European Commission

ICT for a Low Carbon Economy

EEBuilding Data Models

Energy Efficiency Vocabularies & Ontologies

JANUARY 2014

Proceedings of the
4th Workshop organised by the
EEB Data Models Community
ICT for Sustainable Places

Nice, France, 9th-11th September, 2013

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Acknowledgements

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Foreword

The **4th Workshop on EEBuilding Data Models, Energy Efficiency Vocabularies and Ontologies**, was hosted at the ICT for Sustainable Places Conference, September 9-11, 2013, Nice, France.

It is very rewarding that this type of event, which kicked off not that many years ago, has already acquired its own identity, with a strong self-sustainability supported by an informal community using the **eeSemantics** wiki as a knowledge building tool. In this workshop we received for the first time inputs from the Vocabulary Camps - intermediate 2 to 3 day events that discuss deeper each of the chapters treated in the EEBuilding Data Models workshops. This has enriched considerably the content of the presentations.

- eeBEMS and BIM is still a fluent area that must be left open to innovation. However, we see innovation clustering around a couple of projects setting the lead along our Workshops on EEBuilding Data Models. New contributions and new projects adhering to the community build on the knowledge already created and do not start anymore from scratch. This is already a big progress. The channel towards standardisation, especially through the buildingSMART International [1] , was well established in the 2nd VoCamp around Building Information Models (BIM) held on 21-22 February 2012 in Brussels.
- The Smart Home ecosystem standardisation requires some additional thrust. The Ad Hoc Industrial Advisory Group for the Public-Private Partnership on "Energy-Efficient Buildings" has highlighted that issue frequently, including in its proposal for a Research and Innovation Agenda. Our research projects provide evidence of proof of concept installations where we obtain energy savings. However, all projects show a cost barrier at connecting sensors, appliances and actuators. We are decided to boost the progress in this area. The Commission has just launched the "Study on the available semantics assets for the interoperability of Smart Appliances, Mapping into a common ontology as a M2M application layer semantics (SMART 2013/0077)"

We hope will provide the background material enabling all stakeholders to discuss a single ontology for home appliances. ETSI has seconded this idea by creating Action Item A-B92/6 M2M Semantics For Smart EE-Appliances [ETSI/BOARD(13)92_019]2[2].

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[1] http://www.buildingsmart.org/

[2] http://webapp.etsi.org/WorkProgram/Report_WorkItem.asp?WKI_ID=43385

- Energy efficiency beyond the Building will become (and is already becoming) the centre of the discussion around the EIP on Smart Cities. The first H2020 action in standardisation in this field will be a call in 2015: “SCC 3 Development of system standards for smart cities and communities solutions”. Smart Cities is still largely a concept to be turned into something concrete, and our 4th Workshop showed the diversity of angles from which it should be tackled. Nevertheless, we were also happy that "the best paper" award of the event was given to a paper in this area. It proves we already have valuable high-quality proposals to generate a process of fusion

Acknowledgements: We thank the Resilient FP7 European project for the hosting. We thank the Centre Scientifique et Technique du Bâtiment, and to Régis Decorme in particular, for the excellent organisation of the workshop within the event. Thanks to all the projects that have contributed with their high quality papers.

Rogelio SEGOVIA

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About the IDEAS project

The **4th Workshop on EEBuilding Data Models, Energy Efficiency Vocabularies and Ontologies** was organised by the IDEAS project.

The main focus of IDEAS is developing and testing the technologies and business models required to support financially and socially viable energy positive neighbourhoods. Key components of the technologies and business models will be tested at two pilot sites. The project will also explore the possibilities for the incremental rollout of energy positive neighbourhoods across the EU.

The IDEAS project aims to develop and validate the tools and business models required for the cost effective and incremental implementation of energy positive neighbourhoods. These include:

- A Neighbourhood energy management tool: to optimise energy production and consumption;
- User interfaces: to engage communities and individuals in the operation of energy positive neighbourhoods;
- A Decision support urban planning tool: to optimise the planning of neighbourhood energy infrastructures;
- Business models: to underpin the operation of energy positive neighbourhoods that engage end users, public authorities and utility companies.

The neighbourhood energy management tool will enable intelligent energy trading and operation of equipment and buildings along with local energy generation and storage. It will consist of:

- an internet-based infrastructure to manage real-time information flows;
- an optimisation and decision support system for the management of energy production and consumption and energy trading;
- data management and storage services.

The business models and tools will support local energy infrastructures that optimise energy supply and demand, while exploiting wholesale energy markets and local renewables, in ways which make real business sense.

The concept underpinning the business and technical approach is that energy is drawn from national grids only when there is an imbalance in neighbourhood energy supply and demand; or importantly, when it is more economically viable to buy or sell energy from/to the national grid. With the right pricing structure for renewable energy, as a neighbourhood becomes more energy positive it will rely less and less on national energy resources. On reaching energy positivity the surplus energy produced by an energy positive neighbourhood will be a source of revenue profit from intelligent energy trading with national grids.

Energy positivity will become a realistic business goal, for utility companies and public authorities, as tools under development will support a joined up approach to the development and operation of local energy systems. The energy management tool will optimise the current energy supply and demand in real time. The urban planning tool will both improve the efficiency of future urban developments to reduce overall energy demand and help in planning increases to the local supply of renewable energy.

The key performance indicators and data models applied in the IDEAS project seek to build on existing standards, the advances made in earlier EEB projects and learn from the approaches adopted in its sister projects: URB-Grade, EPIC-HUB, EEPOS, ODYSSEUS, ORIGIN, SMARTKYE, E+, COOPERATE and NRG4Cast. All of these projects, like IDEAS, are co-funded by the European Commission under the FP7 program.

As such the requirements for establishing, implementing, maintaining and improving energy management systems in and between buildings in IDEAS will be provided according to international standards (including ISO/FDIS 50001 on Energy Managements Systems, IEC 61850 on Communication Networks and Systems in Substations and IEEE 1547.3 on Monitoring, Information Exchange, and Control of Distributed Resources Interconnected within Electric Power Systems). The lessons learned from the ICT Policy Support Programme (PSP) methodology, used in energy saving management, will also be taken into account.

The eeMeasure methodology for the measurement of energy savings and emission reduction contains information from three previous EU ICT PSP projects: (i) 3e-HOUSES: Energy Efficient e-HOUSES; (ii) E3SOHO: Energy Efficiency in European Social Housing and (iii) eSESH: Saving Energy in Social Housing with ICT. It is based on the International

Performance Measurement and Verification Protocol (IPMVP) standard for energy saving measurement.

The eeMeasure methodology is targeted towards the residential sector where energy use is generally much less, and more difficult to predict, than in the industrial sector. It estimates the amount of CO2 emissions, principally from savings in heat and electricity consumption, that may be avoided by carrying out an energy saving intervention. However there are limitations to the accuracy of these assessments as parameters such as demand response are not fully taken into account in the underlying IPMVP. IDEAS seeks to address this issue as part of its on-going program of research.

Two demonstration sites in France and Finland will be used to validate key elements of the tools, business models developed in the IDEAS project with different business stakeholders and building typologies.

IDEAS website: www.ideasproject.eu

Contact: info@ideasproject.eu

1. Session: eeBIM

1.1. BIM to Energy: Extending BIM for Multi-Model Domain Tasks

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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. This paper addresses the issue of BIM extensions for such multi-model domain tasks on the basis of work done in the EU project HESMOS [3] for the development of an *energy-enhanced BIM framework* (eeBIM) enabling the integration of multiple needed resources (climate, occupancy, material data etc.) and the interoperability of a number of energy analysis, cost analysis, CAD, FM and monitoring tools in an Integrated Virtual Energy Lab Platform [4]. The underlying multi-model framework is based on a flexible and simple link approach, but without higher level semantics that is needed for more sophisticated domain-specific multi-model management features. As an outlook for further research work the paper shortly discusses potential extensions, also reflecting results of the 2nd VoCamp meeting held in Brussels beginning of 2013.

1 Introduction

The advance of Building Information Modelling (BIM) in recent years expedited its use in a growing number of AEC projects and practical tasks. Along with that, various problems that had been addressed earlier in narrower scope had to be reconsidered in search for adequate industry relevant solutions. Such problems include collaborative work support, change and version management, life cycle sustainability and so on [1]. Continuously extending the use of BIM-based working and the related needs for BIM-based interoperability of more and more specialised AEC tools in various building construction subdomains showed also that (1) a global all-encompassing model for all data in a construction project is neither realistic nor practical target, and that (2) BIM data typically have to be combined with other kinds of construction related data in order to be efficiently applied in real AEC tasks [2].

HESMOS is targeting the whole lifecycle of a building. Within these phases analysis and simulation of building energy system performance is done on 3 levels of detail (see *Figure 1*) and requires not only design data that is in focus of current BIM developments [7].

