. gbXML internal and external equipment).

The schema can be further extended (Figure 8) with the introduction of "Schedulers" (Tabak 2008), as well as "Occupancy Anticipators" and "Control Predictors".

The "*Schedulers*" determine the order in which activities and tasks are activated within the building.

The complexity of the data model can increase further when personal scheduler per occupant must be combined with the business processes encountered in an organization. Activity schedulers (*Activ-ityScheduler*) are responsible to determine the plan of an activity (skeleton or intermediate, solo or group, etc.) including but not limited to the estimation of the start time, end time and duration. Given the activity status, "*Occupancy Anticipators*" can further support the simulation process with additional functionalities such as finalizing the involvement of one or more occupants (*Actors*) to specific activity schedules thus also enabling the interaction between building occupants (e.g. number of people needed to perform a primary activity) as well as the specific building zones where occupants will move to perform these activities. Finally, given the occupancy status within each building zone (as provided by the anticipators) the "*Control Predictors*" determine the control actions made by specific actors over the utilities of a specific building zone and towards performing a specific task (e.g. activity "attend meeting" involves the use of a projector, computer, etc.).

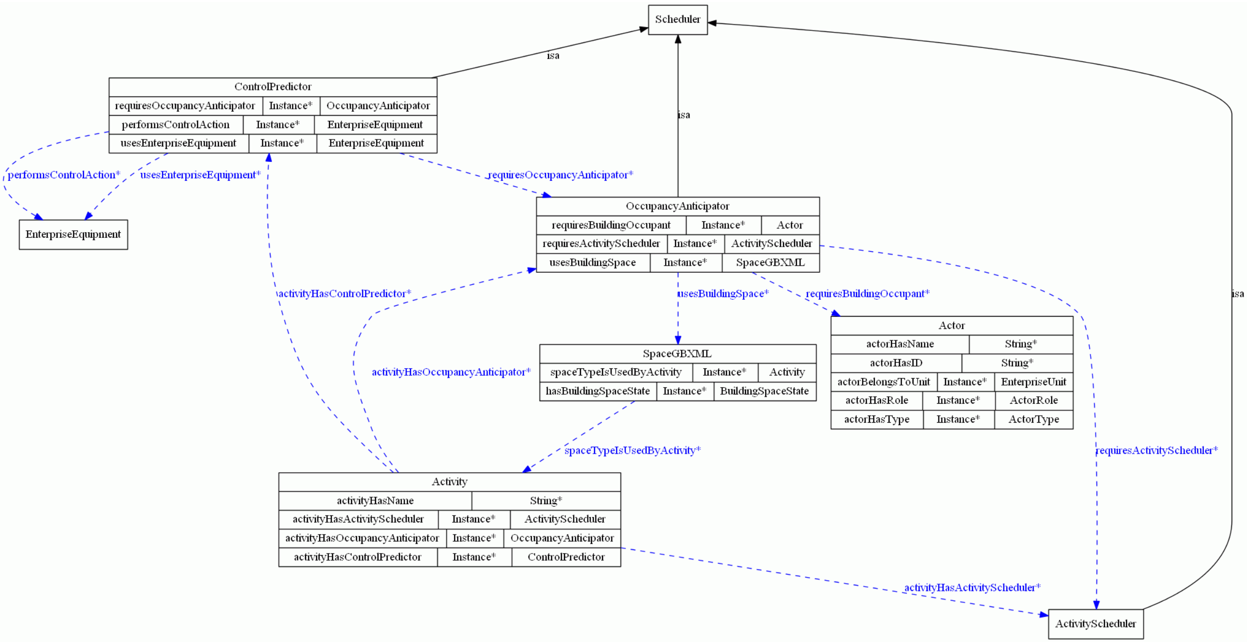

Figure 8: Incorporation of schedulers to support scheduling processes for activities, interaction among activities and/or actors, role-based activity location and participants' selection, etc.

Next section illustrates how the conceptual schemas presented for modelling the dynamic behaviour of a building due to its occupancy and the enterprise can be linked to the gbXML standard, towards further enriching the virtual representation of a building design (VBM) in a flexible and sophisticated way.

5 Occupancy Models in BIM

The past few years' significant progress has been made in terms of interoperability and data sharing in the building industry.

The delivery of respective informational infra-structures (e.g. gbXML, IFC) in the AEC industry has fostered the shareable knowledge between key stakeholders (facility managers, designers, planners, etc.) and improved the data exchange among AEC tools and the processing procedure in various building simulation tools focusing on the energy efficiency of buildings.

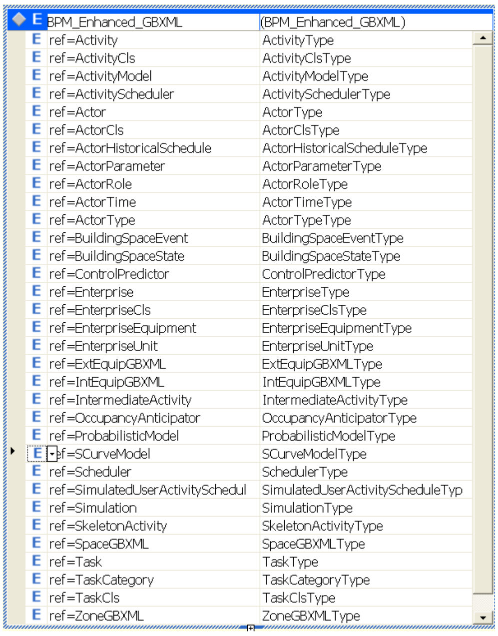

Figure 9: Provisional XML Schema from the conceptual data models presented in section 3 for occupancy and business modelling.

In this section, a provisional extension schema is provided for the gbXML standard towards incorpo-rating in BIM the necessary elements for enabling space utilization simulation in buildings under de-sign. This is the first step towards better assessing new constructions at the early design phase based on the analysis of the human behaviour when housed in buildings, as building occupants have been proven to be one of the most significant factors affecting the energy consumption of a building during its opera-tional phase.

The rationale behind the schema is to provide a groundwork reference schema that can be used for the seamless integration of the enterprise information to the BIM tools and the corresponding building performance simulation software. The schema links the BPM-related data (actors, roles, activities and units of an organization) with the BIM information, mainly with the spaces (or building zones if applicable), where organizational processes will take place and the actual enterprise resources (equipment such as HVAC), as they were provided by the designers and engineers through their design tools.

The overall schema with the additional elements to support the interaction between the business ana-lysts and the designers is illustrated in Figure 7. The sub-models presented in the previous sections 2-4 are combined to constitute a flexible and extendable data model to accommodate the needs of the respec-tive tools that will utilize them, fully supporting the design process through the virtual building model-ling procedure (as the xml schema establishes links and connections with the gbXML representations).

The provided schema elements incorporate in-formation needed for space utilization and behav-ioural user modelling and can be transformed easily to the OWL language format by using Extending Stylesheet Language Transformations (XSLT) doc-uments (Reinisch et al. 2011).

Storage and mapping can be made in a straight-forward manner and the formalization of the xml el-ements to semantic concepts (*classes*) with their at-tributes and properties can be then used in semantically enabled building frameworks, where reasoning capabilities on the actual instances will be available.

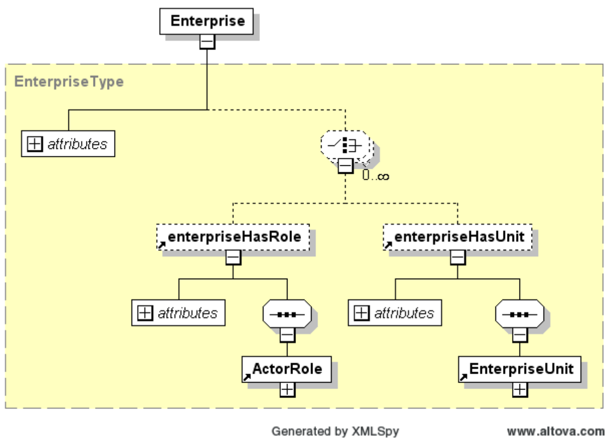

Figure 10: Enterprise view of the proposed schema.

Several information of the schema will be directly inherited from the gbXML standard. For instance, the location where activities of building occupants with specific role in an organization can be per-formed is linked to the space element in the gbXML schema. Furthermore, each actor performing a spe-cific task (composed of a series of activities, skeleton and intermediate) can implicitly be linked with the building information model equipment that has been included in the design process, depending on the level of building development.

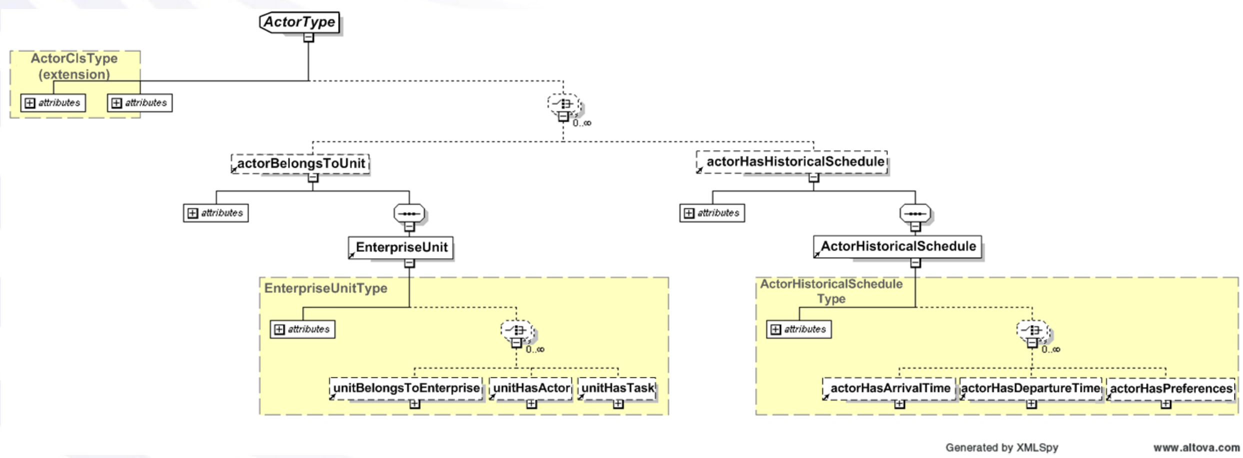

Figure 11: XSD Schema for defining building occupants in a building simulation framework. The actor belongs to an organiza-tional unit, has several roles, performs business processes (tasks), and has a typical occupant schedule that can be parameterized (use of "personas"). A knowledge base will be available to the designers and planners towards modifying the key parameters only for the simulation purposes.

Several different perspectives illustrating the schema defined for the enterprise, the building oc-cupant and the business processes are presented in Figure 8 to Figure 12.

In this paper, the gbXML standard has been se-lected from the BIM modelling standards to deliver the set of models that will enable key stakeholders perform enhanced building performance evaluations (e.g. pre-occupancy evaluation, energy usage simu-lation taking into account the occupancy dynamics, business performance, etc).

The gbXML has been widely used in energy sim-ulation tools developed by commercial software vendors and has the ability to carry additional metadata to the static building information models (BIM) for different purposes such as environmental sensing information (metering), loosing however in most times the semantic relation among elements. Efforts have been made recently to extend the ap-plicability of the gbXML also to other simulations such as lighting control (Dong et al. 2007).

The xml schema defined can be either linked di-rectly to the gbXML standard (via imports defini-tions) or standalone. It has references to the building information models through references to the actual instances of the xml schema of a building under de-sign. In this context, the schema can also be linked to the corresponding representations of the Industry Foundation Classes (IFC).

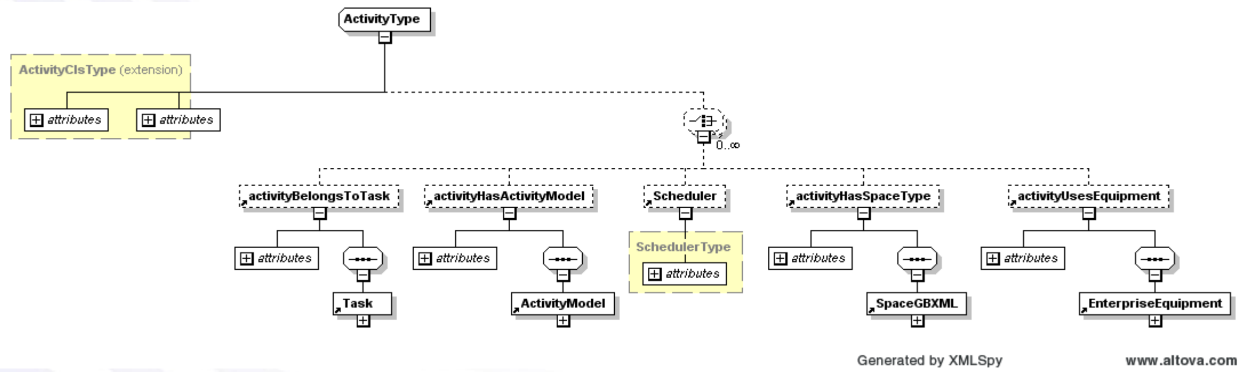

Figure 12: Schema for an activity (e.g. skeleton or intermediate as part of business-related task) linked with elements of the gbXML schema. Activities executed in specific building spaces or zones as already depicted in element activityHasSpaceType. The element has an attribute that correlates the space with an existing space on the input BIM

The IFC and gbXML are the two dominant and well-established information structures in the AEC industry, focusing on improving the information sharing across stakeholders during the whole life-cycle of a building. IFC is the industry de facto standard that adopts a holistic approach to represent an entire building project from the requirements phase, building commissioning and construction to building operation. Its mission is to providing a universal basis for process improvement and infor-mation sharing in the construction and facilities management industries.

With a comprehensive "top-down" data schema, IFC shows potential benenifts in its highly organized and relational data representation. In contrast, the "buttom-up" gbXML schema, focuses mostly on en-ergy related building aspects. It is simpler and easier to understand which facilitates quicker implementa-tion of schema extension for different design purposes. It presents certain limitations compared to IFC (e.g. limited detail in geometric boundaries, etc.), however these are not of significant importance to the simulation of occupant activities and behaviour

To this end, our approach, was based on the gbXML schema, and several views of the extension have been provided towards providing the necessary information to the key stakeholders to further reduce the common set of assumptions and specifications that are adopted across the designer and engineers during the design phases of a building (Maile et al. 2010).

6 Use of proposed models in Building Performance Simulation Tools

Construction Products constitute energy intensive systems through their whole life cycle, comprising energy demanding assets & facility operations but most importantly, occupants that are the driving op-erational force, performing everyday business pro-cesses and directly affecting overall business per-formance as well as overall energy consumption.

As of today, energy efficiency concerns (and therefore respective solutions) have been presented in the past addressing all phases of construction product life cycle (PLC) from the design phase (ear-ly and detailed design and engineering), to the Reali-sation phase (procurement and development) as well as the Support Phase (mostly focusing on Operation and Renovation).

Moreover, extensive market studies through years verify the need to make better strategic solutions in the early design phases of a building.

The next generation of building simulation tools (Figure 11) and frameworks should allow key stake-holders in the early design phases of a construction product to progressively produce realistic simulations of human behaviour in buildings and depending on the level of development to have better predictions between the simulated and the later real behaviour. As illustrated in Figure 11, business analysts, designers and engineers shall be able to easily parameterize the inputs and the parameters to be used in the simulation tools such as the total number of occupants, the organization that will be housed in the building under design, the critical business processes associated with the organization to be hosted, etc.

A knowledge base with open reference models may be available, as illustrated in Figure 11, which will enable the end-users to load existing models for business, occupancy and BIM models. The collabo-ration among key stakeholders will embody a multi-ple-step processing procedure, in which the feedback from the evaluation of alternative designs will finally conclude on the delivery of a high performance building.

The conceptual models proposed in this paper will enable the key stakeholders to share the necessary information needed to the building simulation framework for analyzing user activity and behaviour in buildings, focusing on the space utilization in the spatio-temporal domain and eventually the impact on the energy consumption of a building due to dy-namically estimated occupancy.

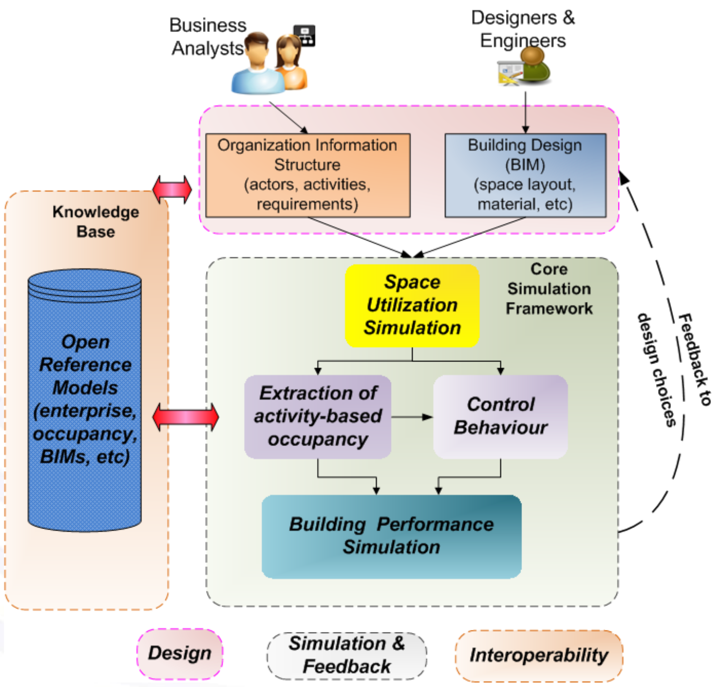

Figure 13: Conceptual view of the next generation of integrated building performance frameworks that fuse two (currently) disjoint worlds, the BIM and the BPM, having as central reference point for analysis the dynamic behaviour of building occupants.

For instance, business analysts already have the tools to define business processes and the organiza-tion structure in respective data models. Formalizing the conceptual models needed by the building simu-lation framework, as presented in Sections 2 to 4 of this paper, business analysts will be able to exchange the necessary information (export and import) with the designer tools and vice-versa. Ideally, a number of templates and reference models should be availa-ble and parameterizable by the experts to better align with the requirements of the building under design. Similar organizations (e.g. hospitals, commercial fa-cilities, etc) may have the same units but some pa-rameters are not always the same (e.g. two hospitals may have different spaces layout requirements and number of occupants to be hosted, etc).

Moreover, next generation of tools should allow designers and engineers to follow a “ceteris paribus” approach, meaning that the Occupancy factor can be isolated and examined separately. Focus will be giv-en on how simulated space utilization affects the overall building energy performance evaluation and optimization, treating the rest of the building design parameters (mostly related to building structural as-pects) that have already been thoroughly studied in the past, as constants. Furthermore, current practises indicate that designers and engineers may need one or more tools towards reaching the final goal of evaluating the building performance in terms of its energy efficiency. Thus, building performance frameworks that combine analysis of human behav-iour in buildings (space utilization simulation) and simultaneously cope with energy efficiency evalua-tion are expected to gain the interest of the AEC in-dustry.

In this context, the data models proposed in this paper contribute in fostering the developments in aforementioned end-user needs, by providing a set of reference models in gbXML format that cope with the modelling of occupancy in buildings in close correlation with its dynamic behaviour at the commissioning phases of its life cycle.

7 Conclusions and Outlook

Building simulation is considered to be common practice in the building industry. It has undergone a substantial growth both in the academic world and the building industry since its emergence three dec-ades ago. Research in the field of building simula-tion is also abundant, for instance with regard to modelling the behaviour of humans in routine busi-ness activities or even activities in egress situations.

Moreover, much research effort within EU fund-ed projects as well as international research action has been devoted to resolve the shortcomings of the current available building simulation and automation programs and respective Building Information Mod-elling (BIM) approaches. However, only recently the focus was shifted on analyzing the overall patterns, semantics and complexity of day-to-day human ac-tivity and movement within buildings, as well as the relation of these activities to domain specific enter-prise processes governing commercial buildings op-eration and performance.