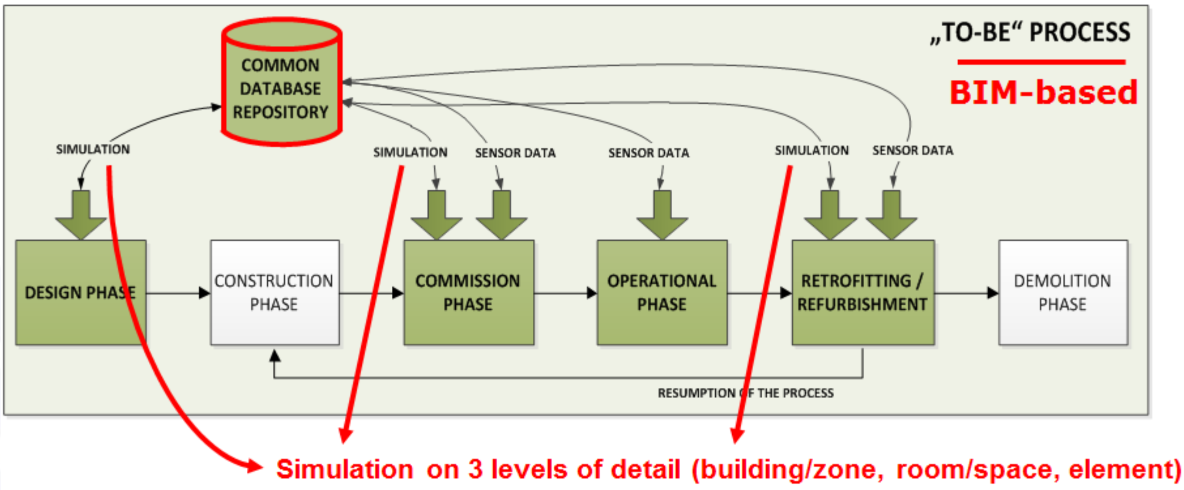


Figure 1: Simulations of building energy system performance within the lifecycle of a building.

2 BIM Extension Approaches

In many cases, available BIM models like the current IFC2x3 or the new IFC4 model [5] do not provide sufficient data to fully support data exchange requirements and tool interoperability for a particular domain. Therefore, while the re-use of already available BIM data is of undisputable benefit with regard to team work, coordination and life cycle information management, the integration of BIM with external information resources is an essential issue to solve for the achievement of an efficient BIM-based work process. However, before actual modelling and/or implementation work starts, the appropriate approach for the targeted BIM extension framework has to be decided.

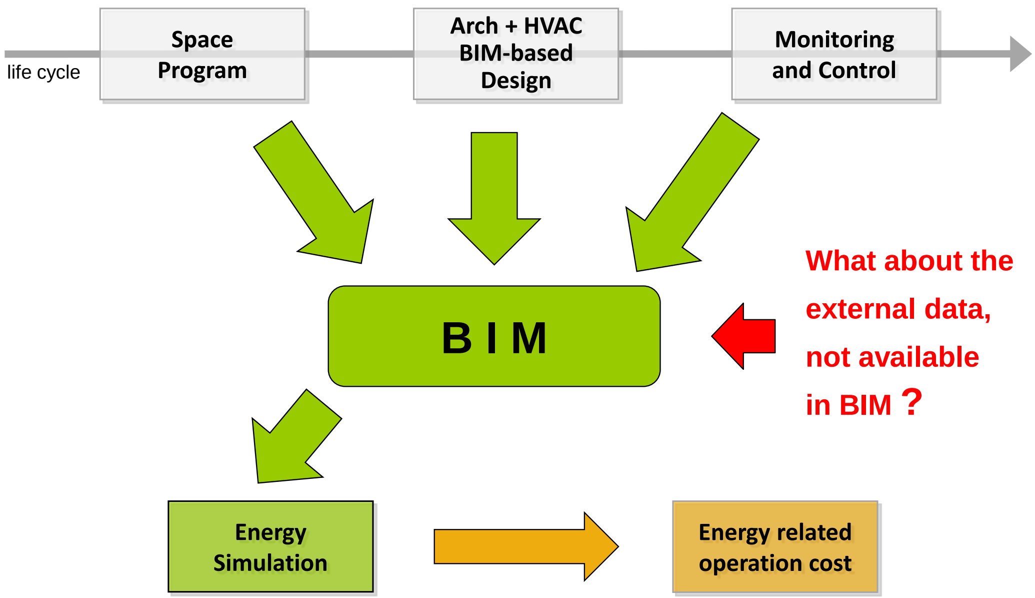
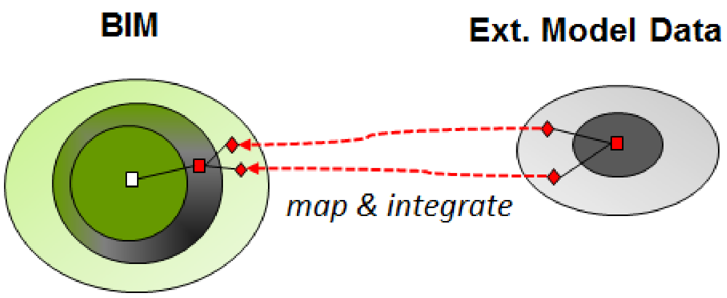


Figure 2: HESMOS integration approach for an energy enhanced BIM.

In principle, three such approaches are to be considered: (1) Extending the BIM schema, (2) Extending the BIM data, and (3) Using a Link Model.

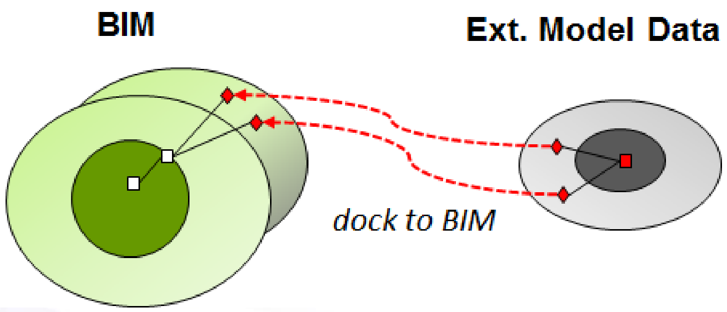
2.1 Extending the BIM Schema

Extending the BIM schema(s) with new concepts, attributes and relations to accommodate the needed external information resources relates to standardisation work done e.g. within the BuildingSMART initiative. Such model extensions are already available for various domains like building services, structural analysis, construction management etc. It requires achievement of consensus among the involved parties and leads to a new version of the standard. Technically, it is the most efficient way to extend BIM functionality but it also has some major drawbacks: development work typically takes very long time, the model becomes increasingly complex and consequently more difficult to use in software, domain applications are overburdened with data of other domains they do not actually need, and – last but not least – external data originating from other sources or even other industry branches (e.g. meteo data, geo data, various supplier data etc.) are difficult to maintain up-to-date and to keep under control. Therefore, this approach is preferable mainly when large, re-usable domain tasks are targeted, the required data is within the competence and control of the AEC industry, and schema changes remain compatible with earlier model versions to ensure fluent implementation. It is less advisable for tasks involving extensive use of external modelling data and ad-hoc situations.



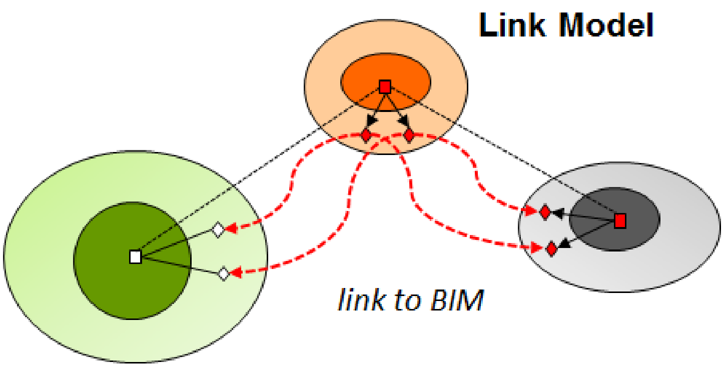
2.2 Extending the BIM Data

Extending the BIM data by using existing interface facilities in the model without changing the model schema provides a different, undisruptive approach. Within IFC various such extensions are possible using the flexibility of the IfcRelationship subclasses, the IfcProxy concept and especially the IFC property set mechanism allowing simple or add-on attribution to various standard BIM entities. The benefit of this approach is the easy to agree upon and implement specification of the needed external information resources and the avoided change of the standard model itself. However, the latter is also one of its main drawbacks because the use of proxies and property sets has relatively low semantic depth and requires agreement between applications in terms of rules or regulations that are not part of the model, an issue of argueable sustainability. Another drawback is that the expressiveness of the available interface extensions can only cover scenarios where the needed external data are of manageable complexity. Thus, this approach is only applicable when the use of external modelling data is limited.



2.3 Using a Link Model

At last, using a separate Link Model [2] as a bridge between BIM and non-BIM data can provide for greatest generality, modularity and implementational scope. It does not require changes in the BIM schema and the external models used and it guarantees maintenance of each model within its own domain (e.g. climate data maintained by meteorologists). Furthermore, it provides for greater semantic depth, helps to handle almost arbitrary data structures and enables a clear interoperability strategy. Its essence is in capturing the relationships of BIM data to external information sources within a separate data structure, the Link Model, and resolving these relationships by means of model management tools at run-time. Drawbacks are the difficulty regarding the maintenance of the Link Model, the need of additional link model management services, some run-time performance deficits due to the increased data complexity, and possible consistency problems in the rare case of overlapping multi-model data. Thus, whilst possible for any multi-model problem, the Link Model approach is most useful where (1) a large amount of external information resources is needed and these resources have non-AEC origin, and (2) where a flexible platform for a set of (exchangeable) software tools is sought. A typical case here is the development of a Virtual Lab for energy-efficient building design and life cycle management.