To facilitate the communication and shareable knowledge across key stakeholders during the pro-gression of construction product (BIM), the Virtual Building Models need to be enriched with additional data models that can express the dynamic behaviour of a building due to the human presence and move-ments and can be utilized in the next generation of building simulation frameworks.

This paper contributes to this direction by propos-ing a semantically enriched conceptual schema for modelling the dynamic behaviour of building occu-pants and establishes a basic reference framework that can be used for both space utilization analysis and energy performance simulations. However, the schema is in its initial stage and needs further devel-opment and improvements towards incorporating them in the building performance software.

This is subject of future study that is currently performed in the context of the Adapt4EE EC-funded project that aims to deliver and validate a holistic energy performance simulation framework that analyzes occupancy behaviour (presence and movement) and incorporates them with architectural metadata (BIM) and critical business models (BMP).

The fusion of these two worlds, among other ob-vious advantages at the early stages of the design, will present the ability to effectively reconciling dif-ferences between the energy analysis of “real” and “simulated” buildings.

Acknowledgements

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2.3 Towards a Context Control Model for Simulation and Optimization of Energy Performance in Buildings

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Abstract

The process of optimizing building energy performance requires complex measurement, estimation and analysis. To address the complexity of designing for energy efficiency, models need to describe a building's different subsystems: the structure, processes, occupants, control equipment, environmental conditions, etc. For example, a Building Information Model (BIM) describes a building's structure, while Business Process Models (BPM) can formalize processes going on in a building, and a Context Control Model (CCM) describes heterogeneous devices in relation to a building's context.

To express the interdependencies between these subsystems an Enterprise Energy Performance Model (E-EPMM) is needed, integrating and extending the subsystems' models.

In this paper we focus on the physical subsystem (the building and devices) presenting a Context Control Model (CCM) for devices and appliances as an integral part of the E-EPMM. Further, we describe a middleware approach for instantiating and using the CCM and its application in a multi-agent based energy performance simulation framework.

1 Introduction

Global warming is one of the major problems man-kind will face during this century. Modern societies and governments invest huge efforts in reducing CO2 emissions by e.g. reducing the amount of energy produced by fossil fuels. Another strategy is to reduce the amount of consumed energy by optimizing energy efficiency.

For example, due to its large share of total energy consumption, significant savings potential lies in the residential and commercial buildings sector. According to the Smart 2020 Report (The Climate Group, 2008), global building emissions make up 8% of total emissions in 2002 (i.e. 3.36 GtCO2e (GigaTonnes of CO2 emissions), excluding the energy

used to run the buildings). The report forecasts an increase of this number up to 11.7 GtCO2e in 2020 and at the same time identifies a savings potential of 15% that can be achieved with the help of ICT: "Globally, smart buildings technology could potentially reduce emissions by 1.68 GtCO2e and be worth €187 billion ($295
billion) of energy savings and €29 billion ($45.7 billion) in carbon costs. This value can be captured by ICT and other high-tech companies." (The Climate Group, 2008).

To increase efficiency and minimize waste of energy, different strategies can be applied. For example, exchanging old equipment with more energy efficient devices, implementing building energy management systems, or motivating people to consume less energy. Of course, only the combined implementation of these strategies will unleash the full potential of energy savings. Further, it is important to consider the whole lifecycle of a building from the design phase to the operational phase.

To allow ICT-based measurement, analysis, and optimization of a building's energy performance in its different phases we need to identify and be able to modify the different aspects that have an impact on this performance. For example, if a building would be retrofitted with a new wireless Building Management System (BMS), this change would have a huge impact on the energy performance. Or, if business processes should be optimized towards in-creased energy efficiency, this could affect other processes or the usage of equipment.

We call these different aspects that affect a building's energy performance the subsystems of a building: The physical subsystem (buildings, devices, environmental conditions in the building), the human subsystem (occupants, with their occupancy and us-age behaviour), and the enterprise subsystem (enter-prise business processes and business goals).

For translating these subsystems into the ICT world, we need models to describe them: For example, a Building Information Model (BIM) describes a building's structure, while Business Process Models (BPM) can formalize processes going on in a building, and a Context Control Model (CCM) describes heterogeneous devices in relation to a building's context.

When looking at the different models and the sub-systems in reality, we recognize a gap between the real interdependencies and the models. For example, a Building Management System might be completely unaware of the structured data that is available in a BIM. Vice versa, a BIM might not include information about devices for measuring and managing a building's energy performance.

To bridge this gap of interoperability, we propose an Enterprise Energy Performance Management Model (E-EPMM) expressing the interdependencies between the subsystems, integrating and extending the subsystems' models. Such E-EPMM serves as the basis for managing a building's energy performance throughout its lifecycle. It can be used for design and simulation as well as for energy management in the operational phase.

In this paper we describe the E-EPMM as an integrated model of the different subsystems, focusing on the Context Control Model. In contrast to BIM and BPM no commonly accepted standard or methodology exists for designing a CCM. We describe our approach to modelling and instantiating a CCM by using a middleware for managing heterogeneous devices. We further present a multi-agent based simulation framework, using the E-EPMM for optimizing processes towards energy performance.

2 Enterprise Energy Performance Management Model (E-EPPM)

The goal of the Enterprise Energy Performance Model (E-EPMM) is to overcome issues of interoperability within the ICT-based energy performance management during the whole lifecycle of a building. Katranuschkov et al. have identified three gaps in building design and management practice, namely (1) the lack of a common data repository, (2) the lack of software interoperability, and (3) the insufficient use of simulation and monitoring during the whole lifecycle (Katranuschkov et al., 2011). This leads to the problem that ICT support in the different lifecycle phases is mostly restricted to one phase. The same goes for energy performance management, if even possible. Furthermore, eventual installations in the retrofitting/refurbishment phase also need to be reflected by the models for energy performance management.

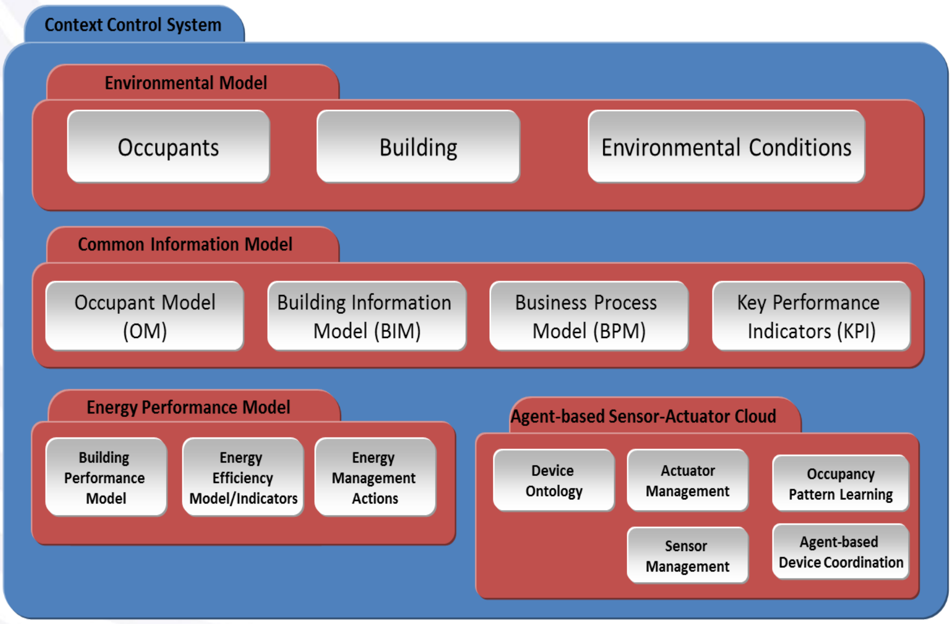

Figure 1. Model of a holistic Context Control System

The E-EPMM extends current Energy Performance Models by incorporating and integrating multiple dimensions: the physical sub-system, the human sub-system, the enterprise sub-system, and the general surrounding environment. By explicitly incorporating the enterprise as actor in this ecosystem, the energy performance model is expected to better ad-just to the characteristics of the business domains.

The goal is to integrate several aspects of an industrial sector: (1) The processes and governance of business and ICT infrastructures, particularly the aspects concerning optimization of cost-efficiency and other business-related Key Performance Indicators (KPIs). (2) The operations and management of the Building and ICT Infrastructure, particularly the optimization of energy-efficiency and its related KPIs (such as, GHG emissions reduction). (3) The agent-based modelling of actors, both stakeholders and supporting systems, with their needs and business-related issues; this includes devising of agent-based negotiation schemes which enable robust and efficient enterprise energy management in terms of the identified KPIs under dynamic and unpredictable situations.

Figure 1 shows the different parts of the E-EPMM and its role in the context of ICT-based energy performance management.

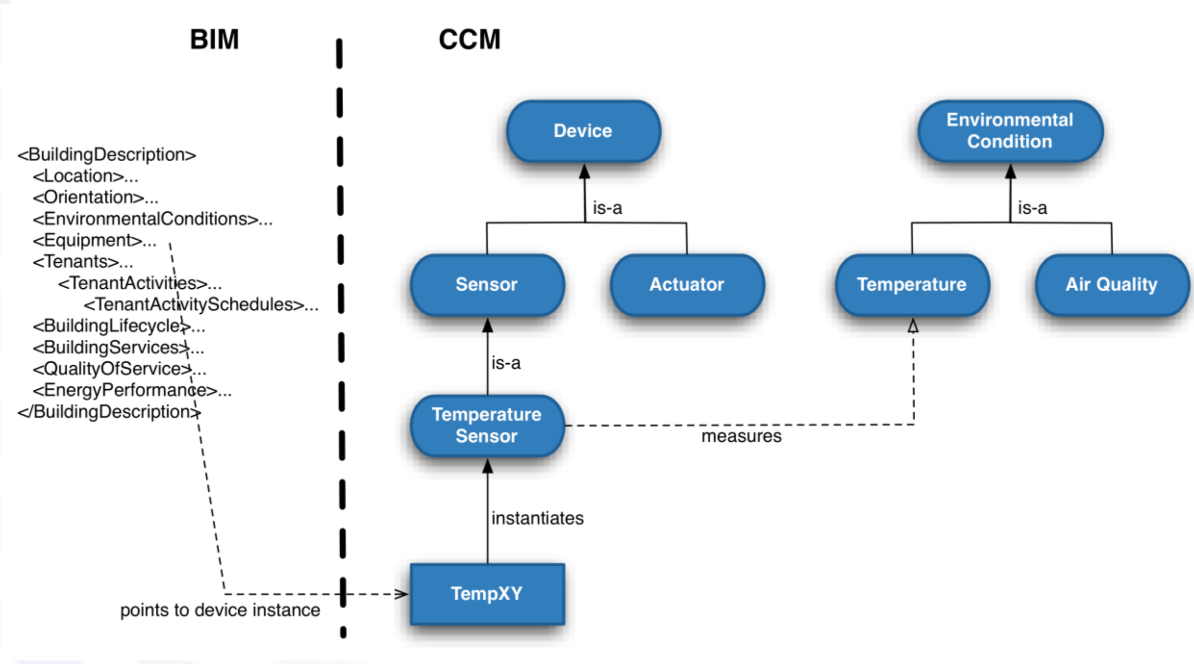

Figure 2. Example of Device Model

The Building Information Model (BIM) is an abstract representation of the physical and environ-mental aspects of the building ecosystem, incorporating architectural metadata and environmental parameters. Several standards for BIMs exist, e.g. IFC core ISO/PAS16739, and formats supporting this standard - gbXML, CityGML, landXML, or CIMsteel. The BIM is needed in the E-EPMM to model the physical subsystem of a building.

The Business Process Model (BPM) is an abstract representation of the functions, processes which the building supports in its daily use by its occupants. It models the enterprise subsystem. From the existing standards for representing BPM, e.g. BPMN/BPEL, BPDM, SBVR, AQPCF, BMM, PRR, we focus on open standards such as BPMN, supported by most commercial tools used in CAD/architecture design practice.

The Context Control Model (CCM) describes the heterogeneous devices in relation to a building's context and is part of the physical subsystem. Such devices can be monitoring equipment like sensors and smart meters but also appliances used in business processes. Further, the E-EPMM needs to include the effect of additional factors, such as environment and human occupancy, on the building energy performance.

2.1 Interoperability Issues

In order to support interoperability of our proposed device models and energy performance simulation tools with existing CAD and energy analysis tools and data standards, we use gbXML as a starting building block for describing CCM and the relation between devices in the control system and occupant activities. We extend the Green Building Energy Performance information with:

1. Location/spatial information (specific for BIM);
2. Process/activities and performing roles in-formation (specific for BPM);
3. Equipment/device information (specific for CCM);
4. Measurement/performance indicators information (specific for KPI);
5. Energy cost/impact information (specific for ANM).

Table 1 shows a possible mapping between the elements of gbXML and the elements of E-EPMM.

gbXML Element	Possible Mapping to E-EPMM
gbXML/Campus	BIM/BuildingPosition
gbXML/Construction	BIM/BuildingStructure
gbXML/Schedule	BPM/TenantActivities/Activity/Schedule
gbXML/WeekSchedule	CCM/Device/Schedule
gbXML/DaySchedule	
gbXML/IntEquip	CCM/Equipment/Devices/Sensors
gbXML/ExtEquip	CCM/Equipment/Devices/Actuators

gbXML/Meter	ANM/EnergyPerformanceSpecifications
gbXML/Weather	BIM/EnvironmentalConditions
gbXML/AirLoop	KPI/InternalAirQuality
gbXML/Meter	CCM/Equipment/Devices/Sensors ANM/EnergyPerformanceSpecifications
gbXML/Zone	BIM/OccupancyInformation KPI/EnvironmentQuality

Table 1. Mapping between gbXML and E-EPMM

3 Context Control Model

The Context Control Model (CCM) is part of a building's physical subsystem, describing heterogeneous devices and their relation to the building (e.g. location in the building). Such model is particularly important to bridge the gap between the early design phase and the operational phase as it provides a common information model for devices (e.g. employed by a BMS) and a relation to the Building In-formation Model.

During the lifecycle of a building both, the structure and the installed devices can undergo significant changes, requiring an adaptable and extensible mod-el that is able to reflect these changes.

3.1 Basic design of the CCM

The most basic dependencies the CCM describes are between devices and locations. Both, devices and locations themselves are described in more detail by their respective taxonomies. For example, devices can be sensors, actuators, computers, smart meters, and so on. Locations are buildings, rooms, etc. where the location information needs to be in line with existing standards like gbXML. Another information that needs to be modelled is the device capabilities. We need to know e.g. if a device can measure or influence environmental conditions, if it can count people or simply be switched on and off. Figure 2 shows a simplified example of a sensor instantiation in the CCM. Sensor TempXY is an instantiation of class TemperatureSensor, which means that it has the ability to measure the Environmental-Condition Temperature. This relation is implicitly inherited from the TemperatureSensor class. In Chapter 4 we will describe how such a model will be instantiated so it can be used by applications.

3.2 Application of the CCM

The CCM (as a part of the E-EPMM) provides important information about the physical subsystem during a building's lifecycle. In the early design and simulation phases of a building it can be used to model devices that are known a priori or to simulate potential devices or Building Management Systems that could be installed. In the operational phase the CCM contains the building's state and provides important information to energy management and performance optimization.

Now that we have a defined a model for describing a building's physical subsystem (especially de-vices), we need to think about how to apply and use such model in real-world applications. This is a serious issue, because – as described above – we deal with many different kinds of technologies and communication protocols. As we want to be able to deal with these different technologies and be open to ever-changing environments, we need to abstract from specific device and subsystem technologies and create a common information and access layer to work with.

Our approach to achieve a high degree of interoperability is to use middleware to manage and instantiate the CCM. Our goal is to use existing standards where possible and to develop reusable and extensible software components and models. In the next section we describe our middleware approach to achieve this goal and how the LinkSmart middle-ware helps to fulfil these requirements.

4 LinkSmart Middleware for Managing Heterogeneous Devices

LinkSmart middleware is used to connect the CCM with the real-world devices. It provides software components for device management and messaging infrastructure to access devices. This is a major advantage because we can integrate existing de-vices/subsystems into our applications quite easily.

The LinkSmart Middleware is a generic middleware for developing Ambient Intelligence (AmI) applications (Eisenhauer et al., 2011). It is the result of the FP6 European Project HYDRA (HYDRA Project).

LinkSmart provides a framework and software development tools for integrating heterogeneous networked devices into AmI applications. Further, LinkSmart comes with software components that provide functionality typically for AmI applications (e.g. message encryption, event management, or device discovery). In the following we will provide a short overview of the LinkSmart software architecture and concepts we apply and develop further in the domain of energy efficient buildings.

4.1 LinkSmart Architecture

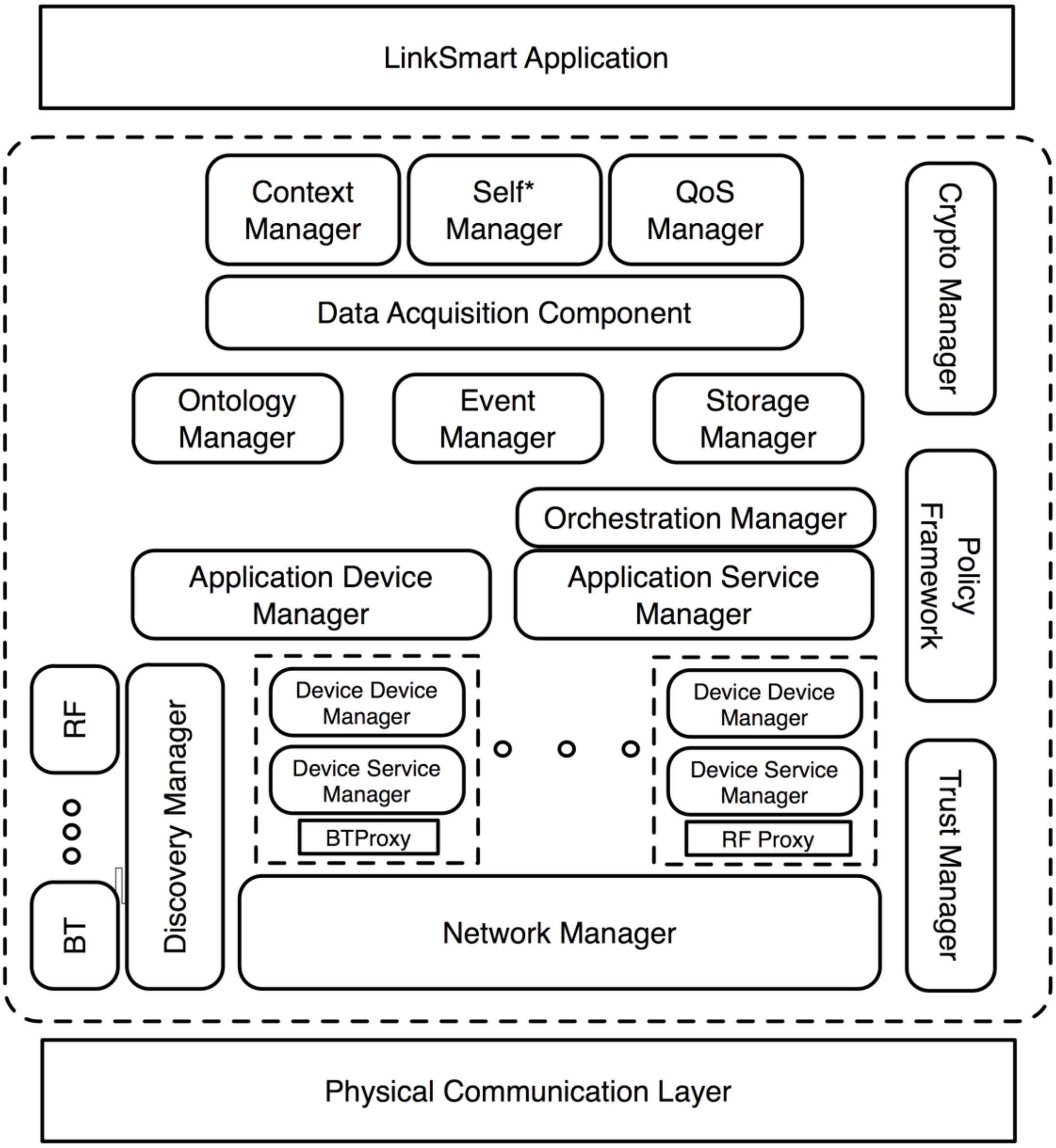

Figure 3. LinkSmart Middleware Architecture

LinkSmart implements a service-oriented architecture providing to software developers a set of components (called managers) they can select from, depending on their specific requirements (see Figure 3) This architecture also adheres to the principles of loose coupling and separation of concerns.