3 Energy Enhanced BIM

Development of an energy enhanced BIM framework (eeBIM) was undertaken by the authors in the frames of the EU project HESMOS on the basis of the Link Model approach outlined above. The objective of the project was to close current gaps between existing data and tools from building operation and design so that to enable efficient lifecycle energy performance estimation and decision-making by developing an Integrated Virtual Lab platform [4] for energy and emission studies in PPP projects. One thing which became clear already at the outset was that realisation of the envisaged eeBIM framework requires (1) *Filtering* the BIM data to a model subset tailored to the needs of the domain, (2) *Inter-linking* the filtered BIM data with the external model data required for the various necessary computations, and (3) *Mapping* specifications and tools for the transformation of the BIM-based data from/to computational application models (energy simulation model, energy monitoring model, cost model). Here we discuss only the use of the suggested Link Model approach in the HESMOS project [11, 12]. Details on the developed overall framework are provided in [3].

Basically, five types of non-BIM data are considered in the eeBIM framework. These are: (1) Climate and weather data, (2) Extended, detailed organised material data providing the needed material properties for sophisticated energy analyses, (3) Energy Templates providing ready-made configurations useful for early design decisions, such as space use, occupancy profiles, default element construction etc., (4) Pre-fabricated components with their specific energy-related properties from digital supplier catalogues, and (5) Sensor data from Building Automation Systems. Each of these types of data requires specific binding to the BIM data as shown in table 1 below. However, the table also shows some of the difficulties that have to be overcome in the practical implementation of the Link Model [9]. Thus, along with the trivial case of 1:1 correspondence between the BIM and the external data (as e.g. between climate data and IfcBuilding) more complex cases need to be resolved, too, such as the association of one external data item to a group of BIM entities known or not known in advance (e.g. material data associated to typed building elements, but also occupancy profile associated to a grouping of rooms that is not available as such in the IFC model) or the inter-linking of nested BIM objects to external entities (e.g. material properties to material layers in IfcWallStandardCase). In addition, there are various situations where geometric algorithms must be considered, such as the estimation of spaces which are bounded by outer (facade) elements, the estimation of the facade elements as such etc. For such cases, a set of open model management services called BIMfit [10] have been developed which facilitate, along with the Link Model, the BIM-based multi-model integration.

Multi-model issue	Related BIM concepts	Link type	Multiplicity
Climate data	Building; Facade	Explicit; explicit or algorithmic	1:1; 1:N
Material data	Building element (and the related subclasses)	Explicit (nested assoc.)	M:N
Energy templates	Building; Storey; Space zone; Space	Explicit (grouping assoc.)	1:1 to M:N
Pre-fab. components	Building / Distribution element (and subclasses)	Explicit (grouping or nested assoc.)	1:1, 1:N, M:1
Sensor data	Space (external, internal); Building element	Explicit (algorithmic for locations)	1:1, N:1

Table 1 – Overview of multi-model links in the eeBIM framework

4 Conclusions and future work

In the preceding sections we presented the main issues regarding the development of an extended BIM-based multi-domain framework. Using the eeBIM framework of the HESMOS project, work on an Energy MVD has now begun within buildingSMART. This work is based on the overall MVD concept and the new mvdXML development enabling the formalisation of partial models as well as the definition of certain model consistency rules [6]. The eight scenarios developed in HESMOS are thereby considered as starting point for the definition of exchange requirements, such as client requirements, BIM to energy analysis, BIM to operational costs etc. [7]. The expected result is an Energy MVD which shall be used for the certification of CAD applications that will support the export of relevant, sufficient and reliably verified BIM data for energy analysis and simulation tools such as EnergyPlus, DOE-2, NANDRAD etc.

The framework of HESMOS 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. Further research work regarding eeBIM includes the realisation of the core Link Model in the OWL ontology language (OWL 2009), including model management and decision support extensions. Such eeOntology is currently under development in the frame of the ISES project and needs to be discussed with the semantic web community. A start has been made in the 2nd VoCamp held on 21st/22nd of February 2013 in Brussels, where experts from the BIM world and the semantic web community tried to find a common understanding of similarities, differences and potential use cases of their technology. This is an on-going discussion about how to combine more static (or stable), centralized and standardized BIM developments with highly flexible, decentralised and quickly evolving semantic web technologies.

Acknowledgments

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References

1. Eastman, C., Teicholz, P., Sacks, R., & Liston, K.: BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors, 2nd Ed., John Wiley & Sons., N.J., 640 p., 2011.
2. Scherer, R.J. & Schapke, S.-E.: A Distributed Multi-Model-Based Management Information System for Simulation and Decision-Making on Construction Projects, Advanced Engineering Informatics, 25(4), pp. 582-599. 2011.
3. Liebich, T., Stuhlmacher, K., Katranuschkov, P., Guruz, R. et al.: HESMOS Deliverable D2.1: BIM Enhancement Specification, HESMOS Consortium, Co-ordinator: Scherer R. J., Institute of Construction Informatics, TU Dresden, 54 p., 2011.
4. Baumgärtel K., Katranuschkov P., Scherer R. J.: Design and Software Architecture of a Cloud-based Virtual Energy Laboratory for Energy-Efficient

Design and Life Cycle Simulation. 9th European Conference of Product and Process Modelling (ECPPM), Reykjavik, Island, 25-27 July 2012.

5. Industry Foundation Classes Release 4 (IFC4), © buildingSMART International 1996-2013. [Online]. Available at http://www.buildingsmart-tech.org/ifc/IFC4/final/html/index.htm

6. Chipman, T., Liebich, T. & Weise, M.: mvdXML - Specification of a standardized format to define and exchange model view definitions with exchange requirements and validation rules, © buildingSMART International, 2012.

7. Bort, B., Geißler, M.-C., Guruz, R., van Woudenberg, W., Kaiser, J., Hensel, B., Zellner, R., Laine, T., Jonas, F., Liebich T. & Katranuschkov P. 2011. HESMOS Deliverable D1.1: Gap Analysis, Use Case Scenarios and Requirements Specification, HESMOS Consortium, Co-ordinator: Scherer R. J., Institute of Construction Informatics, TU Dresden.

8. HESMOS 2010. EU Project No. 260088 HESMOS - Description of Work, HESMOS Consortium, Co-ordinator: Scherer R. J., Institute of Construction Informatics, TU Dresden.

9. Fuchs S., Kadolsky M., Scherer R. J.: Formal Description of a Generic Multi-Model, Enabling Technologies: Infrastructure for Collaborative Enterprises (WETICE), 2011 20th IEEE International Workshops on; Paris, France, July 2011.

10. Windisch R., Wülfing A., Scherer R. J.: A Generic Filter Concept for the Generation of BIM-based Domain- and System-oriented Model Views. 9th European Conference on Product and Process Modelling (ECPPM), Reykjavik, Iceland, 25-27 July 2012.

11. Scherer R. J., Katranuschkov P., Kadolsky M., Laine T.: Ontology-based Integration of Building and Related Information Models for Integrated Lifecycle Energy Management. 3rd eeBDM within the frame of the 9th European Conference of Product and Process Modelling (ECPPM), Reykjavik, Island, 25-27 July 2012.

12. Guruz R., Katranuschkov P., Scherer R. J., KaiserJ., Grunewald J., Hensel B., Kabitzsch K., Liebich T.: Ontological Specification for the Model Integration in ICT Building Energy Systems. 3rd eeBDM within the frame of the 9th European Conference of Product and Process Modelling (ECPPM), Reykjavik, Island, 25-27 July 2012.

2. Session: eeBEMS

2.1. 1st VoCamp - Energy Efficiency Modeling for Adapt4EE

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Abstract

In the current available building performance simulation programs the presence of occupants and their influence on a building are (at best) based on predefined activity/presence schedules. These schedules however, are often assumptions rather than based on measured observations and resulting descriptive and predicting models. The main topic addressed by the 1st Adapt4EE VoCamp was to foster the fusion of two disjoint worlds of Building Information Modelling (BIM) and Business Process Modelling (BPM) by delivering vocabularies and ontologies that associate the relationships among these domains. Participants of the VoCamp were experts from area of Energy Efficiency in Buildings as well as knowledge engineers. Example ontology from scratch was first prepared at the VoCamp to foster common understanding of the topic. Following the example ontology exercise, an already existing complex ontology model was presented and the vocabulary used to create this model was then modified on the VoCamp in a cooperative manner. Following topics were discussed and models of these were added to the existing vocabularies: skeleton activities, occupancy profiles, key performance indicators (KPIs), building occupants as producers of energy, building simulation results visualizations, high-level events inferring based on measurements stemming from semantically enriched devices. The most discussed models were KPIs and skeleton activities. KPIs model combines energy performance attributes with business performance and occupant comfort attributes. Skeleton activity specification enables to describe necessary characteristics of business activity such as resources needed, involved roles and relations to other activities for the construction of business process map. As a result of the VoCamp, modified Adapt4EE ontologies are available on the eeSemantics wiki page. This paper describes the process and presents

outcomes of the VoCamp. The presented research is performed in the frames of the EU Project Adapt4EE (2011-2014).

1 Introduction

Construction Products (and especially those of commercial use) constitute energy intensive systems through their whole life cycle, comprising energy demanding assets and facility operations, as well as occupants that are the driving operational force, performing everyday business processes and directly affecting overall energy consumption. Energy performance of construction products during operation heavily relies on three interrelated spatio-temporal groups of factors: construction assets and facilities, environmental conditions and occupant behaviour. Energy efficiency (EE) concerns and respective solutions have been presented in the past addressing all phases of construction product life cycle from the design phase (early and detailed design and engineering), to the realisation phase (procurement and development), as well as the support phase (mostly focusing on operation and renovation).