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.

4.2 Core Managers for eeBuildings Applications

LinkSmart has been and currently is applied and further developed for developing smart home (Jahn et al., 2010) and energy efficient building environments (Jahn et al., 2011; SEEMPubS Project; Adapt4EE Project; SEAM4US Project). Therefore, we currently strive to define a subset of LinkSmart optimized for energy efficient building environments. Such subset also includes the core managers implementing the basic functionality of LinkSmart:

A basic concept of LinkSmart is to abstract from heterogeneous devices and network protocols and to provide common Web Service interfaces for devices. This means, every LinkSmart device exposes its interface as Web Service (and managers do so as well). A device service can be identified by its HID (HYDRA-ID), which is unique inside a LinkSmart network. A LinkSmart Network is formed by distributed Network Managers that take care of the communication among devices and managers. Every service can register itself at a Network Manager and thus take advantage of communicating inside the LinkSmart network.

The Network Manager enables network communication by creating an overlay P2P network that implements SOAP Tunneling as transport mechanism for Web Service calls (Milagro et al., 2008). This concept allows direct communication among all devices inside a LinkSmart network, no matter if they appear behind a firewall or NAT (Network Address Translator). Further, the HID addressing scheme allows devices to transparently publish and use services anytime anywhere regardless of network boundaries or fixed service endpoints. If a device wants to consume a service of another device, the Network Managers of both devices take care of routing the Web Service calls, using the services' HIDs.

Another core component of LinkSmart is the Event Manager. For smart home and eeBuilding applications it is essential to be modular, extensible and provide low coupling of components, as set-ups can change when devices are removed or new devices are added to the environment. The Event Manager addresses these requirements, implementing a publish/subscribe mechanism for LinkSmart services. Thus, we are able to develop loosely coupled applications, which are flexible enough to face the requirements of dynamic AmI environments. The Event Manager handles all subscriptions and is responsible for publishing events via a Network Manager, compliant to the LinkSmart communication model.

4.3 Devices, Subsystems and Proxies

A core requirement of AmI applications is to support a wide variety of heterogeneous devices and communication protocols. This is also important in the domains of smart and energy efficient buildings. Especially in the refurbishment phase of a building it is necessary for an ICT system to be open to the removal, introduction or exchange of devices.

LinkSmart comes with software components and tools to foster the seamless integration of devices into new or existing LinkSmart applications. The proxy concept allows developers to hide the complexity of the underlying device technology and expose the functionality as LinkSmart Web Services. In AmI application design for larger spaces like commercial or public buildings it is important to take into account existing ICT installations like BMS, or security systems. In LinkSmart the integration of such subsystems can also be realized by proxies. Of course, the complexity of a subsystem proxy depends on many factors, e.g. availability of an open API, communication protocol, etc.

As tool support LinkSmart provides a model driven approach for device integration. The device ontology supports semantic interoperability between the different types of devices. The device ontology is based on the FIPA device ontology specification (FIPA, 2002) and the AMIGO project vocabularies for device descriptions (AMIGO, 2006). It contains basic information about devices e.g. device description and manufacturer (Sarnovsky, 2007). The LinkSmart Device Developmemt Kit utilizes the device ontology to help developers creating LinkSmart devices (proxies). Further, it is used during the runtime device discovery process for semantic device discovery (Kostelnik et al., 2008).

4.4 LinkSmart and the CCM

The original LinkSmart device ontology defines a general taxonomy of device classes which can be used and extended for specific application domains.

An Ontology for smart energy efficient buildings is currently being developed in various research projects, e.g. SEEMPubS, Adapt4EE. This ontology will contain information about common devices and capabilities in the energy efficient buildings domain. For example, a device can have the ability to measure temperature or luminance or other environmental condition. Devices can also have the capabilities to control certain environmental conditions like the temperature while other devices may just have an energy consumption profile.

There is a clear need for having an explicit representation of the role of each device in the energy performance, e.g. through its direct consumption or other building systems and occupant activities that depend on it. For this purpose, we use the mappings indicated in Table 1. This information is used by an agent-based Context Manager, which is able to recognize the impact of devices and occupant activities on the building energy performance, e.g. whether a device is wasting energy without servicing any on-going occupant activity.

4.5 LinkSmart Implementation

The LinkSmart reference implementation is built for OSGi environments. OSGi adheres to the principles of service- and component-oriented programming, providing a Java-based modular service platform. Components (called bundles) can be installed, started and stopped at runtime, not requiring a reboot of the whole environment. Each bundle publishes services that can be looked up and consumed by other bundles. Consequently, LinkSmart managers are available as OSGi bundles that can be plugged together on demand. Further, each manager publishes a SOAP Web Service interface to facilitate remote communication among components.

Components for semantic device discovery are implemented in .NET. As all communication is routed through the Network Managers, the underlying implementation details of a manager or device proxy are not important.

LinkSmart has been designed to meet the requirements of different target users: (1) Middleware developers extend the basic functionalities of the core middleware components or develop branches for specific domains. (2) Device developers are responsible for creating device proxies and keeping track of the device ontology. They program the translation between devices or subsystems and LinkSmart Web Services. (3) Application developers build applications by selecting (and if necessary extending) existing LinkSmart managers and device proxies.

5 Agent-based Simulation and Optimization Framework

The added value of using a Multi Agent-based approach (Kuehne et al, 2005; Ito et al, 2008; Cioffi-Revilla, 2010) to model the building and its elements, including the control equipment, the occupants and their activities, and the environmental factors as active components engaged in interaction as part of the Building Ecosystem, has been proven (Zimmermann, G. 2006b; Zhou et al, 2011). By applying it, we are able to better understand and adjust the interactions of building elements, to meet their intended goals in an energy-efficient manner. The primary objectives of an agent-based approach to coordination are to study the interactions between relatively autonomous entities which lead to emergent properties, such as the ability to coordinate actors to achieve a global conflict-free and feasible schedule: Can the different actors of the building ecosystem, self-interested but unable to achieve their goals without collaboration, achieve near-optimal local coordination, in the form of a global schedule which is both efficient (e.g., Pareto optimal) and robust? How can these agents make and coordinate their decisions in order to achieve a globally efficient and robust schedule in a partially observable and non-deterministic environment?

5.1 Typical CCM Usage Scenario

The typical scenario employed for Energy Efficiency Analysis using agent-based simulation is described below.

1. The Architect defines the Building Design, and selects one architectural change, e.g. conversion of a room in the building for a new purpose or for improved energy performance tuning.
2. The maximum allowed and the actual measured/estimated Occupancy Load Factor for the building segments estimated to be impacted by the change (e.g., how many occupants are expected per room, per m2 of space, per process, or during specific time intervals) are defined as part of the Occupancy Model (OM). This is based on international, national and local property-specific industry standards, defining maximum and/or standard values.
3. Using inputs from the building's Monitoring and Measurement Framework, the measurements from existing control equipment supporting the Building Energy Performance Management are integrated into the current Building Model.
4. Based on the Current Business Process Model with associated services (BPM), enhanced with occupancy information from the Occupancy Model, the BPM/Activity Designer provides the set of activities impacted by the room conversion. From the set of building activities and occupant activities supported, the so-called Future Business Process Model is produced, which includes the new to be supported processes.
5. The Architect initiates a What-If analysis to study the impact on Energy consumption with different occupancy load factors and different equipment installed in the room. This analysis is done using an agent performance simulation platform, which takes as inputs the Building Information Model extracted from the current CAD design, as well as the Business Process Model and Occupancy Model. The simulation platform has a configurable Energy Performance Model, which allows one to either estimate, based on earlier measurements, or to manually specify the impact of activities associated with devices and occupants, on the building Key Performance Indicators.

6. Based on the results of the What-If analysis, a set of alternative designs is selected, each containing the changes and ensuing combinations of effects associated with each type of change.

7. Once a short list of designs has been selected for further refinement, a simulation of the integrated model of the new room as part of the larger building ecosystem is done. Here, populating da-ta with measured and learned occupancy patterns in the neighbouring building segments is done.

8. Subsequently, an end-to-end stress test is done, for the measured or learned occupancy model, with an estimation of energy consumption range in worst case scenario. The result of this phase is a set of differences of estimated financial costs, power consumption, CO2 emissions and waste produced by the change of the building ecosystem generated by the room being transformed.

9. The Architect selects the elements of the design which meet the purpose of reconversion and pre-sent energy-efficiency, having withstood the stress test.

5.2 CHAP Agent-based Model

For the energy performance simulation, we employ our existing multi-agent modelling and simulation tool (Munroe et al, 2005) which supports constraint solving for scheduling, collaborative decision making, distributed coordination and optimization through learning and negotiation. This tool, called CHAP, for Common Hybrid Agent Platform, provides support for adaptation and evolution of application-specific data models and logic, support for integration with existing applications and deployment on different types of enabling infrastructures, such as wireless sensor mesh or mobile ad-hoc networks. CHAP uses a general-purpose, evolvable associative memory, a set of reusable AI modules implementing building blocks of intelligent behaviour, a configurable agent component deployment engine allowing agents to run on mobile devices and to interact with sensors, and a toolset for data visualization. These components can be tuned and adapted to a particular application or business domain using diverse (enabling) ICT infrastructures.

Each device part of Building's Context Control Model is represented as an autonomous CHAP agent. Its activity is the result of composition of multiple aspects of computation – data acquisition and processing, knowledge extraction and manipulation, and resource planning, task and energy management. This corresponds to a goal-aware, utility-aware, and adaptive rational agent, whose lifecycle is SENSE-REFLECT-PLAN-ACT, i.e. simple task selection, composition and chaining rules. The computing cycle of a CHAP agent is formalized as a transformation of the internal state based on environmental conditions observed:

A': next_state(A,Env) = Sense(A,Env) ○ Re-flect(A,Env) ○ Plan(A,Env) ○ Act(A,Env)

These lifecycle activities are supported by the main specialized components of the CHAP platform: LINKS component is responsible for Interaction Management with external world, i.e. Acquiring knowledge through Sensing and Applying plans in practice through Acting; NETS – Task Management, Planning and Scheduling; MEMO – Knowledge Management; MOTOR – Energy and Lifecycle Management. MEMO can be viewed as a distributed, extensible and adaptable tuple space, which stores all observations of the agent about its environment (acquired from LINKS), all knowledge of how to use its existing capabilities (NETS), and all plans and detailed actions for the agent to sustain itself and to change its environment, i.e. actions (including structural transformation and adaptations of CHAP components themselves) to be performed through its actuators (MOTOR).

Example: The Enterprise Energy Performance Management Model (E-EPMM) is defined as a multi-objective function of the Occupancy Model (OM), which is optimized by means of negotiation between self-interested agents with different objec-tives.

EEPMM(OM) = MultiObjectiveOptimisation-ByNegotiation(Agents, Environment)

Environment is a dynamic set of time-dependent constraints, representing the static aspect of the do-main:

Environment = Env(t, Resources, ResourceConstraints, NegotiationSchemes)

ResourceConstraints = {Resource(i,t) | i=1..n, t=1..m}, with Resource(i,t) = <BIM(OM,t), BPM(OM,t), CCM(OM, BIM, KPI, t), KPI(BIM)>

Each agent is seen as a composition of aspects, including prioritized objectives Objectives(t), which is a set of available activities with an indication of the resources required, and their utility as dynamic valuation. The agents try to rationally apply the available activities in order to apply the given objec-tives, using their resource constraints on available resources:

Agents = {Agent(i) | i=1..n agent index}, with

Agent(i) = Agent(t, Objectives(t), OM(t), Resour-ceConstraints(t,i))

Objectives(t,i) = {<Activity(i,j),Resources(i,j),Utility(i,j,t)> | j=1..m is index for Activities}

The impact of Occupancy Model (OM) on the current Building Information Model (BIM) is given as:

BIM(OM,t)= <BuildingStructure(BIM), Environment(BIM(OM,t)), Equip-ment(BIM(OM,t))>

The main BIM-related parameters influencing the building energy performance are: building's structure position and topology (e.g., large volume, high rise wrt its external environment, large windows, many doors, materials, isolation), external conditions, occupants with their activities, and equipment.

BuildingPerformance(BIM) =
BIM(BuildingStructure,ExtEnvironmentalConditions,Occupants,Equipment)

The only truly dynamic parameters that can be influ-enced are equipment and occupant activities.

Equipment = CCM(EquipmentPlacement ○ EquipmentActivationStatus ○ EquipmentPerfor-mance) (BIM,OM,t)

Occupants are expressed in terms of their Occupant density per BIM element and BPM element:

Occupants = OM(BPM,BIM,t)

BPM is influenced by occupant activities, i.e. Ser-vices, Activities and Roles changing over time.

In an adaptive Energy Performance Management Model, CCM must adjust itself to the Occupants' ac-tivity patterns.

The resource dependency and impact of device/agent activities on the building energy performance are expressed as evaluations:

CCMEnergyKPIImpact = KPI(CCM,BPM,BIM,t)

The objectives of agents which are part of the CCM sensor-actuator device cloud are expressed in terms of this energy performance impact. These evaluations are influenced by the building occupants' activity patterns, building performance metrics, and available coordination/negotiation schemes.

5.3 Implementation of CCM using the CHAP Agent-based Modelling and Simulation Framework

The problem of coordinating the CCM sensor-actuator device cloud for energy efficiency is viewed as a constraint satisfaction problem, more precisely a Distributed Resource-Constrained Multi-Project Scheduling Problem with uncertainty and partial knowledge (dRCMPSP/u), in which the resource constraints are provided by device performance specifications and occupants' activities impact on building's energy performance KPIs. For solving RCMPSP, we implemented agent simulations based on CHAP agent platform, able to accommodate autonomous agent negotiations (Ter Mors et al, 2008; Mao et al, 2008; Mao et al, 2009) or collabo-rative decision support problems through voting (Ferro et al, 2009).

An RCPSP problem involves the construction of a "project" schedule specifying for a list of activities the start and/or end-time in such a way that a set of resource constraints (time and other resource usage, such as energy, computing time, etc) are satisfied, and a set of objective functions (describing objec-tives such as minimization of impact on building energy performance) is optimized.

Each "project" in CCM is a list A={a0, a1, ..., an} of activities available for the CCM sensor-actuator device cloud to support the building services (e.g., movement detected, turn on lights, start heating, increase heating, emergency exit door opened, start sprinklers, etc). Each activity ai ϵ A has an estimated processing time, or duration, which is subject to uncertainty factors, such as occupants' movement, availability of computing time, etc. It also has a start time (or release), end time (or deadline), and a set of dependencies on other activities and on resources R={r0, r1, ..., rm}. CCM is an activity network emerging as result of interaction of multiple resource-constrained and inter-dependent "projects" (for instance, an actuator device "project" depends on a sensor device "project"). All devices and controls are represented as "project" agents, while the critical resources such as available energy quotum, time, computing time, but also device services (such as sensing, notification), are represented as "resource" agents. Some agents can be "resource" agents as well as "project" agents.

The internal computation and evolution cycle of each agent agi ϵ Ag can be seen as an activity network (represented as task compositions T(agi) = < t0○ t1○ ...○ ti ○⋯○ tn>, with ti ϵ A), undergoing continuous transformations T(agi) = < t0○ t1○ ...○ ti ○⋯○ tn> ☐ T'(agi) = < t0○ t1○ ...○ t'i ○⋯○ tn>. The transformations are triggered by selection of alternate activities based on highest utility, as provided by the objective function valuation. As mentioned, agent's valuations of task utilities depend on the energy performance impact of each task/activity, utility which is time-dependent.

We define set E: PowSet(Ag) x PowSet(T) x PowSet(Time) ☐ R as the set of objective evaluation functions defined over task compositions, which evaluates societal performance aspects (e.g. total execution time, total resource cost, etc). This allows selection of the best candidate from the alternative candidate task compositions or to adapt them from a structural, functional or organizational perspective. Each agent can have its own objective function, used for negotiating resource exchange with other agents during operation that can be al-tered on-the-fly, based on new acquired knowledge.

Each event e occurring in the CCM sensor-actuator device cloud is represented as a tuple (ag, τ, c, t) where a ϵ Ag is the set of agents in charge of the task, τ ϵ T is the task, part of a set of activities A plus all uncertainty-producing events (incidents) i ϵ I, c ϵ C is a power set of context elements and t ϵ Time is the set of relevant time points.

The goal of the scheduling problem is to find a suitable set of time points ti ϵ Time, such that the impact of an incident i ϵ I on an agent or group of agents ag, working on a task τ, is minimal, while taking into account the context c and the times tj at which all tasks need to take place.

For estimating the performance of potential solutions, and as such constructing recommendation schemes that fit new incidents occurring, the Windmill approach allows comparing new events to past ones. This is done by an estimation function for v which weighs past solutions by their relevance using a relevance metric δ and aggregates the associated performances according to its weights. The performance function associated with each event e is described by v: $A \times G \times T \times C \times Time \rightarrow [0,1]$: higher values correspond to desirable outcomes and lower values to less desirable ones. The performance function comprises measurement of, for instance, the operational performance (e.g., response times) individual judgments (i.e., ratings) or the workload.

This estimation of performance and concurrent running of all optimizations implements a distributed constraint satisfaction algorithm, which is able to select the most preferred solution, i.e. the activation schedule of a set of activities, which maximizes a specific set of objective functions.

Conclusion

In this paper we present an innovative agent-based approach for energy performance modelling and simulation in buildings, based on an advanced Context Control Model. We describe our middleware approach to model and manage heterogeneous devices (as part of the CCM) in energy efficient buildings, and to simulate their activity.

This approach takes into account the need to adjust building monitoring and control equipment based on occupants' activities, and views the ecosystem formed by occupants and the monitoring and control devices as the main factors influencing the internal environmental conditions of a building. Representing explicitly the occupants and the effects of their activities on the building ecosystem makes it possible for building designers to incorporate energy efficiency analysis in the early phases of building lifecycle and to produce better performing buildings. It also allows one to provide a more granular management and control of building equipment (sensors and actuators), and to use this information to achieve a higher building energy performance.

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3. Session: ee beyond the Building

3.1. A Simple Vocabulary for Semi-decentralised Management of Energy Demand in Households

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Abstract

This paper presents a demand-side management approach for electrical energy in households which can utilise locally available renewable energy resources like wind and photovoltaics. The concept which was developed gave rise to two kinds of vocabularies:

The first one is a classification of household appliances which bundles appliances having similar interfaces, user interaction and demand side management opportunities. In particular, the local control actions are the same for each appliance class.

The second vocabulary is used for the communication between a central energy management unit and the appliances. Simple control signals are not sufficient here, since the energy management unit might need a lot of information about the specifics of the appliance and its current state of service. Therefore the EMU issues cost profiles for certain future time periods to be taken into account for the local control.

We also give two examples on how these cost profiles are used in the case of schedulable and thermal services for local control planning.

The work presented in this paper has been carried out in the SmartCoDe project, co-funded by the European Commission within the 7th Framework Programme (FP7/2007-2013) under grant agreement no 247473.

1 Introduction

The project SmartCoDe (www.fp7-smartcode.eu) investigates the use of wireless sensor/actor nodes for controlling appliances in private households and small businesses which have access to locally installed renewable energy resources, e.g. photovoltaics or wind energy. A central energy management unit (EMU) is provided with forecasts for the local renewable energy output, and tries to control the energy demand of the local appliances via the nodes such that the local renewable energy is maximally utilised.

In the course of the project an energy management concept was developed which gave rise to two kinds of vocabularies.

The first vocabulary classifies (electrical) household appliances. It groups appliances which have similar interfaces, user interaction and demand side management opportunities. For example, all appliances providing thermal services (e.g. fridges, heaters, air-conditioning) form one class according to this classification.

This classification was compiled with the goal to combine all appliances which can be handled with the same sensor/actor node software (possibly after parameterisation) and the same communication protocol. The central interest of SmartCoDe is the concrete energy management application in the given use-case (households, local renewables, wireless (ZigBee) communication). Therefore the classification here is much more specialised than e.g. the ontology presented in (Noguero et al. 2011), which provides a platform-independent framework for energy efficiency in buildings with a much more general scope than SmartCoDe. However, the SmartCoDe classification is still more general than the device classification used in the ZigBee Smart Energy 1.0 standard (ZigBee Working Group 2008) which for example lists electrical vehicles as a single class without mentioning any other chargeable entities.The second vocabulary is used for the communication between the EMU and the appliances. Simple control signals (e.g. on/off) are not sufficient here, since the EMU might need a lot of information about the specifics of the appliance and its current state of service (e.g. temperature, program cycle). Also, the more volatile nature of wireless communication (e.g. delays, connectivity) forbids such an approach for critical applications like controlling the compressor of a freezer over the air.

Therefore the EMU issues *cost profiles* for certain future time periods to the sensor/actor nodes, which then control their appliance such that energy consumption is low during peak times of the cost profile, and higher during low-cost times, while still maintaining a service which is satisfactory to the user. The sensor/actor nodes also compute forecasts or even plans of their appliance's *future energy consumption* and send them back to the EMU as load profiles.

Class	Description	Parameters			Energy Management		Examples
		Configuration	Sensor input	Online input	Strategy	cost	
VARSVC	**Variable Service:** The appliance provides a user-variable service which is balanced with sensor input.	tolerance bounds	current state of the service, e.g. illuminance	user demand, e.g. setpoint for illuminance	Minimise consumption by balancing the service with user demand, tolerance bounds and sensor measurement.	No	lighting controlled by illuminance level, dimmable lighting, blinds
THMSVC	**Thermal service:** The appliance provides a inert, thermal service which can serve as a virtual storage.	temperature bounds / hysteresis	temperature	user demand, e.g. setpoint for temperature	Adjust temperature to user demand while exploiting the virtual storage property to minimise costs.	Yes	Fridge, Freezer, Heating, A/C, Water-boiler
SCDSVC	**Schedulable Service:** The appliance provides a service which can be scheduled within a certain time-frame.	runtimes and power profiles of the different programs	none	deadline	Schedule program such that deadline is met and the program's load profile produces minimal costs.	Yes	washing machine, dryer, dishwasher, baking machine
ETOSVC	**Event-Timeout Service:** The appliance is control-led by sensor events and time-outs.	time span	sensor event, e.g. presence detection	none (indirectly through sensor input)	Control appliance according to sensor events and time-outs.	No	lighting controlled by presence detector
CHACON	**Charge Control:** The appliance charges a possibly removable device.	charging policy	current charge status, device presence	device removal re-insertion	Charge device such that costs are minimised, while obeying charging policy.	Yes	battery chargers, hand-held vacuum, emergency backup storages
COMCON	**Complete Control:** Like CHACON, but the usage of the charged power can also be con-trolled.	charging policy, duty cycles, time slots	current charge status	none	Like CHACON, but also control the usage of the appliance cost-effectively while obeying to the given time-slots and duty cycles.	Yes	robot vacuum, robot lawn-mower
CUSCON	**Custom Control:** device does not fit into other classes or has too high user interaction to be controllable.	none	none	user demand	Automatic Energy Management probably not tolerable by user; custom schemes can be defined which are implemented by the EMU.	No	HiFi, PC, Oven

Table 1 SmartCoDe appliance classification

While the protocols for exchanging this information as well as the semantics of the cost-load profile might differ slightly for different appliance classes, the cost-load profile approach provides a standard language for demand side management which is independent of appliance specifics. It especially keeps the control-setup of the appliance with the manufacturer, who has the most competence in this area. Also, the approach is not tied to the use of local renewables, but could also be the endpoint for general demand side management activities of utilities and/or grid provider.

The rest of this paper is organised as follows: Section 2 will briefly present the SmartCoDe appliance classification, and Section 3 presents the SmartCoDe demand-side management approach. Section 4 brings the vocabularies of the two sections together and shows for two appliance classes how the energy management works in practice before concluding. Related work will be treated in the parts of the text where the specific topic arises.

2. Appliance classification

The appliance classification used in SmartCoDe can be seen in Table 1 and has essentially been presented already in (Damm et al. 2011) and (Grimm et al.) such that we won't discuss it in detail here.

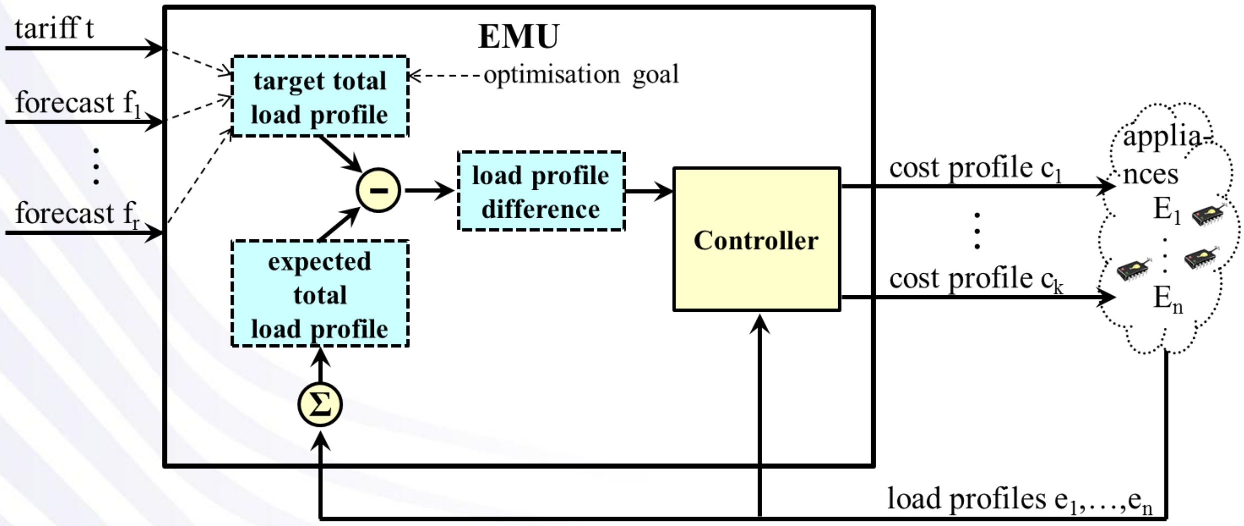

Figure 1: Partially decentralized energy management

One change made was renaming the class previously coined as "VSTSVC" (Virtually Storable Service) to "THMSVC" (Thermal Service). The members of THMSVC are still virtual storages, since they store energy in their thermal capacitance which can't be transformed back (hence the term "virtual"). But all the representatives of this class in typical households have to do with either heating or cooling. A non-thermal (but also very non-typical) example would be a local water reservoir which has to maintain a certain water pressure and is filled using a water pump, which could be switched on only in favourable times or when the pressure is too low. And since in the meantime we have developed an energy management approach making explicit use of the knowledge of the thermal process (see Sect. 4.2.) it was obvious to also reflect this in the classification.

The column "cost" indicates if the cost profile introduced in the next Section is of relevance for the local appliance energy management. This is set to "No" for VARSVC, ETOSVC and CUSCON appliances, because users in general won't, for example, tolerate their lights dimmed or their TV switched off according to the current energy cost or wind turbine output.

3. Global cost-load profile Energy Management approach

The overall energy management approach of SmartCoDe is depicted in Figure 1 and proceeds in general as follows:

1. The EMU has a certain target load profile for the combined power consumption of the managed appliances. How this target load profile is determined is of no concern here, but will in general depend on the available future tariff and forecast information, and a certain optimisation goal (e.g. grid stability or selling energy to the grid).
2. The appliances (i.e. the SmartCoDe wireless nodes) produce forecasts (or even plans which they are committed to) of their future power consumption and send them to the EMU in the form of load profiles.
3. The EMU collects these load profiles and compares their sum to the target load profile. A controller (which has also has access to the single load profiles) then issues new cost profiles. Regarding the latter, there are three possibilities:
    - A cost profile broadcasted to all appliances of a specific appliance class according to Table 1.
    - A cost profile broadcasted to all appliances of a specific utility enrolment group, i.e. a set of appliances grouped together
    - A cost profile sent to a single specific appliance.
4. The SmartCoDe wireless nodes receive the cost profiles and try to control their appliances such that they use less energy in high-cost times and more energy in low-cost times.

The message formats used for cost- and load-profile are shown in Figure 3. The cost profile is based on the ZigBee Smart Energy 1.0 load control event (ZigBee Working Group 208) which describes an event with a start time, a duration and several values to control different kind of appliances, e.g. temperature setpoints. One of these values is the *Criticality Level* also used in the SmartCoDe cost profile. The Criticality Level is basically appliance-independent and indicates with a range of 6 values how costly the use of energy is during that time-span; from 1 (cheap) to 6 (expensive). There are also additional values to indicate e.g. planned outages.

The energy management approach described above could in principal be realised already using the ZigBee SE load control event. I.e. a cost profile with *n* entries could be transmitted with *n* load control events. However, the time-granularity targeted (10 minutes) is relatively fine, such that a lot of these load control events would be required. Also, the ZigBee SE load control event contains additional information we only have little or no use for in our approach.

SmartCoDe cost profile

Data Type	Unsigned 8-bit int	Unsigned 8-bit int	8-Bit Flag register	UTC Time	Unsigned 8-bit int	Unsigned 8-bit int	Unsigned 8-bit int	(repeat) …	Unsigned 8-bit int	Unsigned 8-bit int
Field Name	appliance class	utility enrolement group	Time Resolution	Start Time	cost profile length n	Criticality Level 1	Duration 1 (in time resolution units)	…	Criticality Level n	Duration n (in time resolution units)

SmartCoDe load profile

Data Type	Unsigned 8-bit int	Unsigned 8-bit int	8-Bit Flag register	8-Bit Flag register	UTC Time	Unsigned 8-bit int	Unsigned 8-bit int	Unsigned 8-bit int	(repeat) …	Unsigned 8-bit int	Unsigned 8-bit int
Field Name	appliance class	utility enrolement group	Power Resolution	Time Resolution	Start Time	load profile length n	Load Level 1 (in power resolution units)	Duration 1 (in time resolution units)	…	Load Level n (in power resolution units)	Duration n (in time resolution units)

Figure 2: SmartCoDe cost- and load-profile

An important reason for the relatively fine granularity used is the utilisation of wind forecasts which use a 10 minute granularity; for a discussion on this see (Bertényi et al. 2010)

Therefore we bundle a series of load control events, but specialised only to the Criticality Levels, in the SmartCoDe cost profile. For maximum flexibility, the time granularity can be chosen from 1 second to 1 hour. The load profile message is similar, but contains the load per step (in units of Watts or multiples of Watts) instead of the Criticality Level. The granularity of the load can be set using the power resolution field.

4. Using the vocabulary

In this section we show how we use the described vocabulary, i.e. how cost- and load profiles are used in the global energy management control loop depicted in Figure 1 for the appliance classes SCDSVC and THMSVC.

4.1. SCDSVC local control and protocol

The *local control* for a SCDSVC appliance with a given deadline and cost profile is straightforward if the load profile for the chosen program is known: The SmartCoDe node simply tries to find a start-time within the given time frame such that the product of load- and cost-profile is minimised. However, computing the load profile might not be as simple, since it might depend on several conditions like the current water temperature, which influences the length of the initial heating cycle. But it should be possible for the manufacturers to find a satisfactory estimate, since they understand the process of their product the best.

The *protocol* for SCDSVC appliances looks as follows:

1. The EMU broadcasts a cost-profile to all SCDSVC appliances in the network. The base of this initial cost profile is of no concern here; for example it might reflect the power consumption of all other appliances in the network, effectively identifying "gaps" where SCDSVC appliance operation could be placed.
2. If a user starts a SCDSVC appliance, the SmartCoDe node schedules the operation according to the deadline provided and the load profile of the chosen program. It then sends the load profile (which then contains the additional information of the start-time) to the EMU. It is now *committed* to this load plan unless the EMU sends it a specific custom cost profile designed to change the node's initial load plan.
3. The EMU computes a new SCDSVC cost-profile and broadcasts it.
4. If the conditions change (like change in wind-forecast), the EMU has the option to send a custom load profile to already load-profile-committed SCDSVC appliances in order to change their load plan. For example, time periods which are absolutely unfavourable could be explicitly blocked with maximum cost values.

Note that this protocol could also be realised in a centralised manner, with the SCDSVC appliance sending load profile and deadline to the EMU, which then sends back a starttime. However, there are two disadvantages: For one, additional special message types would be required. But more gravely, such an approach would not allow for *interruptions* of the program, since the appliance would send a fixed-duration load profile to the EMU. By letting the SmartCoDe node make the initial decision on the start-time, it can also include interruptions if the cost profile would present the opportunity.

Depending on the process, interruptions might only be possible at certain times of the process. For example, interrupting a washing machine shortly after the start when the clothes are soaked in detergent and letting them sit for two hours is probably unfavourable. But interrupting for some time after rinsing before the final centrifuging might be OK. Again, the manufacturer has the best knowledge for decisions like this, which he could include in the sensor/actor node software for the cost-profile dependent local control decisions.

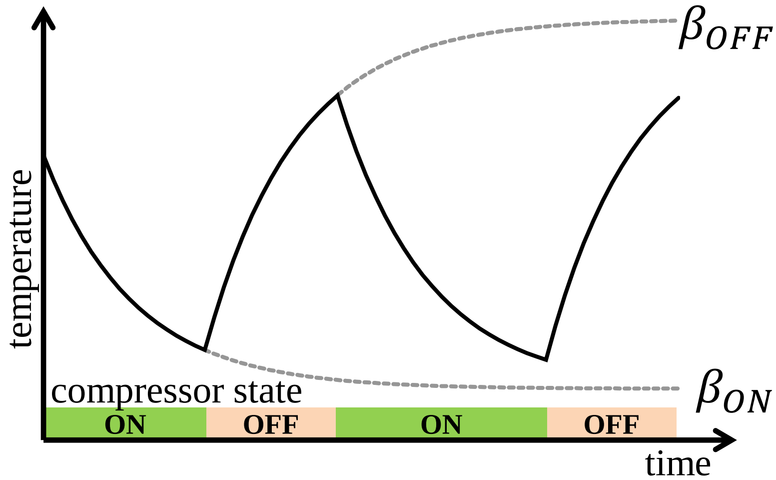

Figure 3: THMSVC temperature model4

4.2 THMSVC local control

The operation of a THMSVC appliance is much more volatile than in the SCDSVC case. It depends largely on the outside temperature and the thermal capacity of the current load. Therefore, having a temperature forecast available which adapts to these circumstances is a good base for THMSVC load planning.

In the next section we present an approach for THMSVC temperature forecasting which has been implemented in the SmartCoDe project and is novel to the best of our knowledge. While it is not essential for the discussion of the SmartCoDe energy management vocabulary, it serves as case study on the complexity which can be introduced by demand side management.

4.2.1 LEARNING AND FORECASTING THE THERMAL PROCESS

Since our application measures the temperature periodically with equidistant steps, the most straightforward approach is to formulate the problem in discrete time. That is, the temperature curve is a discrete series of samples t_1, t_2,…, t_i,… and the sampling period Δ_T between two consecutive measurements is of no significance for the problem. The goal is to use a certain initial segment of the temperature samples to learn the thermal process such that we can predict subsequent temperature samples. What we want to be specifically able to do is the following

- Predict the value of a sample t_{i+k} on input of the current temperature t_i and $k > 0$ and

- On input of a temperature threshold B, a sign factor $f \in \{-1, +1\}$ and the current temperature t_i, predict the number of steps *k* until the threshold *B* is breached, i.e. $t_{i+k} \geq f \cdot B$

It is well known that the temperature profile of such thermal processes can be modelled as a low-pass filter in the time domain (see e.g. (Kupzog and Roesener 2007)). A low-pass filter can be modelled as follows in discrete time:

(1) $t_{i+1} = \alpha \cdot \beta + (1 - \alpha) \cdot t_i$

For the temperature modelling case, β is the value (in the following also referred to as *target temperature*) where the temperature would asymptotically tend to would the appliance stay in a given state (like on or off) indefinitely. That is, for each power state of the appliance there is a specific β. In the case of a fridge, β_{OFF} would be room temperature if it stayed switched off, and β_{ON} would be a certain temperature (usually) below 0°C if it stayed on (see Fig. 3). For brevity, we will omit these subscripts when we don't have to distinguish different power states. In (Stadler et al. 2009) a more elaborate discrete time temperature model is used taking factors like insulation and thermal mass into account. But since our algorithm should not depend on such information, we use this simple formula.

The value α is the discrete time equivalent of the time constant τ (in fact, $\tau = \Delta_T \left(\frac{1-\alpha}{\alpha}\right)$), and is sometimes referred to as *smoothing factor*.

If α and β are known, we can iterate (1) to get the temperature after *k* steps:

(2) $t_{i+k} = \beta - (1 - \alpha)^k \cdot (\beta - t_i)$

and if we set $t_{\{i+k\}} = f \cdot B$ and solve for *k* in (2) we get

(3) $k = \frac{\log(\frac{\beta - f \cdot B}{\beta - t_i})}{\log(1-\alpha)}$

to determine when we breach the temperature bound *B*. To solve the problem, we use the least squares method. The principle of least squares is to fit a sequence of observations (in our case *k* temperature measurements $t_0, \ldots, t_{\{k-1\}}$) to a parameterised model function *f(i,P)* with parameters $P = (p_1, \ldots, p_m)$ such that the error term $\sum_{i=1}^{k-1} (f(i, P) - t_i)^2$ is minimised.

The parameters for the case at hand are $P = (\alpha, \beta)$, such that our model function is given by $f(i, \alpha, \beta) = \alpha\beta + (1 - \alpha)t_{i-1}$, which results in an error term

(4) $error_k(\alpha, \beta) = \sum_{i=1}^{k-1} (\alpha\beta + (1 - \alpha)t_{i-1} - t_i)^2$

which can be rewritten as a polynomial in α and β:

(5) $$error_k(\alpha,\beta) = \sum_{m=0}^{2}\sum_{n=0}^{2} C_{m,n,k}\,\alpha^m\beta^n$$

With coefficients

(6)

$$C_{2,2,k} = k$$

$$C_{2,1,k} = -2\sum_{i=0}^{k-1} t_i$$

$$C_{2,0,k} = \sum_{i=0}^{k-1} t_i^2$$

$$C_{1,1,k} = 2(t_0 - t_k)$$

$$C_{1,0,k} = -2(C_2,0 - \sum_{i=0}^{k-1} t_i t_{i+1})$$

$$C_{0,0,k} = -t_0^2 - C_{1,0,k} + t_k^2$$

$$C_{0,1,k} = C_{0,2,k} = C_{1,2,k} = 0$$

With a straightforward gradient analysis we now can find closed expressions for α and β in terms of the coefficients in (6):

(7) $$\alpha = \frac{C_{2,1,k}C_{1,1,k} - 2C_{2,2,k}C_{1,0,k}}{4C_{2.2.k}C_{2.0,k} - C_{2,1,k}^2}$$

(8) $$\beta = \frac{-C_{1,1,k} - \alpha C_{2,1,k}}{2\alpha C_{2,2,k}}$$

That is, we need to compute $C_{2,2,k}$, $C_{2,1,k}$, $C_{2,0,k}$, $C_{1,1,k}$ and $C_{1,0,k}$, and then use (7) to determine α which then is inserted in (8) to get β.