Energy-intelligent constructions incorporating innovative ICT (self-organized integrated frameworks of sensors, actuators, meters etc) will present the ability to efficiently adapt to occupant needs and preferences, maximize energy performance while at the same time comply to overall business requirements. This can be further realized through the fusion of two (currently disjoint) worlds: a) Building Information Modelling (BIM) and b) Business Process Modelling (BPM), having occupants as the main catalyst.

In the current available building performance simulation programs the presence of occupants and their influence on a building are (at best) based on predefined activity/presence schedules. These schedules however, are often assumptions rather than based on measured observations and resulting descriptive and predicting models. Thus, the results of such simulation systems are tentative at best and may often be misleading. Therefore, future research should aim to deliver and validate holistic energy performance models that incorporate architectural metadata (BIM), critical business processes (BPM) and consequent occupant behaviour patterns, enterprise assets as well as overall environmental conditions.

One of the topics addressed by the 1st Energy Efficiency Modelling VoCamp was to foster the fusion of these two disjoint worlds by delivering vocabularies and ontologies that associate the relationships among these domains. The Vocabulary Camp focused on the delivery of ontologies that can be used for the analysis of the Building Performance in terms of its Energy Efficiency. Focus was given to domains, in which vocabularies and ontologies used are not mature yet. The ultimate goal was to deliver or enrich existing ontologies that can be used in various stages of the Building Lifecycle and especially on the early design stages. The 1st VoCamp addressed both Simulation & Management systems and models were created for multiple factors that contribute to the Energy Consumption in Buildings, having as main catalyst the human behavior and presence (building occupants).

2 Simulation of Space Utilisation

Energy consumption in enterprise buildings is a major source of carbon emissions and is highly dependent on human presence and behaviour in such environments [6, 7]. As of today, various strategies and methods have been proposed to improve the energy efficiency of commercial and home buildings that consider various environmental factors including occupancy modelling [1, 10]. However, energy use or waste due to human behaviour in the spatio-temporal domain is not yet fully investigated in the literature. Data on human presence and movement are valuable input data for building-simulation tools such as indoor-climate simulation and working-condition assessment. However, reliable data on human presence and movement in buildings are scarcely available. Existing human-movement models are, typically, developed for (semi) public spaces and lack applicability to indoor spaces [13]. As far as contemporary research or existing technological tools [2, 4] is concerned there is no enterprise modelling (or simulation systems) which fully exploit/address the actual effect of occupants and their respective actions/behaviour in their working environments.

Building performance simulation (BPS) is a powerful tool which emulates the dynamic interaction of heat, light, mass (air and moisture) and sound within the building to predicts its energy and environmental performance as it is exposed to climate, occupants, conditioning systems, and noise sources [3].

In the research field of building performance simulation different research trends are observable. One of such trends aims at development of advanced behavioural models. In the current available building performance simulation programs the presence of occupants and their influence on a building are (at best) based on predefined activity/presence schedules. These schedules however, are often assumptions rather than based on measured observations and resulting descriptive and predicting models. Thus, the results of such simulation systems are tentative at best and may often be misleading. Research is now mainly focused on improving the prediction of the interaction between occupants and environmental controls (e.g. lighting, window, heating/cooling and shading systems).

There is intention to make building performance simulation available and applicable in all phases of the design process, not only in the later design phases. Currently, building performance simulation is mainly applied in the later design phases. However, in the early design phases where the impact of design decisions on the course of the design process, as well as on the performance of the building (design) is biggest. Building performance simulation programs should play an important role in the early design process. [12] discuss research to improve the usefulness of building simulation programs in the early design phases. Improvements of the interoperability between the available simulation tools can easy simulation of space utilisation. A design project is normally a complex, multidisciplinary process. Each involved discipline uses its own set of applications (e.g. CAD software or building simulation tools). Generally, each application has its own model and format to store data. Consequently, the interoperability between applications is still quite limited. The development of a neutral data model for describing and exchanging building data could seriously improve the interoperability. An example of a neutral data model is IFC (Industry Foundation Classes), which receives much attention throughout the field of building research [8]. Another standard that improve the interoperability is the Green Building XML (gbXML) open schema. It helps to facilitate the transfer of building properties stored in 3D building information models (BIM) to engineering analysis tools[3].

Within the Adapt4EE project, we are aiming at augmenting the contemporary architectural envelope by incorporating business and occupancy related information and thus providing a holistic approach to the design and evaluation of the energy performance of construction products at an early stage and prior to their realization. We were/are facing the need to develop of a common data model for describing and exchanging building data and combine them with business process data and data about space utilisation by occupants. First the data about space utilisation are measured in the real building of a specific type. This is called a measurement phase. The measured phase enables to gather real occupancy related data (after analysis of measured data). The data about business processes are modelled in a BPM tool ADONIS while the data about designed BIM are modelled in Open Studio. Based on these data the agents can be trained for a specific building type to be able to simulate space utilisation in the newly designed building of this type.

3 Adapt4EE architecture

The Adapt4EE architecture proposal was described using different Architectural Perspectives [9]. The proposed conceptual architecture of the Adapt4EE system can be seen on *Figure **3***, Figure 4. The architecture is viewed from two basic perspectives, firstly the measurement framework and then the simulation framework. The measurement framework is used to measure data in real buildings, which is then used in the simulation framework to simulate

[3] http://www.gbxml.org/

building utilization to measure energy, business, and comfort performances in a new building of similar type. The Measurement-Training Framework aims at the training and calibration of the Adapt4EE simulation components and reusable simulation models, based on the collection and monitoring of real-life training data from the Adapt4EE pilot sites. Analysis of this framework addressed core data models necessary to support both the calibration of the Adapt4EE components as well as potential persistent data that need to be passed on to the simulation framework. The Simulation Framework aims at assisting on the building design and performance simulation task. The Common Information Interface Module (CIMIM) of the Adapt4EE system serves as a bridge between measurement and simulation frameworks.

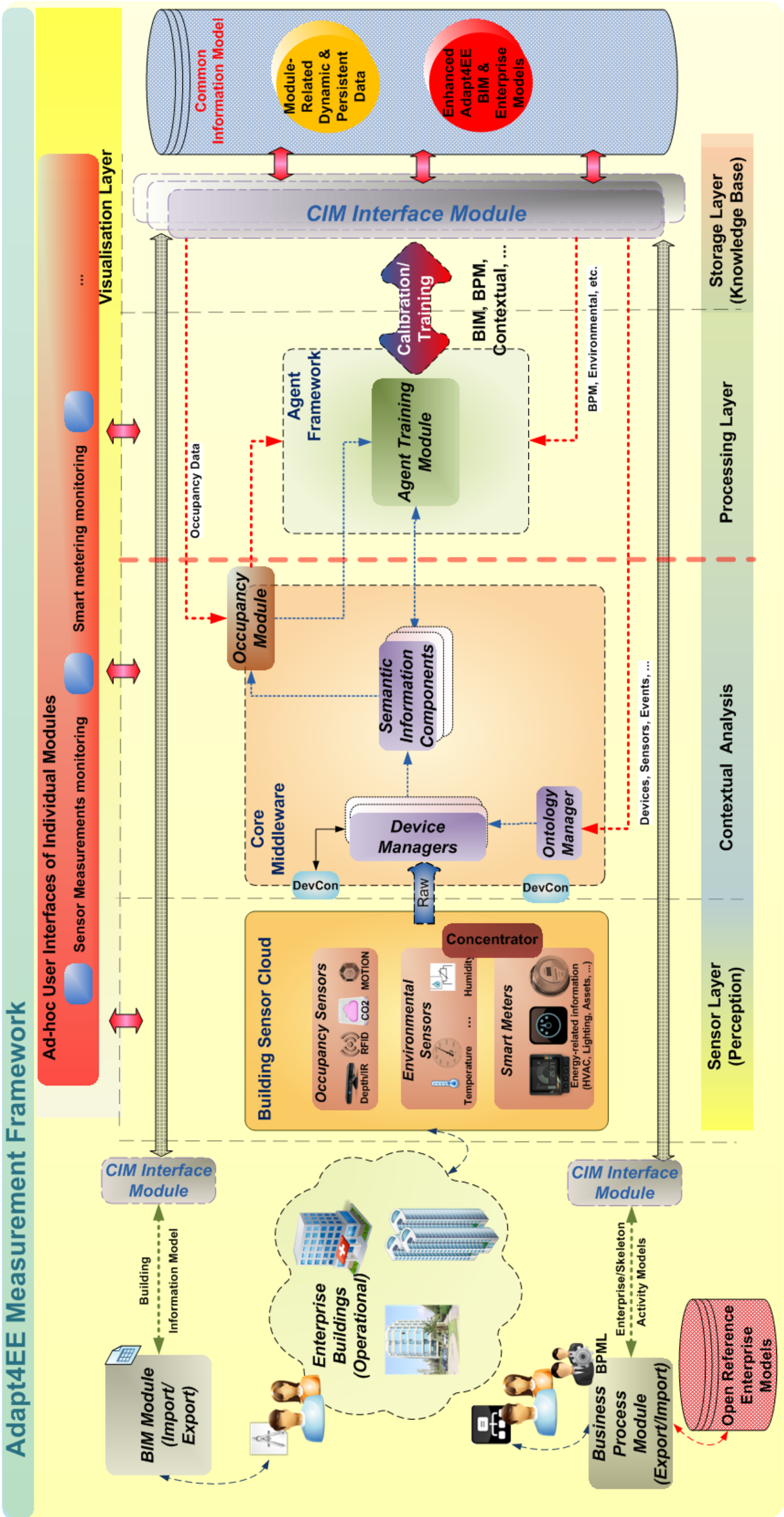

Figure 3: Adapt4EE Measurement Framework.