The advantage of these formulas is that we don't have to collect the temperature samples of one *run* (i.e. from the time the appliance switches into a specific power mode until it leaves it), and *then* compute α and β*.* Instead, we can *update* the coefficients with each measurement, effectively aggregating the samples of a run concisely in these five variables. That means the algorithm has constant memory requirements and does not depend on run length and sample period. Also the runtime is constant. These two attributes are important for microcontroller algorithms, since memory might not only be scarce, but also has to be allocated statically, and the runtime of processes are usually limited by a watchdog.

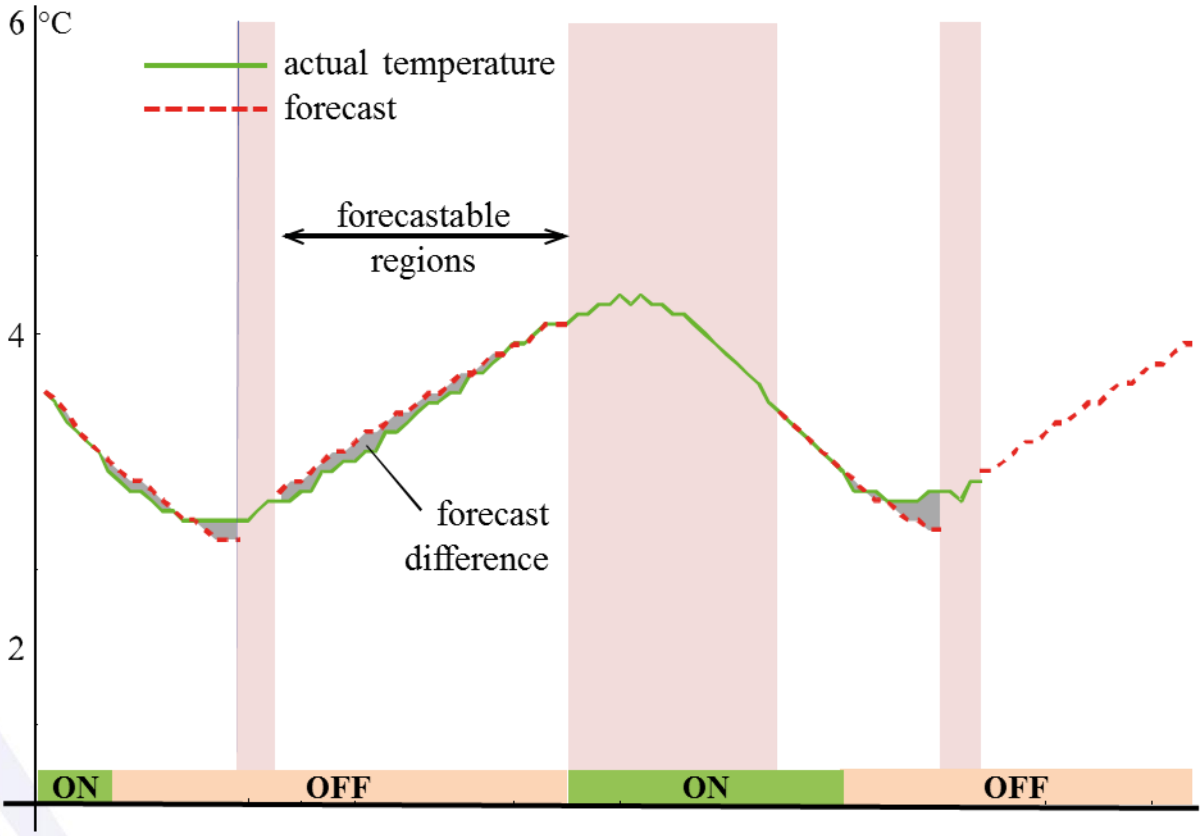

Figure 4: Example forecast performed by a SmartCoDe node controlling a fridge

The algorithm for computing α and β (for the respective power state) now works as follows:

- As long as the EuP remains in one power state (e.g. on or off), *short-term coefficients* $C_{m,n}$ are constantly updated after each measurement. I.e. after the i^{th} measurement we have $C_{m,n} = C_{m,n,i}$. For example, $C_{2,1}$ is initialised with *0*, and with the arrival of the next temperature sample t it is updated as $C_{2,1} = C_{2,1} - 2t$ (see (6)).
- If the appliance is switched into another state, new *long-term coefficients* $\hat{C}_{m,n}$ are computed as $\hat{C}_{m,n} = w\hat{C}_{m,n} + (1-w)C_{m.n}$, with the weight $0 < w < 1$. That way we can accumulate the information we need over several runs, with the long term coefficients initialized as *0*.
- After each update, the long-term coefficients $\hat{C}_{m,n}$ are used to determine α and β using (7) and (8), and the short-term coefficients are reset for the measurement run of the new power state.

Note that the usage of the long-term coefficients is a crucial step, since practical experiments showed that the information gathered during one run is not enough to get good temperature forecast results, but after 3-4 runs the forecasts are usually satisfactory.

However, there is a problem with the presented temperature forecasting when applied in reality: After switching to a new power state, it takes some time before the temperature pulls strong enough to the new target temperature. During these "turnaround times", we cannot use the forecast, as can be seen in the real-life example in Figure 4, which shows also that the forecast works well in the so-called forecastable regions. How to make use of this restricted forecast is shown in the next Section.

4.2.2. PI-BASED COST-PROFILE DEPENDENT LOCAL THMSVC CONTROL

In the previous paper (Damm et al. 2011) we presented a simple approach how to control THMSVC appliances depending on the cost-profile by adapting the temperature bounds, and showed simulation results how this could be used for load balancing by issuing phase-shifted periodic cost-profiles. While this worked well, the problem is to provide a forecast of the local power consumption to the EMU.

If we could *seamlessly* forecast the temperature without any gaps, we could simply *simulate* this (or an y other) control algorithm for a certain future time period by using temperature forecasts instead of real measurements. However, we just saw that this not possible by only using the above approach, with the reason essentially being that the model function used is not suitable for the transitional time-spans between two different power states.

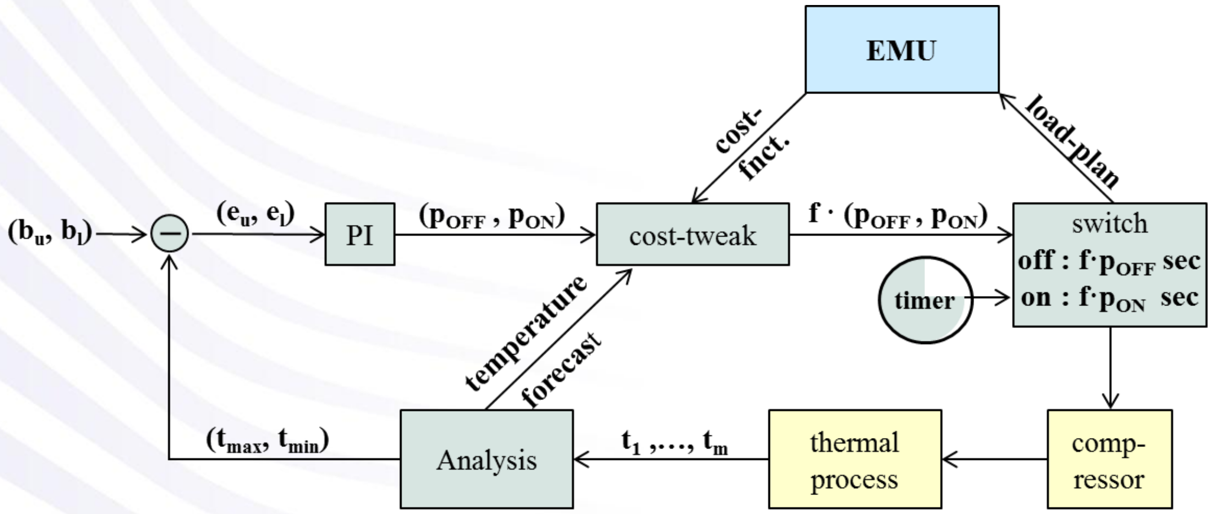

Figure 5: cost-profile dependent PI-based THMSCV control loop

But even if the forecast gap could be closed, the simulation of the control algorithm, which would have to run on the microcontroller, would be very time consuming since it had to be performed in a step-by-step manner. Therefore we chose another approach. The following local control algorithm for fridges and freezers can make use of the partial forecasts, namely by forecasting the time when the upper (more critical) temperature bound is hit.

In an *initial learning phase*, usual bang-bang control is used. Apart from initial values for the parameters (α, β) of the process, we also learn the normal duty cycle which is used to to parametrize a PI controller. After that, the node goes into *planning mode*, which works as follows:

1. For each Off-On cycle, the lowest and highest temperatures are determined.
2. After switching off, the node waits until the temperature rises strong enough (w.r.t. the slope) to predict when the upper bound is hit.
3. A PI controller determines an initial schedule (p_{OFF}, p_{ON}) based on the difference (e_u, e_l) of the max/min temperatures (t_{max}, t_{min}) of the last off/on cycle to the temperature bounds (b_u, b_l)
4. This initial schedule is now tweaked until the most cost-effective schedule is determined, safeguarded by the temperature forecast. Note that this control loop has a delay of about 1 hour or more for a fridge; with the temperature forecast we get more safety to obey to the upper bound.
5. The SmartCoDe node then sends back this schedule and is committed to it until the next switch-off, unless the temperature bounds are breached by an unacceptable amount due to drastic events like putting hot food in the fridge.

Figure 5 shows an overview of this algorithm. In the case of a periodic cost function, the most straightforward approach for the cost tweak is to search for the nearest cost-minimum. Figure 6 shows the simulation trace of four fridges being controlled using four periodic cost profiles shifted by $\pi/2$, with the goal to reduce the overall peak consumption (similar to (Bigler et al. 2011)) as well as its volatility. Although the EMU in the simulation does not make use of the load profiles of the fridges yet, the combined power consumption is less volatile than in the usual bang-bang case, as can be seen by observing the sample variance.

To the bottom right there is also the trace of the local control of a real fridge, which shows that it indeed switches on near the minima of the cost profile as desired.

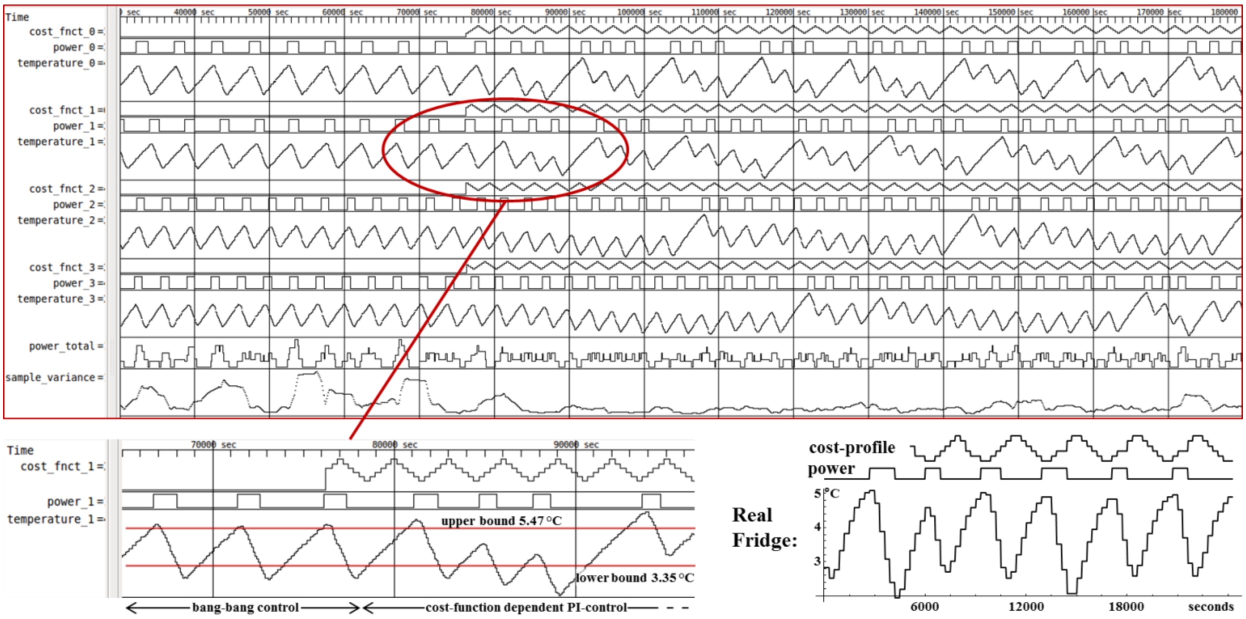

Figure 6: Simulation Screenshot, together with an example form a real fridge

Conclusion and Future Work

This paper presented the vocabulary used in the SmartCoDe project for domestic demand side management:

- A simple appliance classification which collects electrical appliances that can be handled with the same local and global energy management approach.
- Two simple step function-like messages, the cost- and the load-profile, which are used for the communication between the EMU and the appliances.

We also demonstrated how this vocabulary is used on the global and local level. Globally, the EMU generates cost-profiles with the help of the appliance load-profiles, together with additional information like forecasts and tariff. Locally, the SmartCoDe sensor/actor node uses the cost-profile to control its appliance for cost-effectiveness, while also computing a load plan which it can commit to.

As a case study, it was demonstrated how temperature forecasts can be generated and used for the local cost-profile dependent control of fridges/freezers. This approach should be easily extendable to other appliances in the THMSVC class.

We finally showed a simulation example how this approach can be used for load balancing of THMSVC appliances, even though the global control loop was not closed yet in that case. The ultimate goal is to *model a given power consumption curve* in that way by closing the loop, which is currently ongoing work.

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3.2 SEMANCO: Semantic Tools for Carbon Reduction in Urban Planning

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Abstract

The goal of the SEMANCO project is to develop an ontology-based energy information system and associated tools that help stakeholders involved in urban planning to make informed decisions about how to reduce CO_2 emissions in cities. An ontology system is to be developed from the requirement analysis per-formed at the case studies. This approach enables data, services and stakeholders to be taken into account in the process of building ontologies. To create the ontology-based system we have adopted a decentralized approach according to which modular ontologies from diverse domains become interlinked through a semantic framework. In this paper we summarize the project vision and discuss some research issues currently being developed in the project concerning ontologies for energy information at the urban level, multi-scale analysis of carbon reduction problems and integration of GIS with linked data.

1 Introduction

1.1 Applying ontologies to energy information

During the last four years, we have been developing a line of research aimed at applying ICT to the modelling and analysis of energy information first at the building scale and later on at the urban level. In the IntUBE project carried out from 2008 to 2011 within the 7th Framework Programme, we have proposed an energy information integration platform (EIIP) to capture the energy information flow throughout the different stages of the whole building life cycle (Böhms et al. 2010). The platform was composed of four data repositories to store building, simulation and performance data generated throughout the different stages of the building life cycle An OWL ontology was created to model the data in each repository according to the knowledge provided by domain experts. Later on, in the RÉPENER project co-financed by the Spanish 2009-2012 National RDI plan, we have moved from the idea of an integrated platform to the creation of an energy information system which integrates both proprietary and open data, following the initiative of the Linked Open Data movement. In this project, we have created an energy model based on existing energy information standards which encompass building data as well as the contextual data –climate, economic and social– which impact buildings' energy efficiency. Based on this model, we have created local ontologies which integrate proprietary and public data and present the data on the Internet using RDF language (Madrazo et al. 2012). Lastly, in 2011 we started the SEMANCO project –also co-funded by the 7th Framework Programme– whose purpose is to apply semantic technologies to modelling energy information at the urban scale. In this paper, we will introduce the project's aim and discuss some areas of the research which are currently under development concerning the design of ontologies for energy data at the urban level, modelling of complex systems, and integration of GIS with linked data.

2 SEMANCO: the projects Aim

2.1 Project scope and structure

Continuing with the work we developed in the IntUBE and RÉPENER projects, the purpose of SEMANCO is to create a system of energy information using semantic web technologies which –unlike the previous projects– is not limited to buildings but extends to the urban scale. Specifically, the objective of SEMANCO is to provide methods and tools, based on semantic modelling of energy information, to help different stakeholders involved in urban planning to make informed decisions about how to reduce CO_2 emissions in cities.

- Supporting access to, and analysis of, distributed and heterogeneous sources of energy related data, both open and proprietary
- Semantic modelling of energy data according to energy and ontology standards
- Integrated tools that access and update the semantically modelled data, based on new and existing IT solutions for decision making in development of CO_2 reduction strategies
- An analysis of requirements to ensure that the tools and CO_2 reduction strategies developed address real world problems represented by the case studies.

2.2 Semantic Energy Information Framework

A key component of this research is the design and implementation of the Semantic Energy Information Framework (SEIF). This framework is the nexus be-tween the different data sources and the tools which use the semantically modelled data (Fig. 1). The semantic mapping will act as a bridge between different domains (city planning and energy provision) and contents (consumption data, pollution sources, simulated energy profiles and benchmarks). This semantic model will support interoperability among systems by enabling translation and mapping between different modelling methods and tools to support decision making in urban planning. Through the SEIF, a set of analysis and visualization tools to be developed in the project will access the heterogeneous and distributed databases containing different types of energy related information. This data integration is done with ontology matching techniques which are well-known and have proved to inter-relate heterogeneous data sources (Euzenat 2011).

Semantic data integration will require defining a local ontology for each data source. The SEIF implicitly contains an energy model which provides the necessary language to understand and interpret the complexity of different data sources and their inter-relationships. The energy model is implemented as a global ontology which embraces all terms that the tools need to interact with the SEIF. The energy model ontology and the local ontologies use the OWL standard language, and data is presented on the Internet using the RDF language following the Linked Open Data (LOD) initiative.

The terminology contained in the semantic energy model is based on international energy and environmental standards. Nowadays, ISO standards are all in terms of the building scale, and –to the best of our knowledge– there are no specific International Standards for energy modelling at the urban scale. However, starting from analysis at the building scale, the ISO standards also can be indirectly applied to urban energy modelling. This statement is confirmed by the majority of studies on urban energy modelling, which have been carried out based on energy assessments of reference (representative) buildings and then extrapolated through analysis to the urban area by applying statistical data (Brownsword 2005, Jones 2001 & Yamaguchi 2003).

Specifically, energy model terminology is specified in ISO/IEC CD 13273 (Energy efficiency and renewable energy sources), ISO/DTR 16344 (Common terms, definitions and symbols for the overall energy performance rating and certification of buildings), ISO/CD 16346 (Assessment of overall energy performance of buildings), ISO/DIS 12655 (Presentation of real energy use of buildings), ISO/CD 16343 (Methods for expressing energy performance and for energy certification of buildings), and ISO 50001:2011 (Energy management systems – Requirements with guidance for use).

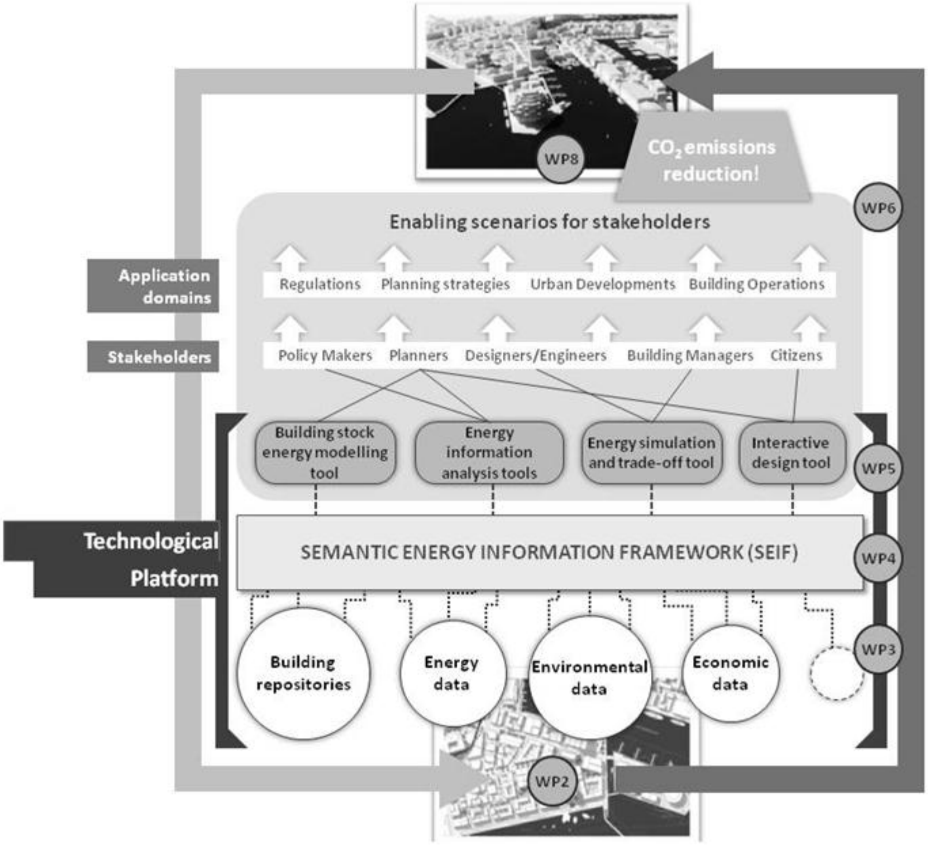

Figure 1. Structure of the SEMANCO project.

2.3 Integration of multiple scales

The problem of CO_2 emissions reduction is difficult to delimit to a particular geographical area. It is a systemic problem in which multiple dimensions and geographical scales need to be integrated. For instance, we can focus the description and analysis of an urban system on different scales: at building, neighbourhood, district or city level, among others. The existence of multiple scales conveys important challenges to be addressed in the analytical process concerning carbon emissions: the relevant aspect considered to perceive and represent the system would change depending on the chosen analytical scale. In order to address the multiple dimensions involved in the problem of CO_2 emission reduction, the tools and methods developed in SEMANCO will integrate the various geographic scales at different demonstration scenarios (Fig. 2).

Through the SEIF, the energy data associated with the different geographic scales will become inter-related (Fig. 3). The SEIF provides data that the analysis and visualization tools need for a specific task at a given scale. Conversely, the outcomes generated by these tools enhance the energy model implicit in the semantic framework.

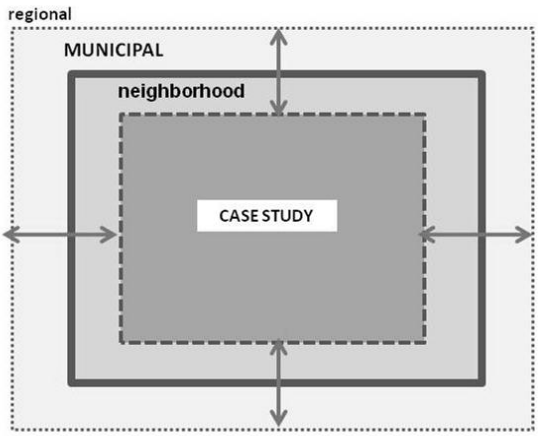

Figure 2. Integration of multiple geographic scales in the case studies.

2.4 Research methodology

The methodology adopted in the research is based on a case study approach. Different scenarios located in Denmark, Spain and the United Kingdom will enable delimiting the scope of the research and defining the specifications for the tools needed by stakeholders in different domains: planners working on the development of new areas or the renovation of existing ones; policy makers setting targets and regulations to reduce carbon emissions, and citizens applying energy efficiency measures in public and private buildings. Furthermore, the demonstration scenarios will help to:

1. Identify relevant indicators; interrelationships between factors contributing to CO_2 reduction; emission reduction strategies; baselines for energy consumption; and uses of energy efficient and renewable energy technologies;

2. Verify effectiveness of tools and methods; reductions of energy consumption and CO_2 emissions; social impact; improved indoor environmental qualities (IEQ); and investment costs.

In order to create the energy model embedded in the SEIF, it is necessary to compile a set of existing data sources and a set of tools which make use of the data within a limited application realm or use case. In the context of this research, a use case delimits a research problem concerning carbon reduction in a specific domain. The use case describes how actors, tools and data interrelate in order to fulfil a strategic goal.

3 Project development

In this section we discuss some of the project areas which are currently being developed regarding the creation of ontologies for energy information in urban environments, multi-scale analysis of energy systems, and integration of GIS and linked data.

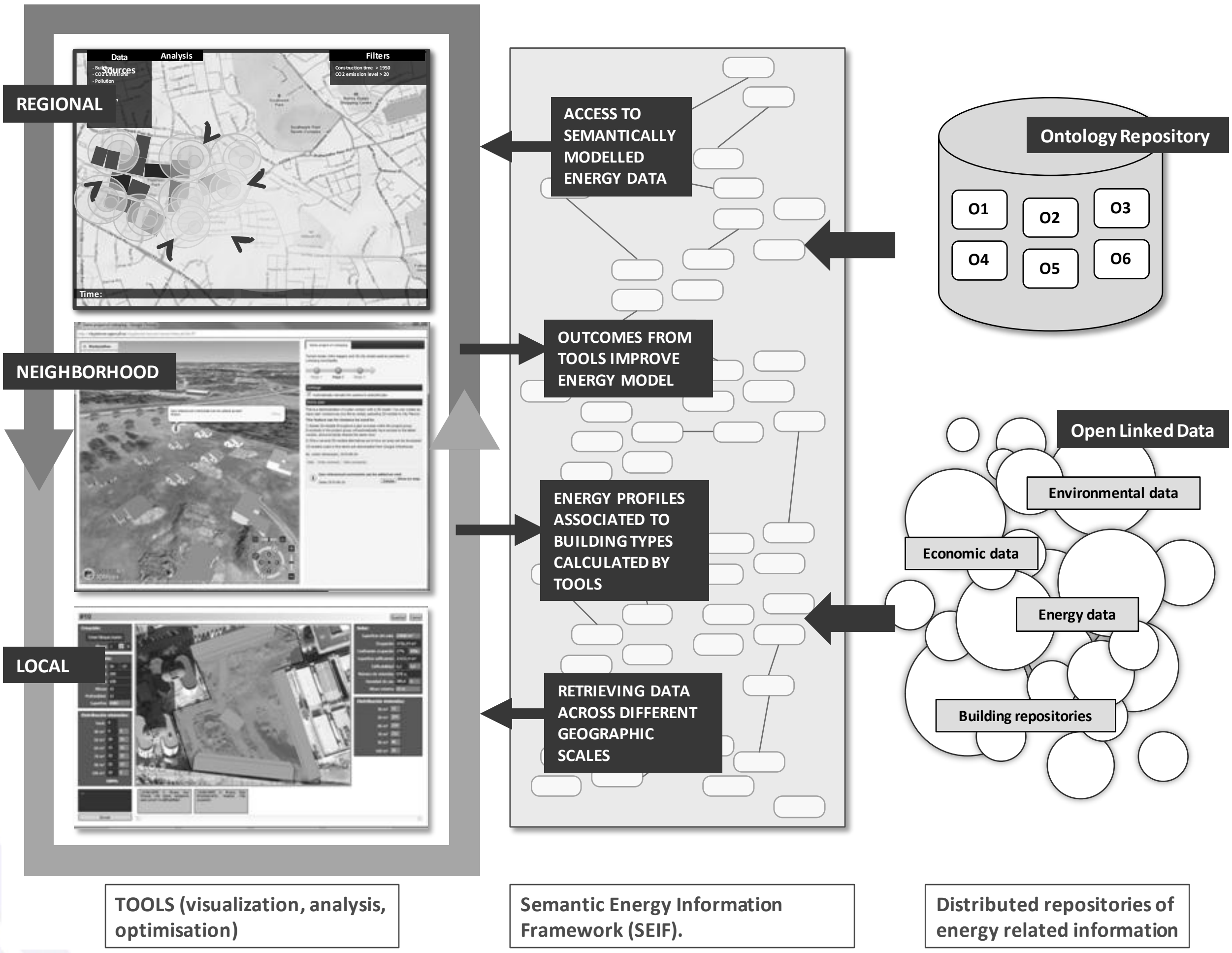

Figure 3. SEMANCO technological platform.

3.1 Ontologies for energy information in urban environments

As Guarino & Giaretta (1995) had explained, within the knowledge engineering community "ontology" refers to a particular object rather to a discipline (e.g. the philosophical notion of Ontology). This object can be thought of as an informal conceptual system, a formal semantic account and "an explicit specification of a conceptualization", as Gruber (1993) had defined it. Considering ontology from a technical point of view, a clear distinction should be made between "an ontology" intended as a particular conceptual framework at the semantic level and an ontology intended as a concrete artefact at the syntactic level to be used for a given purpose" (Guarino & Giaretta 1995).

In the context of the current level of development of the semantic web, ontologies make it possible to connect different views of the word fostered by different disciplines and domains which are embedded in the information structure of different data sources. More recently, the linked open data initiative has provided a new impulse towards the transformation of the web in a global knowledge base (Heath 2011).

3.1.1 ONTOLOGIES, ENERGY AND GEOGRAPHIC INFORMATION

Although in the recent literature we find applications of semantic technologies to specific domains related to energy efficiency in buildings –operation, interoperability, smart grid (Kofler et al. 2012, Noguero et al. 2011, Han et al. 2011, Kabitzsch & Ploennings 2011 & Wagner et al. 2010) – not much work has been done so far with regard to using the ontologies to integrate energy data from different domains in an urban context. Nor have we been able to find references to application of ontologies to represent the complex interaction between data from multiple domains –social, economic and urban– involved in the modelling and understanding of carbon emissions in urban environments. Further difficulties to be overcome have to do with difficulty obtaining the data that is necessary for energy efficiency research (Lannon & Linovski 2009).

The integration of urban energy models with GIS systems using ontologies, however, opens up an area of research which will require systems able to capture the relationships between buildings rather than the buildings themselves; the interaction between different levels of the built environment (between buildings and streets, for example); and changes over time (Lannon & Linovski 2009). Even though there are many environments to manage ontologies, so far they have not been dedicated to modelling of geographic information (Zaki et al. 2009).

3.1.2 ONTOLOGY DESIGN

Ontology design conveys a process of knowledge sharing between a community of users (domain experts, users of semantic-based applications) and ontology engineers. It also requires having access to existing data sources (proprietary and public) and defining the relationships between data based on the use that will be made of that data (by application services and different users). Adding semantic meaning to data, therefore, is inextricably related to the use that will be made of these data in a particular context. The case study approach adopted in the project brings together actors, data and services within a particular frame, which we refer to as "use case". This approach enables us to take into consideration the user's needs, in order to ensure that ontological systems are of use to different stakeholders involved in urban planning (Lannon & Linovski 2009).

The process of creating an ontology requires a certain methodology, and precisely this lack of established methodologies is one of the difficulties to overcome. As Gómez & Benjamins (1999) contended, "The ontology building process is a craft rather than an engineering activity. Each development team usually follows its own set of principles, design criteria and phases in the ontology development process." Because of this, the creation of ontologies is still a craft which requires specific strategies for each particular case. In the process we have started, users and domain experts formulate use cases which delimit a research problem describing how actors, tools and data are interrelated in order to fulfil a specific goal. Use cases are broken down into activities which in turn can be shared by different cases. Then, as the Neon methodology proposes (Suárez-Figueroa et al. 2012), the activities are described in form of requirements and competency questions to capture knowledge of the users and domain experts. Domain experts take into account the data sources and use cases to model a local ontology, guided by ontology engineers.

In the SEMANCO project we are creating a set of ontologies which respond to the requirements of the use cases and help to model the different data sources.

Energy data sources are usually stored in relational databases such as MySQL, SQL Server, or Oracle. In order to have integrated access to these heterogeneous sources, a data integration process needs to be carried out. According to the semantic web community, the relational data should be complemented with semantics. This process involves a mapping from the relational database to the datasets, and implies a transformation of the relational data into an RDF expressed in an ontology which has been previously defined.

The first step of the integration process is to design local ontologies which match the data sources. The methodology applied to the creation of the local ontology follows design patterns which ensure compatibility with the energy model which is implemented as a global ontology. In particular, the application of these patterns ensures that: 1. A local ontology uses the terms that are defined in the energy model, 2. The local ontology reuses data structures from the energy model (e.g. adding standard units to a data type property such as distances or measures), and 3. The integration of new data sources can improve the energy model, adding new terms and relationships which might be needed by new use cases.

Once a local ontology has been created for each data source involved in a particular use case, the next step is to transform the relational data into RDF format, which is the standard to describe resources on the Internet. A survey published by W3C RDB2RDF incubator group has identified several tools to make this transformation such as Virtuoso RDF View, D2RQ, R2O, RDBToOnto, or Dartgrid (Sahoo 2009). The survey states that there is not a standard method for representation of mappings between RDB and RDF and, whenever possible, it is better to implement on-demand mapping to access to the latest version of the data. The RDB2RDF group is currently working on the first conclusions regarding the R2RML language recommendations dated February 2012, which are being implemented by some projects at this time.

3.1.3 ONTOLOGY MAPPING TOOLS

As part of the SEMANCO project, we have started to develop tools which help users – domain experts and ontology engineers– to integrate data collaboratively using standard semantic technologies. These tools facilitate the design of ontologies by enabling users to work together in the same environment and to automate parts of the process, such as mapping file creation according to an ontology. We have not found an existing tool which fulfils all these requirements. Therefore, we have started to implement our own tools based on the D2RQ platform (Bizer 2007). We have decided to use this platform because it provides a language which supports on-demand mapping and also can provide complete RDF datasets; it performs well because it rewrites the SPARQL queries into SQL; it is a stable and light-weight solution; mappings are represented with D2RQ mapping language which is easily customizable; and it is currently developing a version which supports R2RML.

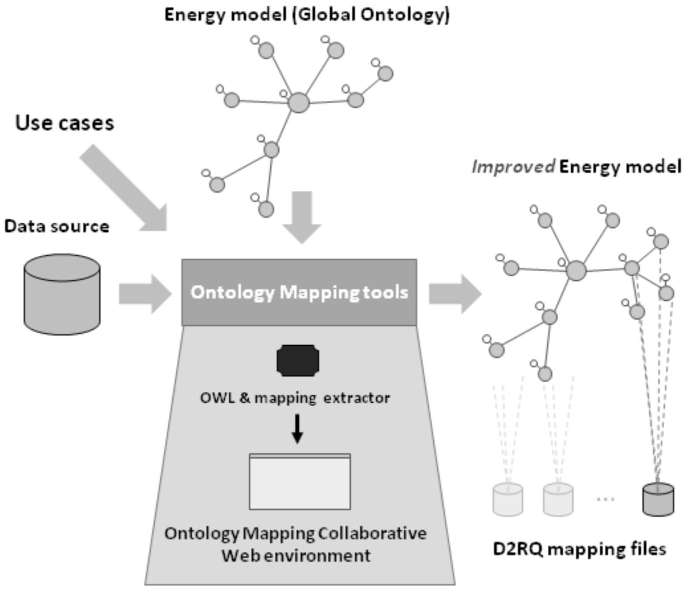

Figure 4. Ontology mapping tools. Inputs and outputs.

The inputs of the ontology mapping tools are the use cases (provided by the users), the current version of the energy model, and a data source. The outputs are an improved version of the energy model and a mapping file which transform relational data into RDF. The ontology mapping tools which are being developed are an OWL and mapping extractor and an ontology mapping collaborative web environment (Fig. 4).

The goal of the OWL and mapping extractor is to automatically generate a local OWL ontology file and a D2RQ mapping file. The tool is configured defining the database connection parameters. Additionally, the user selects which columns would need units. The tool reads the database structure and, following the design pattern mentioned above, generates the output files. This tool is being developed in Java as a command line program in which configuration parameters are given by command line.

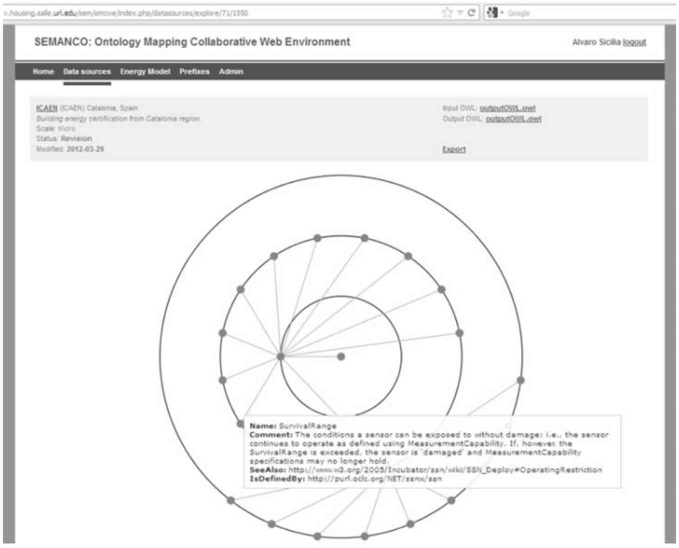

Figure 5. Ontology mapping environment.

The ontology mapping environment facilitates the collaborative work of domain experts and ontology engineers to integrate a local ontology into the energy model (Fig. 5). Once the user has uploaded the files generated by the extractor, he or she can view the list of terms of the local ontology. Furthermore, a user can redefine the source terms by selecting a term of the energy model or providing a new one. In the case of new terms, users supply super-terms to connect them to the energy model. In this collaborative environment, users can track the activity of their colleagues and also comment on their actions. Finally, users can export the work done, generating an OWL ontology. This ontology is a portion of the energy model. Each time a data source is integrated, the energy model grows, embracing new terms and properties. The front-end of this environment is being developed in HTML, Javascript and CSS. CodeIgniter framework for PHP is used for the logic layer and MySQL for the database. Some free PHP libraries have been used such as ARC2 and the JITG.

3.2 Multi-scale analysis of urban energy systems

3.2.1 URBAN ENVIRONMENT AS COMPLEX SYSTEM

From a physical point of view, we can think of the urban environment as a hierarchical system in which, for example, buildings are grouped in neighbourhoods, neighbourhoods in cities, cities in regions, and so on. From this point of view, an urban area is a complex system made of smaller systems each consisting of a set of elements which work with each other in a certain way. However, as Alexander contended in his text *The city is not a tree*, published in 1966, when the urban environment is considered as phenomena rather than as physical objects, there are many more relationships occurring which cannot be represented as a simple hierarchical structure like a tree but with the more subtle and complex structure of a semilattice. On the other hand, Koestler, in his book *The Ghost in the Machine* from 1967, contended that in complex systems such as living organisms and social organizations, the elements making up the hierarchy are at the same time part and whole. He coined the term "holon" to reconcile the atomistic and holistic approaches. According to Koestler, holons are defined by fixed rules and flexible strategies. Therefore holons are not well-defined components, but rather relative positions within a system of relationships which help to understand certain aspects of reality.

These views about the urban environment and the structure of complex systems, formulated almost fifty years ago by Alexander and Koestler, are worth being reminded of as we start to address the problem of modelling energy systems at the urban scale. Let's consider, for example, an energy system as a holon. On the one hand, it has to maintain coordinated operation between holons of the same level of the hierarchy. In practical terms, that means that the energy sector has a) to keep control of the elements comprising it (e.g. to assure coordinated operation between energy transformation plants, transport and distribution systems), and b) to "compete" with other socio-economic sectors for the resources needed to perform its tasks. Examples of those required resources are the necessary human activity (e.g. requirements of skilled labour) and land (e.g. whether to construct a wind-farm or to conserve the cultural landscape heritage to foster eco-tourism). On the other hand, the energy sector has to fulfil some specific functions expected by the upper-level elements of the hierarchy. In this case, it has to deliver a certain mix (in amount and quality) of energy carriers required by the rest of the society. That is, a holon should have coordinated interaction both with elements of the same level of the hierarchy (horizontal coupling) and elements of different levels of the hierarchy (vertical coupling) (see Giampietro et al, 2006 for a detail description of these concepts).