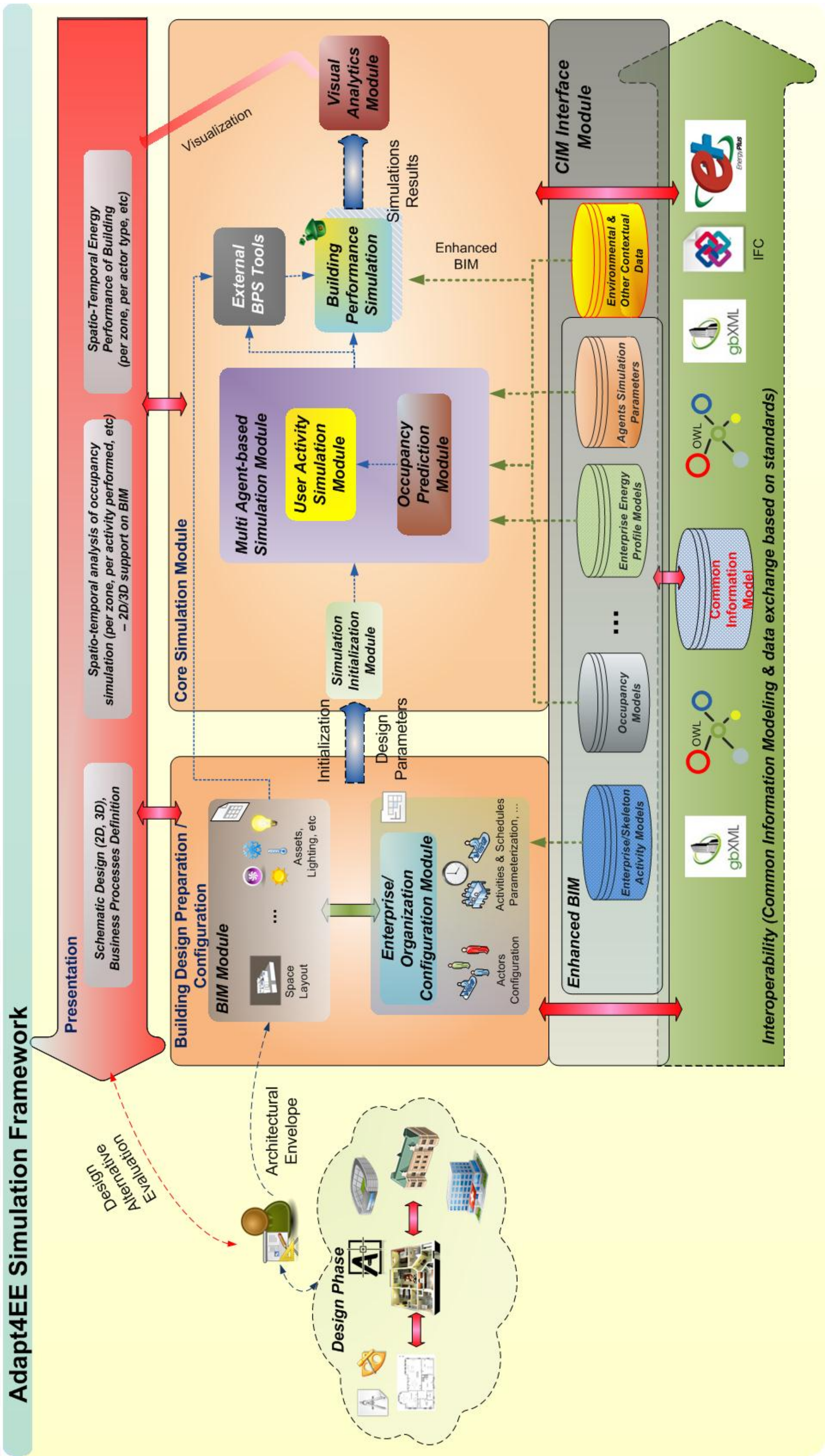

Figure 4: Adapt4EE Simulation Framework.

The CIMIM is a common interface used by other modules to retrieve and to store information within the CIM. It provides these functionalities:

- BIM import-export - Component providing the enhancement of the BIM by relating its parts to the common vocabulary entities. Export functions will be considered.
- BPM import-export - Linking BPM elements to the common vocabulary in the CIM. Exporting the enhanced BPM will be considered.
- CIM Storage - The CIM storage component will take care of physical storing of the data in various formats and transforming between them.

The CIMIM interacts with most of other Adapt4EE modules as seen on *Figure **5***.

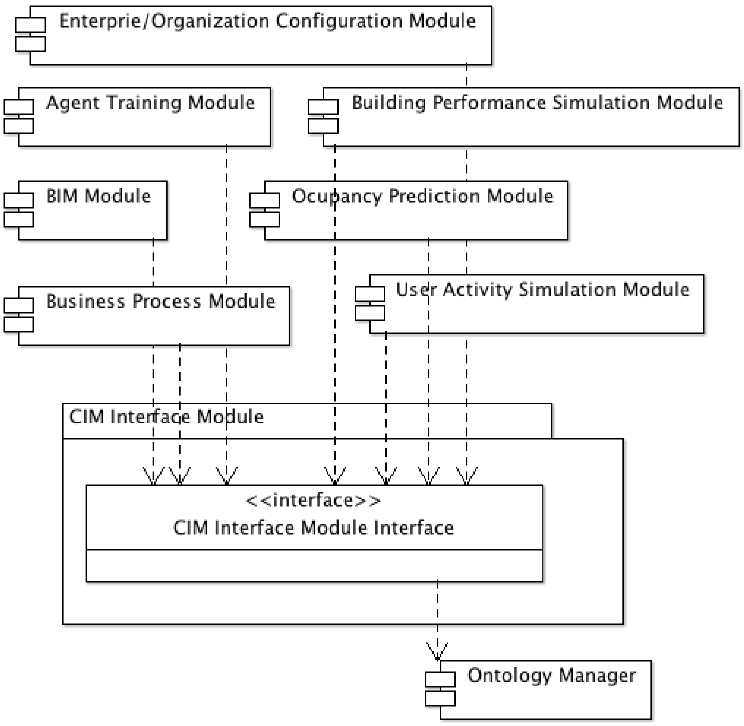

Figure 5: CIM Interface Module – External.

The CIMIM uses noSQL databases to store the information and has an access to the OntologyManager, which can be used to store semantically enhanced data and to retrieve semantic queries about the data. The main task of the CIMIM is to retrieve or serve information in a common vocabulary named in our case the Common Information Model (CIM). Different views of the proposed architecture were presented in the [5]. These included the Functional, Information, Development, Deployment and Concurrency views. From modelling point of view, the Information view is of course the most interesting one. It defines how different Functional components of the system exchange information. The Information view of the Adapt4EE architecture was proposed as Exchange of messages between different modules based on the CIM.

4 Adapt4EE CIM

The Adapt4EE project tries to deliver a SW system, which can calculate an energy, business, and comfort performance of a building based on a simulation refined by values achieved in advance by real measurements in another buildings. The CIM describes the information sources that are used by modules of both measurement and simulation frameworks of Adapt4EE system [11]. The design of the CIM for the Adapt4EE project is mainly determined by the information required by the Adapt4EE modules that can be generated only as a combination (and/or modification) of particular information models (BIM, BPM, Context Control Model, Ontology Model, General Surrounding Environment Model). The CIM is defined as a set of XML schemas defining inputs and outputs of the Adapt4EE SW modules and is supported by an owl ontology model generated from the schemas. For reusability and easier readability of the model, the model is split into several parts. Every part of the CIM has its target namespace and a corresponding XSD source file:

- http://www.adapt4ee.eu/2012/schema/cim/ (adapt4eeCIM.xsd) – the main file that can be used to validate possible XMLs. Contains common elements of the CIM.
- http://www.adapt4ee.eu/2012/schema/bim/ (adapt4eeBIM.xsd) - BIM elements, like building, space, HVAC, …
- http://www.adapt4ee.eu/2012/schema/bpm/ (adapt4eeBPM.xsd) - BPM elements, like process, activity, user role
- http://www.adapt4ee.eu/2012/schema/device/ (adapt4eeDevice.xsd) - sensor related elements
- http://www.adapt4ee.eu/2012/schema/event/ (adapt4eeEvent.xsd) - events related elements
- http://www.adapt4ee.eu/2012/schema/environment/ (adapt4eeEnvironment.xsd) - external environment elements
- http://www.adapt4ee.eu/2012/schema/kpi/ (adapt4eeKPI.xsd) - key performance indicators and simulation results
- http://www.adapt4ee.eu/2012/schema/occupancy/ (adapt4eeOccupancy.xsd) - occupancy related elements
- http://www.adapt4ee.eu/2012/schema/units/ (adapt4eeUnits.xsd) - units, enumerators and values used in other elements

5 VoCamp Development methodology

The 1st VoCamp on Energy efficient Buildings organised by Adapt4EE project hosted more than fifteen experts around Europe. Their active participation was used towards refining vocabularies used for Energy Efficiency in Buildings, mainly targeting in improving on the near future the semantic interoperability and data interchange formats used in eeBuildings domain. After the introductory section on energy efficiency, data modelling and ontology engineering process by the invited speakers of the VoCamp, activities of the workshop continued on selected topics which main purpose was to actively contribute to the elaboration of the vocabularies and ontologies addressed in each session. Firstly, a new example ontology was prepared from scratch, giving an example what the Adapt4EE needs in such a model. Following the creation of the example ontology, the current complex model was presented and small parts of it were selected for further refinement in separate sessions. These sessions, their main topics, and results are described in the following sections.