All of these activities take place in the "system energy" and in the physical space which supports it. This leads us to the discussion of the definition of the spatial boundaries of the system under analysis.

3.2.2 SPATIAL BOUNDARIES

Along with the notion of the urban environment as a complex system which encompasses the physical space as well as the activities taking place in it, we need to consider the issue of the system's spatial boundaries and geographic scale. At the outset, we can think of a spatial boundary in two ways: one which considers space as a set of relationships and the second which thinks of space as a container (Fig. 6). In Figure 6a, the former is represented by a dynamic flexible boundary which might be determined by the interactions between the elements of the sys-tem (between data, between stakeholders, between factors influencing CO2 emissions). Space as a container is presented in Figure 6b as an established boundary determined by administrative reasons (a neighbourhood, county, region etc.) which might vary from one country to another.

On the one hand, we have areas and regions with dynamic and flexible limits: limits that are determined by the interactions between identified elements of the system (e.g. the system by which the problem of CO2 reduction is conceptualised). On the other hand, there are areas and regions that have established limits, such as administrative regions. These areas/regions are also decision-making domains, for instance, at the political and administrative levels. This is the case for districts/wards, cities, municipalities, provinces and so on. However even these "static" boundaries can be flexible and dynamic. For instance, laws and policies defining boundaries of action may change over time: new laws may redefine the administrative boundaries, and urban planning schemes may change their conception of spatial scales to incorporate these changes. In SEMANCO, we need to integrate and make compatible both notions of space.

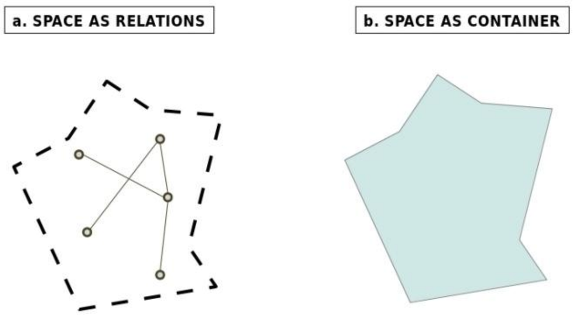

Figure 6. Understanding spatial boundaries as relations or as container.

3.2.3 ACCOUNTING FRAMEWORKS

Another important consequence of dealing with complex systems operating at multiple scales is the need for an adequate accounting framework to develop and assess a robust set of performance indicators across scales. A system has certain properties and behaviours that are not possessed by any of the individual parts making up the whole. The opposite also applies: there are emergent properties of the parts which conform to the whole that are not possessed by the system as such. For instance, urban lighting systems are important components of the system at the neighbourhood and city levels. At these levels, the energy accounting system should consider the energy consumption of the urban lighting systems, which may become irrelevant in the analysis of the energy performance of a building. In fact, the requirements of human, economic and technical resources needed for the functioning of the public lighting system are usually covered by a municipal company or a public utility which operates at the neighbourhood and city level. As the identity of the system depends on the scale of analysis, we can expect different values for the same indicator evaluated at different scales (e.g. the electricity consumption per capita may vary if we carry out the calculation at building or neighbourhood level). The important thing here is that we need an accounting framework allowing the analyst to scale the information up and down, producing coherent results across scales (e.g. if the electricity consumption per capita varies if calculated at building or neighbourhood level, then the accounting framework and the aggregation method should produce different values).

The Multi-scale Integrated Analysis of Societal Metabolism (MuSIASEM) developed by Giampietro et al. (2009) is an analytical framework explicitly dealing with the issue of multiple scales. It also provides a flexible accounting framework that allows coherent assessments across scales.

MuSIASEM relies on the concept of the holon in order to perceive and represent the system under analysis. We can represent a city using several lower-level compartments, such as residential and non-residential areas, which can be further split into lower-level elements. For instance, a residential area can be split in different neighbourhoods, which in turn conform to building typologies (e.g. residential, schools, offices and hospitals, among others), the street network and other urban elements.

This approach provides a flexible accounting framework whose categories can be tailored according to the objectives of the analysis. For instance, we can distinguish high and low-income residential areas in order to perform a specific analysis based on the socio-economic conditions of the inhabitants.

Then, the assessment of the performance of the system is based on the fund-flow model developed by Georgescu-Roegen (1971). Fund categories describe what the system is (e.g. capital, people, Ricardian land) and flow categories describe what the system does (e.g. added value, water, energy, matter). On the time scale of the representation, funds transform input flows into output flows, and flows are either consumed or generated in order to reproduce the funds categories.

Following this approach, we can aggregate funds and flows categories of lower-level elements in order to assess the performance of an upper-level element. In the same way, we can disaggregate variables of an upper-level compartment and assess the performance of its components. The assessment is complemented by using intensive indicators: flow/fund or fund/fund ratios to describe the pace of the metabolism of the compartment under analysis (e.g. flow of energy carriers per square meter, measured in kWh/m2). They describe how the system does what it does. For instance, if we disaggregate the consumption of electricity of the elements making up a neighbourhood (residential buildings, public services, office buildings, street lighting and other urban elements) and the surface used by those compartments, we can identify those elements with levels of consumption per square meter that are above the expected or reference values (i.e. benchmarks).

Summarizing, we can say that the ability of the MuSIASEM approach to defining analytical categories according to the objectives of the analysis might be mutually complementary with the flexible (semantically modelled) data structure provided by SEMANCO's semantic framework. Also, it provides adequate flexibility to deal with the different conceptualization of space mentioned above. Finally, it provides an accounting framework to scale information up and down, producing coherent performance indicators across scales.

3.3 GIS and semantic data

Typically, a GIS software represents the built environment according to the structure required by a particular organization (a transportation agency, a real estate company). In doing so, for GIS the built environment is a fixed structure rather than a complex system of interrelationships. As Kuhn (2000) had claimed, "GIS should support human activities. Instead, they are often designed as passive models of the work, with too little concern for the task contexts in which they will be used". The view of the world that GIS provide would have "less to do with human activities than with existing data holdings". According to Kuhn, the use of ontologies would make geographic information systems more useful and usable, with a focus on human activities.

To facilitate the exchange of data across multiple GIS systems –and, indirectly, across multiple views of the built environment– the Open Geospatial Consortium has promoted the CityGML standard. The standard is based on the OGC GIS standard GML 3.0 and offers a way to describe most (or all) needed characteristics of a 3D city model as GML features and geometry in a standardized XML document.

Even though CityGML claims to take into consideration not only the geometric properties of objects but also their semantics, there are some doubts about the capacity of the language to represent the semantics of urban information. In particular, CityGML might be insufficient to represent information in urban projects involving multiple actors (from citizens to specialists in different fields) and multiple tools such as plans, legal texts or 3D representations (Métral et al. 2009). To overcome these limitations, additional ontologies have been connected to the CityGML ontology. Montenegro (2012) has proposed a land use ontology which is the core of 4CitySemantics, a tool for city planning which assists participants in the urban development process. In the OUPP and CALAKMULL projects, ontologies have been used to interconnect models representing different views of the urban environment with CityGML (Métral et al 2009). Further-more, adding ontologies to CityGML can also help to model not only the entities constituting a geo-graphic space but also the actions that take place within particular domains (Camara et al. 2000, Smith 2000 & Kuhn 2000). As a result of the current trend towards integrating linked open data using modular ontologies, the original central position of CityGML as a standard to exchange geographic data might change. In this context, CityGML would become one more source of data to relate to other data (Ronsdorf 2011).

In line with these approaches, SEMANCO aims at integrating geographic data in CityGML format with other kinds of open data using semantic technologies. This way it would be possible to bring together the different kinds of data –from different domains, geographic scales and applications– that are needed to model an energy system, and to apply the appropriate evaluation and multi-scale analysis techniques required in particular use case.

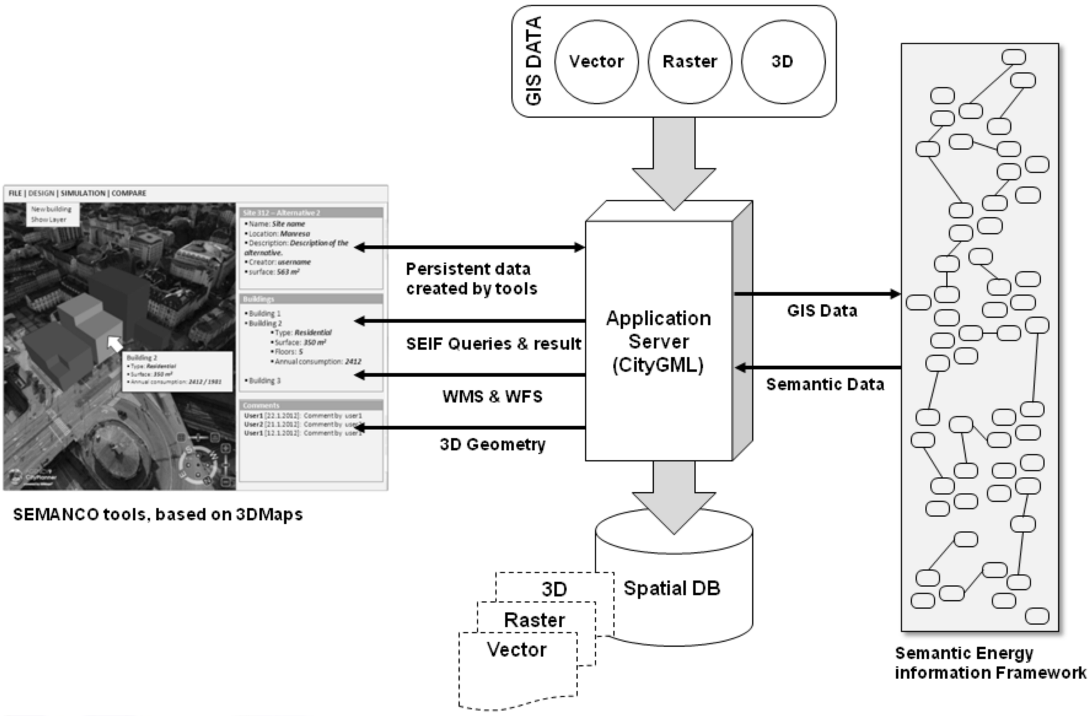

Figure 7. Integration of the SEIF with 3dMaps GIS software.

3.3.1 GIS SYSTEM 3DMAPS

The semantically modelled data facilitated through the SEIF will be used by stakeholders at different decision-making domains and by different applications integrated in 3dMaps GIS software from Agency9. This is a rich web platform with a JavaScript enabled API to handle most use cases from simple editing to rich visualization and user interaction. The platform also offers a set of tools to automatically create 3D maps from aerial photography, DEM/DTM, WMS and WCS data, as well as tools to process and optimize large batches of 3D models to be served from an HTTP cache.

Figure 7 shows the integration of the SEIF with the visualization tools integrated in the 3dMaps software. An application server will have the task of managing import and export of GIS and semantic data to the platform, populating the spatial database with GIS data and maintaining the 3D web cache with updated optimized data. This server will also facilitate the different tools implemented for the data in the SEMANCO project and provide a layer for interoperability between the tools. The storage of GIS data and persistent data created by the tools will be handled by a Spatial Database. The Application server stores and fetches data when needed from the Spatial DB. The 3D data could be stored in a structure similar to 3D City Database in order to use the OGC standard CityGML internally as well as for input and output to the platform.

4 Conclusions

In the SEMANCO project we have adopted a comprehensive approach to modelling energy information at the urban scale using ontologies. In this context, ontologies would help: 1. to integrate data at multiple geographic scales; 2. to capture domain expert knowledge; 3. to interrelate different domains involved in the evaluation of CO_2 emissions; and 4. to exchange data generated by various applications (interoperability across GIS, simulation programs, and sensor systems).

The decentralized approach based on interlinked semantic databases driven by the linked open data community is one of the pillars of the SEMANCO project. The purpose is to make use of a net of inter-connected standards (e.g. CityGML, ISO/IEC CD 13273, ISO/DTR 16344) rather than placing a particular standard at the core of the energy information system. In this context, our goal is to create expressive ontologies –rather than vocabularies– to model data as well as perform data analysis and inference processes.

In order to build the ontologies, we have adopted a methodology based on the integration of data sources, services and actors around a particular use case. A use case provides the specifications necessary to design the ontologies, while it ensures that the data and analysis processes will be of use for a particular group of stakeholders in the actual world.

Ackowledgements

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3.3 An ontology for modeling flexibility in smart grid energy management

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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 briefly present an approach to incorporate flexibility into demand response and present the generic MIRABEL information model for expressing flexibility in consumption or distributed generation. In addition, we focus on an ontology for flexibility in smart grids that was designed on the basis of the MIRABEL information model. This ontology is represented in OWL and defines the objects involved in flexibility and their relationships. Thereby, this ontology gives a semantically better view on the flexibility concept and its meaning in relation to the building on the one hand and the smart grid on the other hand. Moreover, this ontology forms the basis for a vocabulary that can be published via the web and used to connect IT systems from various stakeholders in the energy domain that handle supply and demand of energy.

1 Introduction

Use of renewable energy sources is enforced by national and international regulations, c.f. [1] and [2]. Drivers for such policies include mitigation of cli-mate 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, with-out 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 ma-chines, dishwashers, photovoltaic cells, micro combined heat power units, electric heat pumps, and electric vehicles. These flexibilities include temporal shifts of activities (e.g. delay operation), temporary reductions of load comparable to existing demand response scheme's 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 re-al-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 briefly present the flexibility approach and the generic MIRABEL information model for expressing flexibility in load or distributed generation. In addition, we describe an ontology that was designed based on this information model and that can be used to form the basis for an energy management vocabulary. Such a vocabulary can be used throughout the chain of energy stakeholders to couple and integrate the IT systems of these players.

In section 2 we provide an overview of the MIR-ABEL approach and present some business ad-vantages and global financial incentives. In section 3, we compare it with the related work on demand response and on information modelling and ontologies in the combined building and energy management domain. In section 4, we give an overview of the types of actors in the grid and their interactions involved in the approach as well as the information model for energy flexibility. In section 5, we present the flexible energy ontology and an OWL-representation that we derived from the UML-based information model including the method and under-lying principles that we used. In section 6, we dis-cuss the use of this ontology in relation to the MIR-ABEL system and the flexibility concept in the context of building energy management. Finally, in section 7, we draw some conclusions on the usability of ontologies in the energy management domain.

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.

2.1 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 Fig. 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.

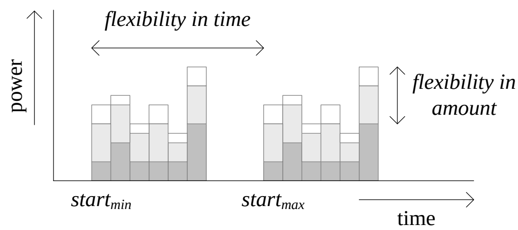

Fig. 1. Example of a flex-offer specification

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 sys-tem. 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 renew-able 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 re-quests 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 behaviour.

2.2 Business advantages and global incentives

The conceptual and infrastructural approach that is developed within the MIRABEL project offers ad-vantages throughout the energy domain. In general, the flex-offer concept increases the ability to balance consumption and production in the electricity sys-tem.

Currently, the power output of most renewable energy sources (RES, e.g. windmills, photovoltaic) 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.

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 man-age 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 de-vices that it can influence directly. The disadvantage that the consumer no longer has complete freedom to make his own decisions about energy consumption and production in the household.

A second (very popular) approach towards demand side management is to use some form of dynamic pricing as an incentive for certain demand-response behaviour. Pricing information is sent to consumers to influence their behaviour 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) [6] where a price profile (consisting of 15 minutes time slots) is sent to the consumer. Although the price profile can be interpreted manually by consumers it is much more convenient to use an Energy Management Sys-tem (EMS) to do this. The advantage of this approach is its simplicity. The disadvantages are that the consumers are quite passive and that the use of price profiles by energy suppliers makes it difficult to transparently compare the offers of several sup-pliers.

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 ex-change can be an effective means to adapt demand to intermittent supply. An example of this approach is the PowerMatcher [7]. Central to this approach is an auctioneer that accepts bids from participants and calculates a market equilibrium price.

The big advantage of an exchange is its simplicity. The disadvantage is that it works best when bids are evenly spread; some participants require a lot of energy while others can do without for a while. However there are cases where such a spread 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. Participants 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.

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 par-ties 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 or-der 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. 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 pro-cessed. Examples of flex-offers can be found in the next section.

There are various national and international projects that incorporate energy usage into the existing Building Information Systems (BIM). With these models it is possible to analyse things such as energy efficiency and CO2 emissions. Examples of such approaches are: gbXML [13] and HESMOS [14]. These models are fairly static however and cannot be used to actively shift load and/or production in the sense of the demand response approaches described in the previous sections. One interesting example of a data model that can be used for smart grid purposes however is the one produced by the FIEMSER project. It defines various information elements that can be used to express flexibility [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 Flex-Energy data model of MIRABEL is an important topic for future investigation.

4 Flexibility Roles and Information Model

The flex-offer approach is aimed to be applied with-in 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.

4.1 Providers and acquirers of flexibility

Fig. 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 restrict the number of providers and/or acquirers. E.g. when applied within the context of a balance group (as described in [8]), an arbitrary number of parties connected to the grid (many providers of flexibility) offer flexibilities to their balance responsible party (the single flexibility-acquirer).

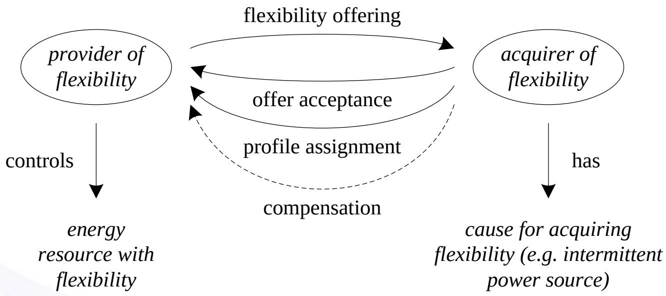

Fig. 2. Schematic view of provider and acquirer roles

Providers of flexibility control one or more energy resources (load and/or generation), either directly or indirectly; i.e. control of their 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. E.g. to reduce imbalance cost due to intermittent renewable energy sources, optimize power plant operations, etc. Offerings of flexibility are either accepted or rejected by the acquiring party. When offered flexibility is ac-accepted, a profile assignment must be provided by the acquiring party to indicate the desired behaviour (within the constraints as expressed in the flex-offer).

4.2 Role interactions

Fig. 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.

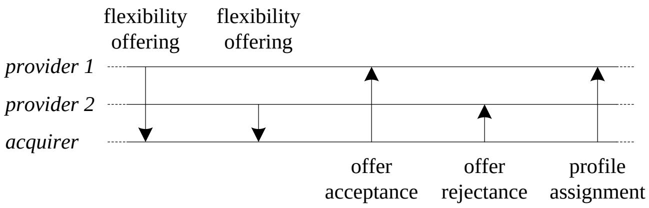

Fig. 3. Example interactions between two providers and one acquirer

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.

In the following subsections, we describe a data model for expression flexibility in supply and demand as well as concrete examples of flex-offers for electrical vehicle charging, heat pump operations and combined heat power system operations.

4.3 Flexibility offering examples

4.3.1. ELECTRIC VEHICLE CHARGING

Electric vehicles will typically be used during the day to commute and charged during the night. An electric vehicle owner can offer flexibility by ex-pressing the constraints that have to be met in the charging process. 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 be-fore 11pm. The reason for this constraint is that it gives the owner the possibility to use his car for emergency situations. The remainder of the charging processes can be allocated at any time during the night as long as the vehicle is fully charged by 7.30am. Figure 8 shows a graphical representation of this FlexOffer.