Creating an example ontology from scratch

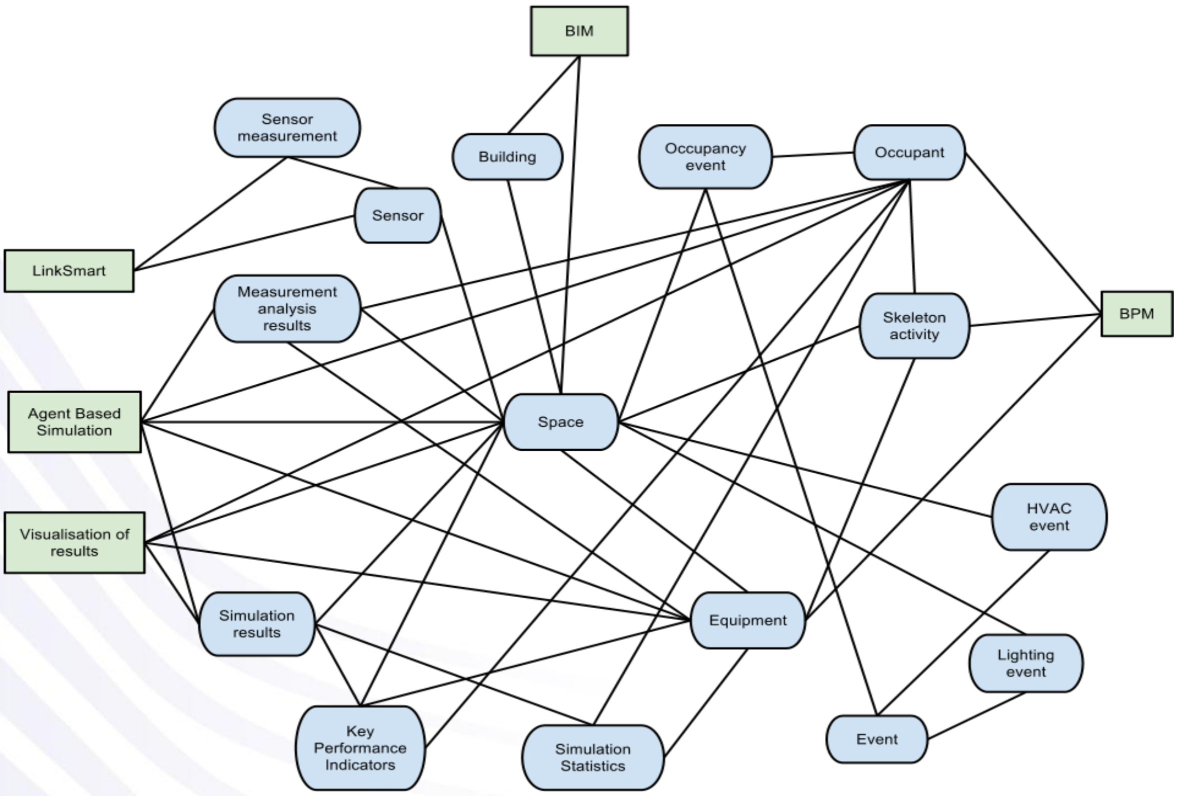

Figure 6 Adapt4EE Common Information Model structure.

The example of a model was created on a white board in the first section of the Adapt4EE block on the VoCamp. The proposed model is related to external data providers and consumers of the Adapt4EE system. As we see on the *Figure **6***, the central point of the Adapt4EE CIM is the Space concept. The space can be a room or a corridor or a part of the room in the building. It is imported into the model from the BIM model together with a building description. Skeleton activity is a simplified version of activities in business processes that take place in the space. Skeleton activities can use resource devices (equipment) and are performed by occupants. Skeleton activities are imported from the BPM external tools. Sensors devices are linked to the LinkSmart middleware (a SW tool to enable sensors to communicate with the application) and can produce measurements. Events are generated by measurements. Simulation component uses events, measurements, and the building model and produces the simulation results. Simulation results are then used by the visualization.

Extension of model to support skeleton activities

Skeleton activity is a part of the business process performed within one room (space). During the VoCamp we have defined several aspects that are important for the description of the skeleton activity. Duration times were defined including waiting and transport times. User heat gain related to the activity was defined. Also we have defined the equipmentIntensityOfUse property that can define less then 100% usage of the equipment. Activities can also be set as business or non-business. The resulting skeleton activity element of the CIM is depicted on *Figure **7***.

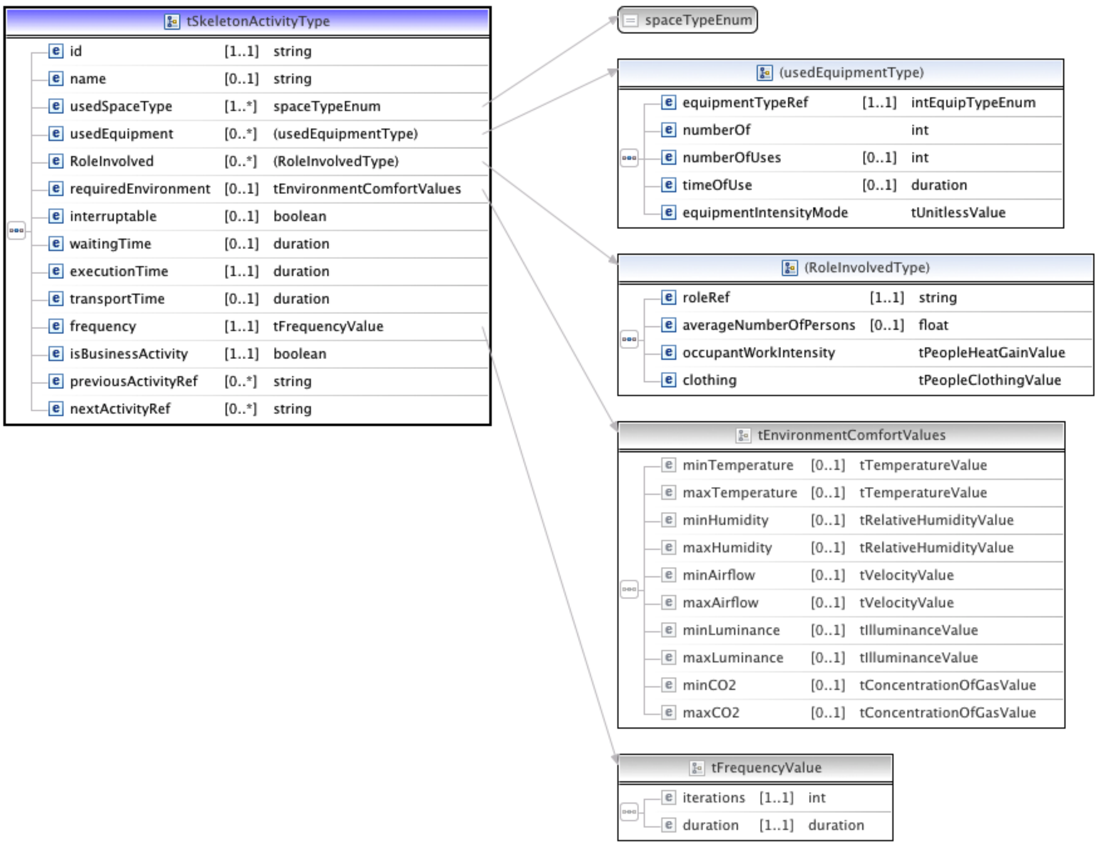

Figure 7 Skeleton Activity.

Extension of model to support occupancy profiles

We have defined the comfort values of occupant and his/her working time. Intensity of occupant work is defined in the skeleton activity template described in previous topic.

Extension of model to support key performance indicators

Key performance indicators (KPIs) were defined in the CIM. These are part of the Agent Simulation Output. We have divided them into 3 subgroups: (i) Energy KPI – related to the emission production by equipment, HVAC and equipment, (ii) Business KPI – related to utilization of building, equipment, roles, business processes, (iii) Comfort KPI – related to dissatisfaction of occupants and overcrowding factor. These indicators should be used to quickly compare different buildings. In Adapt4EE project it will be used also to visualise different aspects of the building. On *Figure* ***8***, the resulting key performance indicator value structure is depicted.

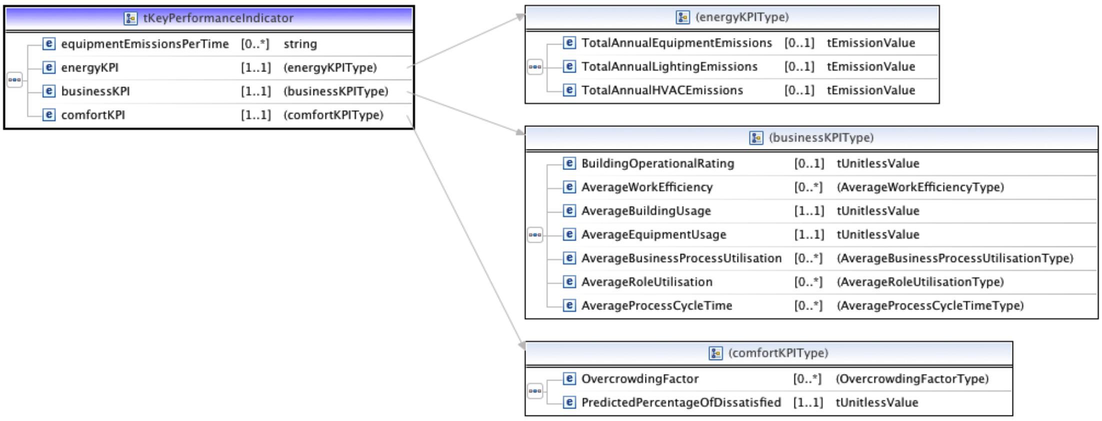

Figure 8 Key Performance Indicators.

Extension of model to support simulation results visualization

The visualization is partly related to the KPIs depicted in the *Figure* ***8***. Another part of the CIM needed for the visualisation are statistical data related to different parts of a building. As our simulation is agent based, the resulting data structure is called an Agent Based Simulation Module Output. Its part are the mentioned KPIs an also some additional statistical data from simulations. The resulting structure is on the *Figure* ***9***.

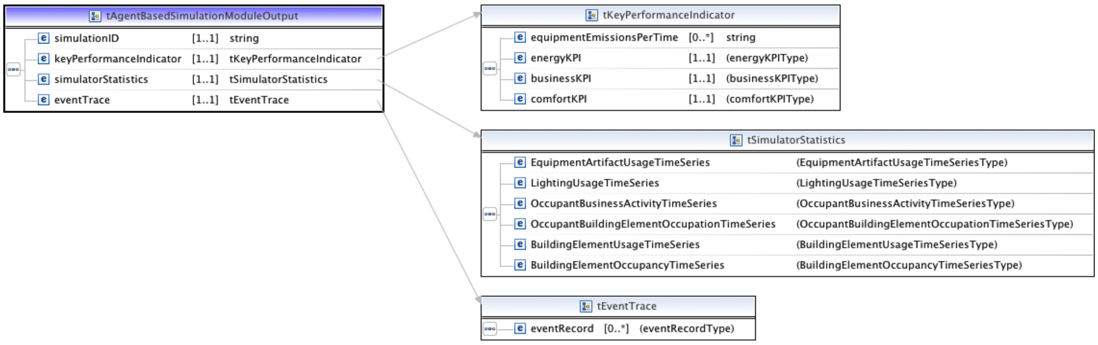

Figure 9 Agent Based Simulation Statistics.

8 Conclusions

Within the Vocabulary Camp a number of models were developed or refined in terms of Energy Efficiency in Buildings. Results are publicly available at the VoCamp wiki pages. The VoCamp results are clearly advantageous for the Adapt4EE project as the knowledge of external experts can be used. The advantage for all external actors to participate in the VoCamp was the introspection to the Adapt4EE solution structure. Both parties can benefit on effort to make the Adapt4EE CIM more public and in line with standards already existing or emerging for the topics covered. Extended Adapt4EE models prepared on the VoCamp are currently fully used within the Adapt4EE project for pilot applications. The limitation of the proposed solution is mainly its dependence on real data for our application. As the model is built prior to its deployment, it was produced mainly using a top down approach. The final model is quite complex and can be considered too complex for particular solutions. Thus the models will be further refined and updated using a bottom up approach within the project pilots toward the final version released at the end of the project duration.

Acknowledgments

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References

1. Bourgeois, D., Reinhart C., Macdonald I. "Adding advanced behavioural models in whole building energy simulation: A study on the total energy impact of manual and automated lighting control", Energy and Buildings Vol. 38, pp. 814-823, 2006.
2. Chen, Q., "Ventilation performance prediction for buildings: a method overview and recent applications", Building and Environment 44 (4), pp. 848–858, 2009.

3. Crawley, D. B, Lawrie, L.K., Winkelmann, F.C., Buhl, W. F., Huang, Y.J., Pedersen, C.O., Strand, R.K., Liesen, R.J., Fisher, D.E., Witte, M.J. and J. Glazer, 2001, "EnergyPlus: creating a new-generation building energy simulation program", Energy and buildings, 33 (4), p. 319-331.

4. Crawley, D., B., Hand, J., W., Kummert, M., Griffith, B., T., "Contrasting the capabilities of building energy performance simulation programs". Building and Environment 43(4), pp.661–73, 2008.

5. Jahn, M., et al., Adapt4EE Conceptual Architecture, Adapt4EE Project deliverable D2.1, 2012.

6. Kashif, A., Binh Le, X. H., Dugdale, J., Ploix, S., "Agent based framework to simulate inhabitants' behaviour in domestic settings for energy management". In ICAART 2011 (International Conference on Agents and Artficial Intelligence), Rome, Italy, January 2011.

7. Liao, C. and Barooah, P., "An integrated approach to occupancy modeling and estimation in commercial buildings," in Proc. American Control Conf. (ACC), pp. 3130-3135, 2010.

8. O'Grady, W. and M. Keane, 2005, "Specification of an IFC based software application to support CFD simulation", IBPSA building simulation.

9. Rozanski, N. and Woods, E. (2005): Software systems architecture: working with stakeholders using viewpoints and perspectives, Pearson Education.

10. Seung, H., Hong, J., Yong, O., "Method to analyze user behaviour in home environment", Personal Ubiquitous Computing. 10, 110–121, 2006.

11. Skokan, M., et al., Adapt4EE Common Information Model, Adapt4EE Project deliverable D2.2, 2012.

12. Struck, C., Kotek, P., and J. Hensen, 2007, "On incorporating uncertainty analysis in abstract building performance simulation tools", Proceedings of the 12th symposium for building physics, p. 193-205.

13. Tabak V, de Vries B, Dijkstra J, 2010, "Simulation and validation of human movement in building spaces" Environment and Planning B: Planning and Design 37(4) 592 – 609.

2.2. Low carbon district – Energy and behaviour modelling

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Abstract

The main objective of the CSTB Low District program is to develop a set of new energy management tools to reduce carbon footprint at the district scale. Such tools should allow the development of strategies aiming at electrical load reduction, such as demand response, distributed energy resources energy integration and load management. In that context, a high resolution (1 minute) load curve simulator framework has been developed. It aims at being a virtual benchmark for local smart grid strategies.

The framework proposed in this paper is a combination of top-down and bottom-up approaches. On the first hand the district information model is described in a top down fashion by a joint distribution allowing the generation of a statistically representative sample of buildings, appliances and dwellers. The joint distribution is derived from publicly available census data and expert knowledge whenever experimental data are missing.

On the second hand, the dwellings load curves are simulated using a bottom up approach. In this work, appliances are stochastically triggered conditionally to the dwellers activity. The behaviour models are based on the homogeneous Markov chains used in (Richardson et al. 2008) .

Deterministic part of the electrical load, such as heating and cooling consumption, is simulated through a reduced model of the multi-zone building model from the SIMBAD library (Husaunndee et al. 1997).

This paper presents the general approach and modelling hypothesis of the load curve simulator and shows first results of behavioural load curves simulations.

Keywords: occupancy model, demand model, electrical end-use model, conditional sampling

Introduction

The "Low carbon district" project investigates district scale technologies to reduce energy related carbon emissions. This work is therefore oriented on energy, environmental and economic aspects, as well as safety and feasibility of integration according to the various existing technologies.

District decarbonisation solutions revolve around several potential directions:

- Increasing the part of renewable energy sources
- Mutualizing energy sources
- Lowering energy demand
- Lowering electrical power demand

Traditional hourly based energy simulators are well fitted to model slow thermal systems such as district heating networks and have a good record at simulating yearly energy consumptions (Judkoff & Neymark 2006). Though those tools can be used to address energy demand solutions, they lack the time resolution to address power specific phenomena, such as peak demand and energy storage sizing. Unfortunately, carbon emissions highly depend on electrical load. As shown in *Figure* ***10***, the energy production carbon footprint grows rapidly with the electrical load and is maximal in peak periods, which only represent a small fraction of the year. The high resolution load curve simulator framework presented in this paper is designed to tackle power load issues that cannot be approached through hourly based energy simulations.

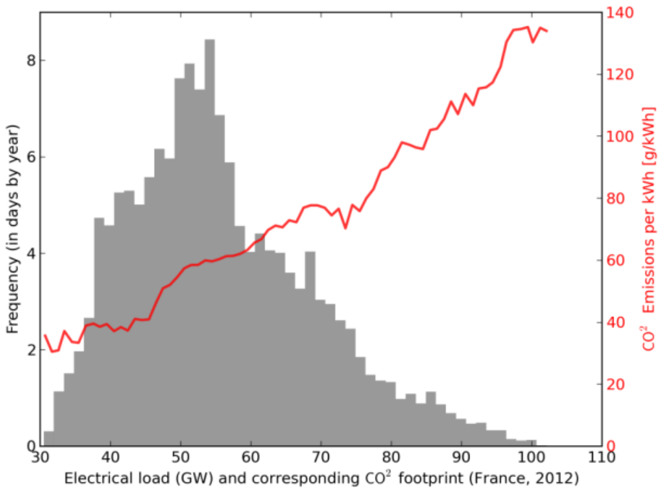

Figure 10: carbon footprint of electricity production in France (RTE 2012).