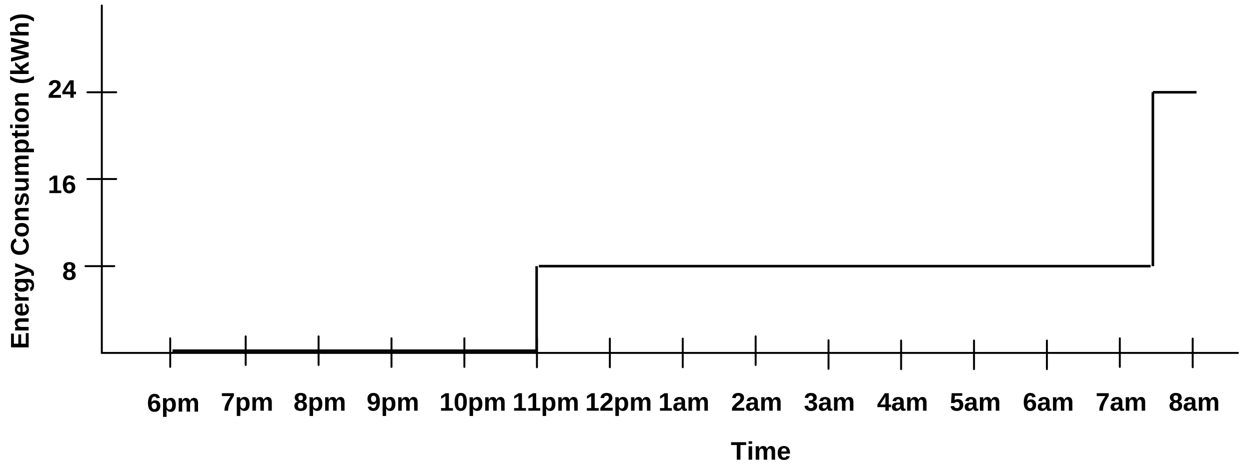

Fig. 4. Flexibility offering for electric vehicle charging

4.3.2. HEAT PUMP

Heat pumps for domestic use draw up to several kilowatts from the grid. Operations are thermostat-based. However, 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.

Fig. 5 shows an example of such a flex-offer. The y-axis of this figure represents power and not energy as in the previous electric vehicle charging example. 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.

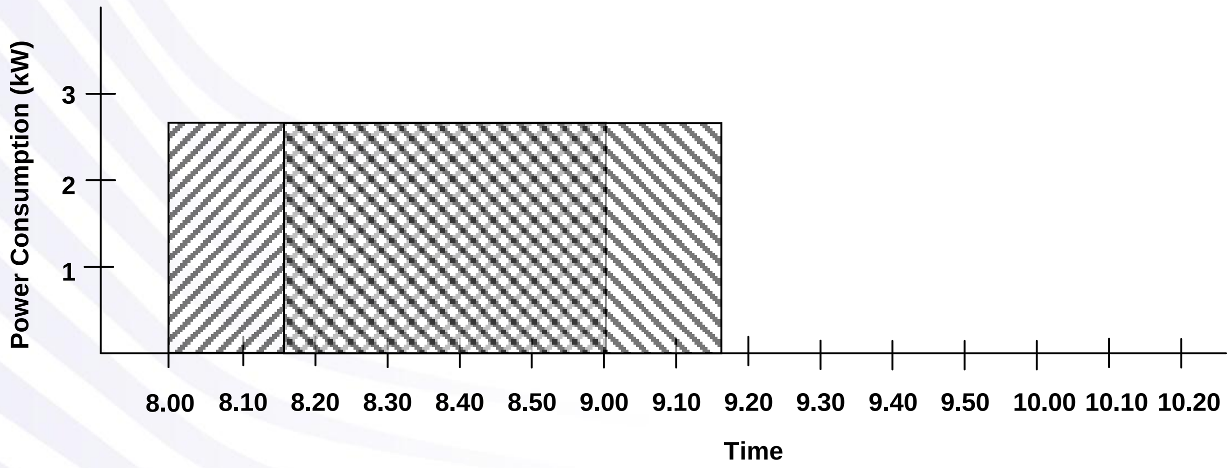

Fig. 5. Flexibility offering for heat pump operations

4.3.3. COMBINED HEAT POWER SYSTEM

A residential Combined Heat Power (CHP) sys-tem consumes gas and produces heat and electricity and is often thermostat-controlled. 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%). The resulting flexibility may be offered with a constraint on the power level in combination with a constraint on the volume of energy in order to achieve the desired total heat output (e.g. to raise temperature in a building). This is depicted in Fig. 6. The ability to shift the operations of a CHP in time is omitted from this figure.

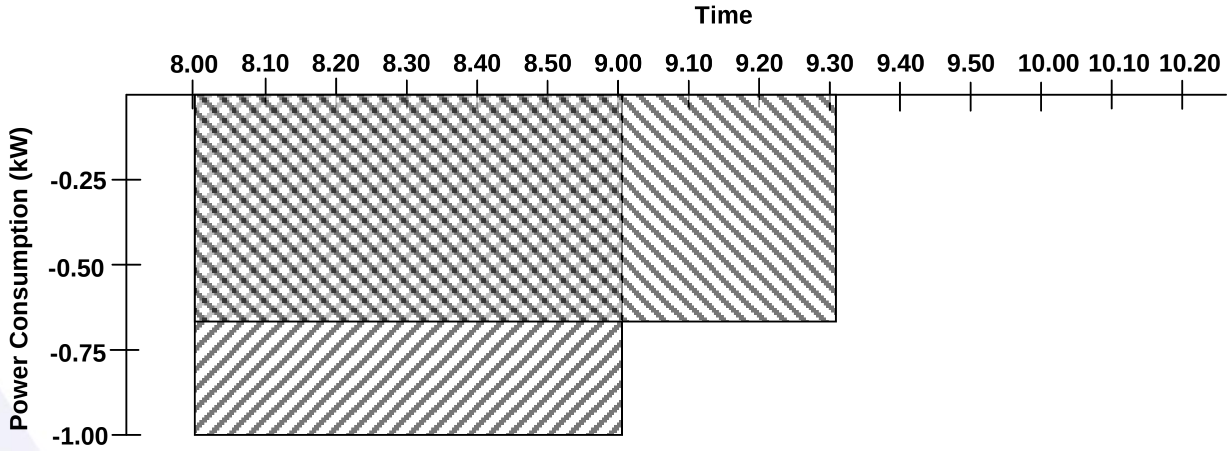

Fig. 4. Flexibility offering for combined heat and power system operations

4.4 Flexible energy data model

Based on flexibility concept described here, we de-fined the MIRABEL flexible energy model of which the main part can be found in Fig. 7. An instance of the FlexEnergy class is the root of an expression of flexibility, i.e. contained in a flex-offer. The entire data model is specified in [11].

The data model allows specification of various constraints of a financial, energetic and temporal nature as well as combinations thereof. These constraints set the boundaries of flexibility, e.g. offered to another party. The constraints can be expressed on the level of the entire expression of flexibility (e.g. the total energy consumed must be between x and y kWh) as well as in a profile of subsequent intervals. The profiles express 1) the ability to produce more or less (in terms of power and energy) throughout a period of time and 2) the willingness (in financial terms) to produce / consume more or less throughout a period of time.

5 Flexible Energy Ontology

In this section an ontology for the smart grid domain is developed that focuses on the FlexOffer concept. The development of an ontology for the flexoffer concept can aid in the conceptualization of the do-main semantics and the development of a shared understanding of the domain. An ontology is a computer-based resource that represents an agreed understanding about the domain semantics. An ontology is a knowledge representation scheme that provides the glue to hold everything together and defines the terms used to describe as well as represent an area of knowledge. It defines the vocabulary and the meaning of the vocabulary in context [15]. Unlike data models that are commonly used to develop software, the fundamental asset of an ontology is the relative independence of particular applications, i.e. an ontology consists of relatively generic knowledge that can be reused by multiple applications in the same domain [16]. Common components of ontologies include individuals, classes, attributes, relating, functions terms, restrictions, rules, axioms, and events. Ontologies are used in artificial intelligence, semantic web, software engineering, biomedical information, library science, and information architecture [17]. Popular other means to develop shared domain understanding are data models and UML models. But in contrast to these task specific and implementation-oriented means, ontologies are, in principle, as much generic and task independent as possible. Furthermore, languages for ontologies are far better equipped to express domain rules, support greater support for automated reasoning, offer a cleaner solution to define complex relationships, and are better maintainable than UML or data models [16]. Furthermore, semantics of data models often constitute an informal agreement between developers and the users of the data model (Meersman 1999), ontologies promote first order logic relation-ships, allow concise specification of hierarchical conceptual structures, allow robust specifications of complex relationships, and allow robust specification of constraint values of entities and relationships [15].

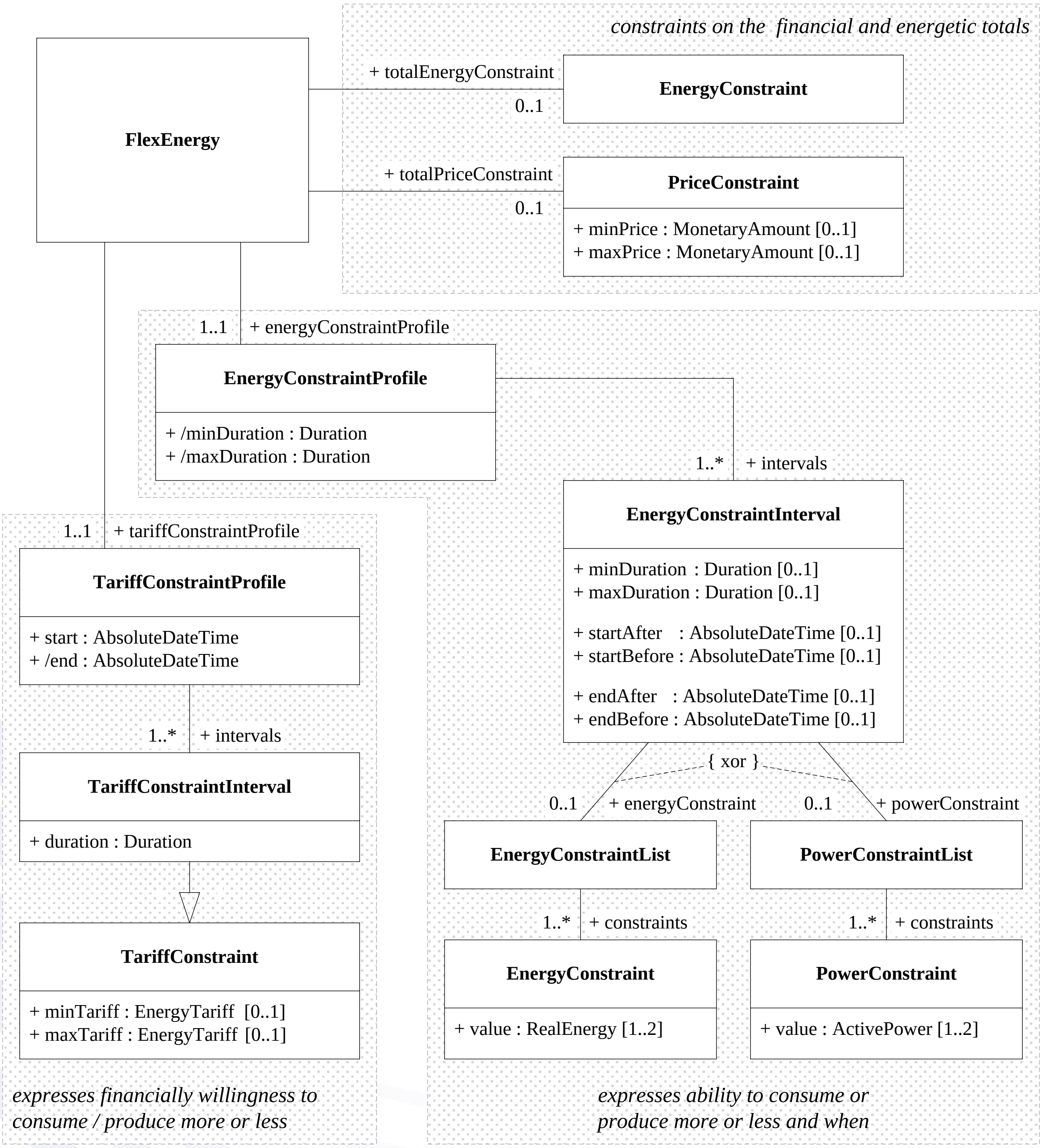

Fig. 5. MIRABEL flexible energy data model that forms the basis for flex-offer generation.

In the GWAC stack of interoperability defined for the energy domain, ontological development is part of the semantic under-standing stage, see Fig 6.

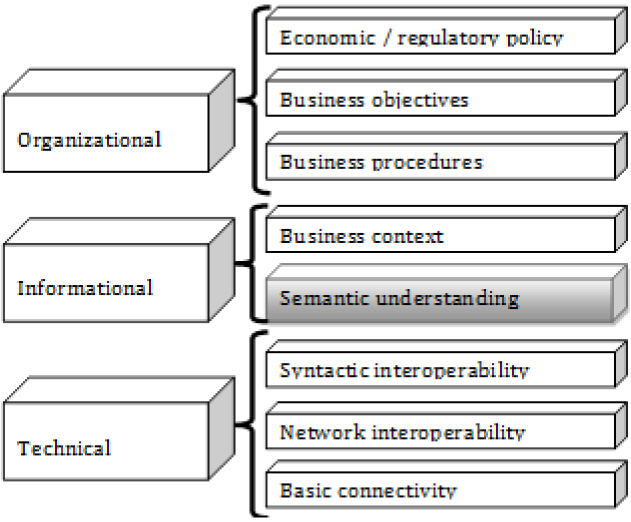

Fig. 6. GWAC stack – interoperability categories.

In the smart grid domain, ontologies promise to deliver extra added value since the present power system operation environment is primarily is com-posed of many distributed tools and components. The interfaces of the various components must be standardized to work in a plug and play concept [15]. The main contributions of ontologies in smart grids are: the possibility to include intelligence in the smart grid, the reasoning using conditional probability as in machine learning algorithms, security, maintainability, testability, management, and development [18].

There are various methodologies to develop an ontology, such as TOVE, Methodology, IDEF5, Ontoligua, and a general approach most often indicated as the Enterprise Model Approach as is described by Uschold and Gruniger in their seminal paper [19]. Although most methodologies for development of ontologies in general terms are comparable, the approach taken in this paper is based on the latter approach. The stages in this approach are: definition of the purpose of the ontology, identification of the scope, data collection and analysis, initial ontology development, producing of definitions, refinement, formalization, and review/evaluation of the result in several iterations. For this research Protégé is used to develop the ontology, because the resulting ontology can be easily exported to XML and RDF/OWL [15].

In Fig. 7 an abstract overview of the FlexOffer ontology is presented that is the result of the ontology development process. This abstraction can be further used to instantiate a lower-level domain ontology that can be used to develop software systems.

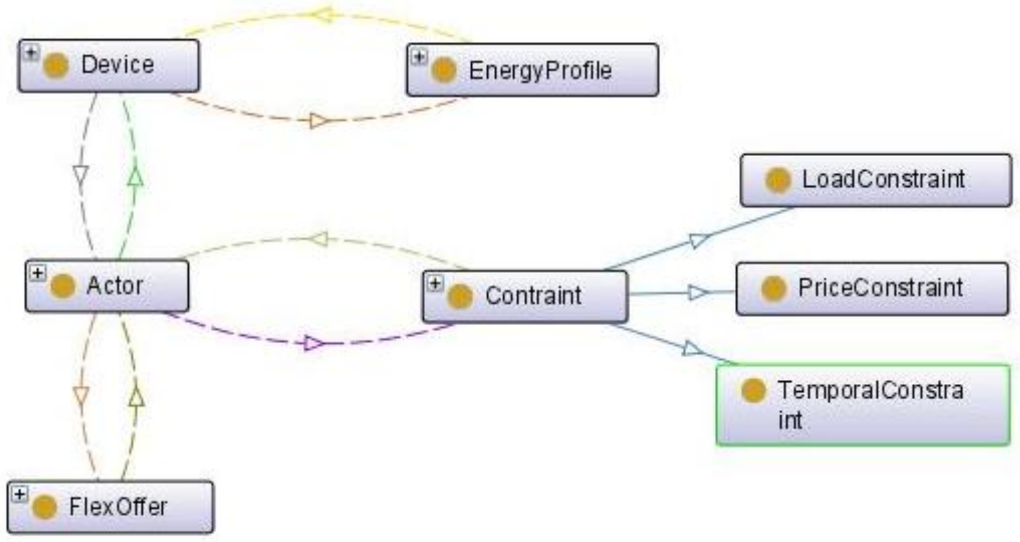

Fig. 7. FlexOffer ontology, expressed in Protégé.

In this figure, five main elements are presented:

- Device: an electricity consuming and/or producing appliance
- EnergyProfile: the energy load production and/or consumption of a Device over a time span
- Actor: the owner of a Device, and issuer of a FlexOffer
- FlexOffer: issued by an Actor, representing the Constraints and the EnergyProfiles corresponding to the Devices owned by an Actor
- Constraint: minimum demands by an Actor for the electrical consumption/production of a De-vice.

Constraint is specialized into three subclasses: LoadConstaint (minimum/maximum energy consumption/production expressed in kWh), PriceConstraint (minimum/maximum price for energy production/consumption) and TemporalConstraint (minimum/ maximum time span in which the energy for the Device is produced/ consumed).

These elements represent the main concepts of the ontology to generically represent flexibility produced by parties connected to the grid based on profiles of devices present at these parties.

6 Application in the Energy Efficient Building context

In this section we elaborate on the relation between the concepts in the FlexOffer ontology and the building that is connected to the grid. From a consumer point of view, 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 buildings 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. In terms of the FlexOffer ontology this is covered by the concepts Device and EnergyProfile. 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, 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 is subject to some kind of buffering. Examples of these devices are heating or cooling pro-cesses, 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 in-crease 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.

(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.

These four types of devices can be added to the ontology as being specialisations of the Device concept and the corresponding characteristics of each device can be added as specialisations of the EnergyProfile concept. In order to leverage 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 program, 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 programs.

Based on the entire set of devices in a building and the various energy-profiles, the BEMS should then be able to generate flex-offers that adhere to the MIRABEL flexible energy model and the ontology derived from it. The ontology is represented in OWL and can thus be easily published, found and used via the web. In fact, this ontology can form the basis for a vocabulary that is used on-line to provide semantic interoperability between IT systems from various stakeholders in the energy domain that handle supply and demand of energy. In the case of the MIRABEL system this also concerns the IT systems for aggregation and scheduling of flex-offers at the actor that represents the balance supplier. In principle, the FlexOffer ontology can be used by any stakeholder in the domain. However, it would be more suitable to extend the ontology in the future to also incorporate the main concepts that play a role in the energy domain at the other side of the balance supplier, i.e. at the market side where demand and supply is bought and sold at (inter)national markets or in the future maybe even local and regional markets.

Conclusions

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 a high-level ontology that is derived from this information mod-el. The model is currently used for producing flex-offers and exchanging these flex-offers with scheduling algorithms that make use of these flex-offers to match demand and supply. These algorithms also use forecasting and aggregation techniques on flex-offers in order to decrease the complexity and in-crease the chances of matching the electricity of demand and supply. The ontology can be used as a basis for a vocabulary that can be used across the entire energy domain to unambiguously define the generic terms in the domain and their relationships. Because the ontology is expressed in OWL, the vocabulary and the messages that are being exchanged based on it can become part of the semantic web. This enables automatic reasoning about the concepts in the ontology as well as the recognition of additional relations between concepts. Future work in this direction includes the extension of the ontology towards the larger energy domain as well as the more detailed representation of the concepts that are involved in the building energy management do-main.

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