Previous attempts at high-resolution load curve simulation can be classified in three ways (Granjean 2013). The distinction can be done between top-down, bottom-up and hybrid models.

-Top Down approach:

These models require large databases of housing load curves. Load curves are grouped into clusters which are consequently used to build new load curves, either directly from querying existing ones from the database (Aigner et al. 1984; Bartels et al. 1992) or by using machine learning technique such as Markov chains (Labeeuw & Deconinck 2013). It is important to note that in top-down approaches, occupant behaviour is never modelled explicitly.

- Bottom up approach:

These models require large databases of appliances load curves. Those databases can be constituted from field measurements or may consist of physical or regulatory models. The load curve of the district is built from the bottom up by assembling appliances elementary load curves building by building. The difficulty of this approach is to build appliances activation model representative of the occupant occupancy or activity. In this model category, the reader can refers to (Walker & Pokoski 1985; Capasso et al. 1994; Widén et al. 2009; Richardson et al. 2010) .

- Hybrid Approach:

These models are a mixture of the two previous models. The model developed in this paper is part of this category. The definition of the district (building and occupants typologies, appliances) is defined by a top-down approach from statistical data. The housing and district load curves are built through a bottom up approach based on stochastic triggering appliances scenarios.

The hybrid approach has been chosen in order to meet the following requirements :

- The simulator should produce an electrical load curve for each of the end-use (applicances, heating, domestic hot water (DHW), etc)
- Buildings, equipments and simulated occupants should be statistically representative of the diversity of the considered district
- Computational time should not be prohibitive
- The simulator should produce results consistent with experimental data for the following indicators:
  - average patterns of consumption
  - distribution of power demands
  - daily peak time statistics
  - seasonality and load structure
  - share of appliances consumption

Those requirements imply the ability to simulate the folowing phenomena :

- the building thermal behaviour
- energy systems (heating, cooling, etc)
- building occupancy

- appliance usage conditional to the occupancy (lighting, equipment ...)
- The building management system based on occupancy (set temperature, recovery ...)
- Major appliances electrical load

The model coupling architecture is presented in part 1. Part 2 presents the generative data model. Part 3 presents the different model layers constituting the appliance part of the load curve.

1. Models architecture and coupling:

Architecture

The class diagram of the models is described in *Figure **11***. The model of the district load curve is composed of building models. Each building model includes a building thermal model, occupancy and activity models, systems models and appliances models. The general organisation underlined by the class diagram is the seperation between process models (how a process works) and use models (how processes are operated). Building thermal models, heating and cooling systems models and appliances electrical models belong to the process models category. Occupancy models, activation models and BEMS use models belong to the use models category.

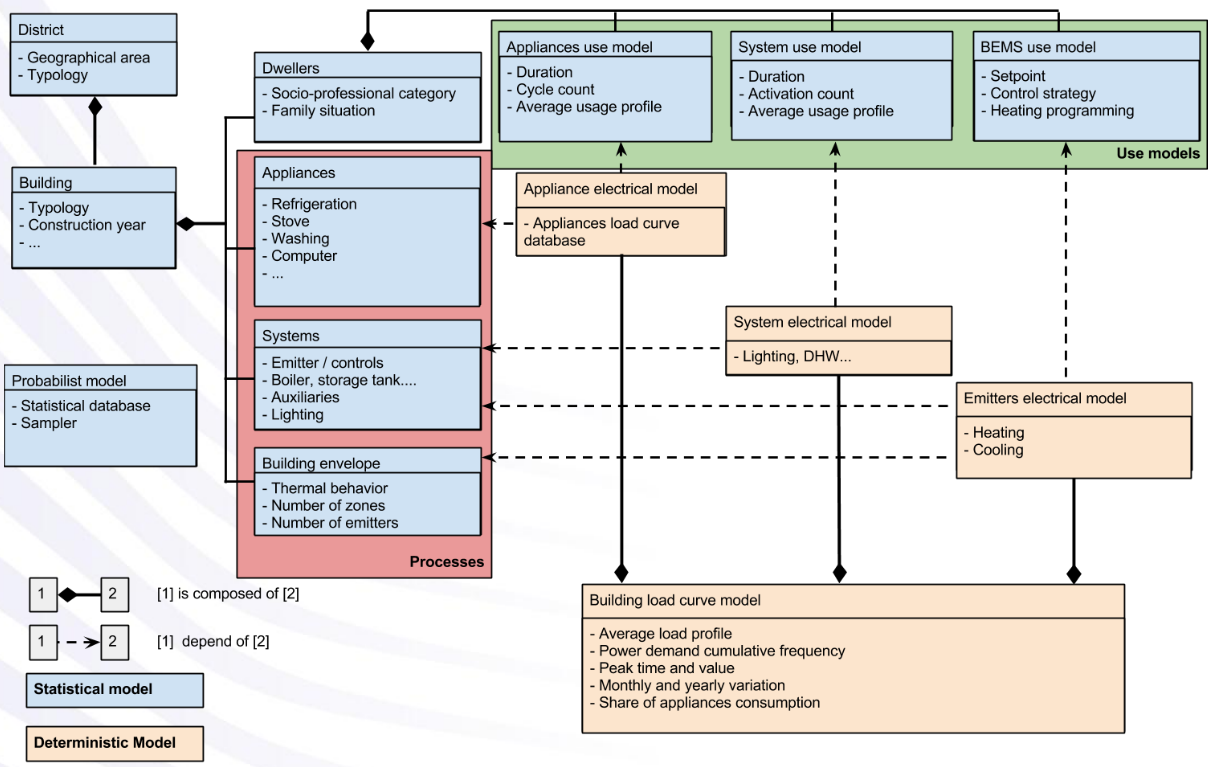

Figure 11: Class diagram of the simulator.

A building load curves model is the resulting sum of all the electrical model of the different processes being operated as dictated by the use models.

Coupling

Thermal coupling impose at least a weak one-directional coupling between the building thermal simulation and the activation models through heat generation. If the occupant behaviour (presence and activation patterns) is considered temperature dependant, this coupling is bi-directional (see *Figure **12***).

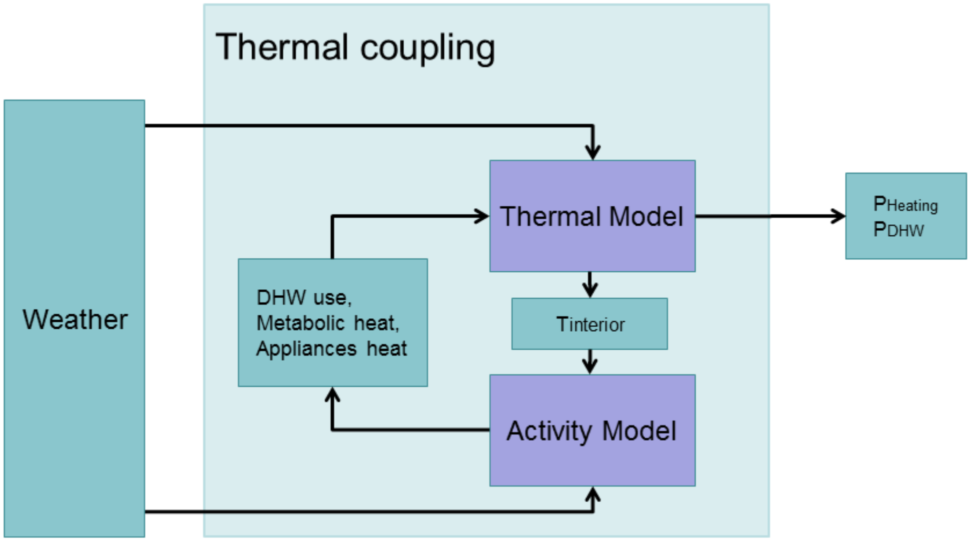

Figure 12 : thermal coupling.

Thermal simulation is performed through a reduced model of the SIMBAD multi-zone building simulation tool (Rife & Vanderkooy 1989; Husaunndee et al. 1997; Ljung & Söderström 1983).

2. Generative data model:

Developing and testing new smart grid strategies can only be achieved through high resolution load curve simulation tools. Unfortunately, such simulations require highly detailed models of a district where buildings envelope, occupants behaviour and energy systems need to be described in detail. Unfortunately, such a fine grained level of information remains practically out of reach. In order to circumvent this issue, a procedural approach of district description based on statistical modelling has been developed.

Figure 13 presents a probabilistic network modelling the joint distribution between the model parameters. Starting from the root node "geographical area", each child node is determined randomly from a statistical distribution depending on each of its parents nodes. Populating a disctrict model with parameters is thus a forward sampling of the probabilistic network ("forward" meaning from root to leaves). This kind of approach allows to retain all the statistical dependencies between the parameters without having an actual detailed description of the disctrict. In terms of inputs, a classical descriptive data model (a district BIM) would have required a comprehensive description of all the buildings whereas the generative approach only require the conditional dependencies between each node (Kollar & Friedman 2009). Such data can be directly calculated from housing census data and other available statistics.

Another advantage of this approach is that for large districts, the size of the sampled population no longer needs to reach the size of the actual disctrict. The statistical behaviour of the district can be approched from a small sample with an accuracy level depending on the sample size, the exact same way nation wide voting behaviour are estimated from polling a small subset of its population.

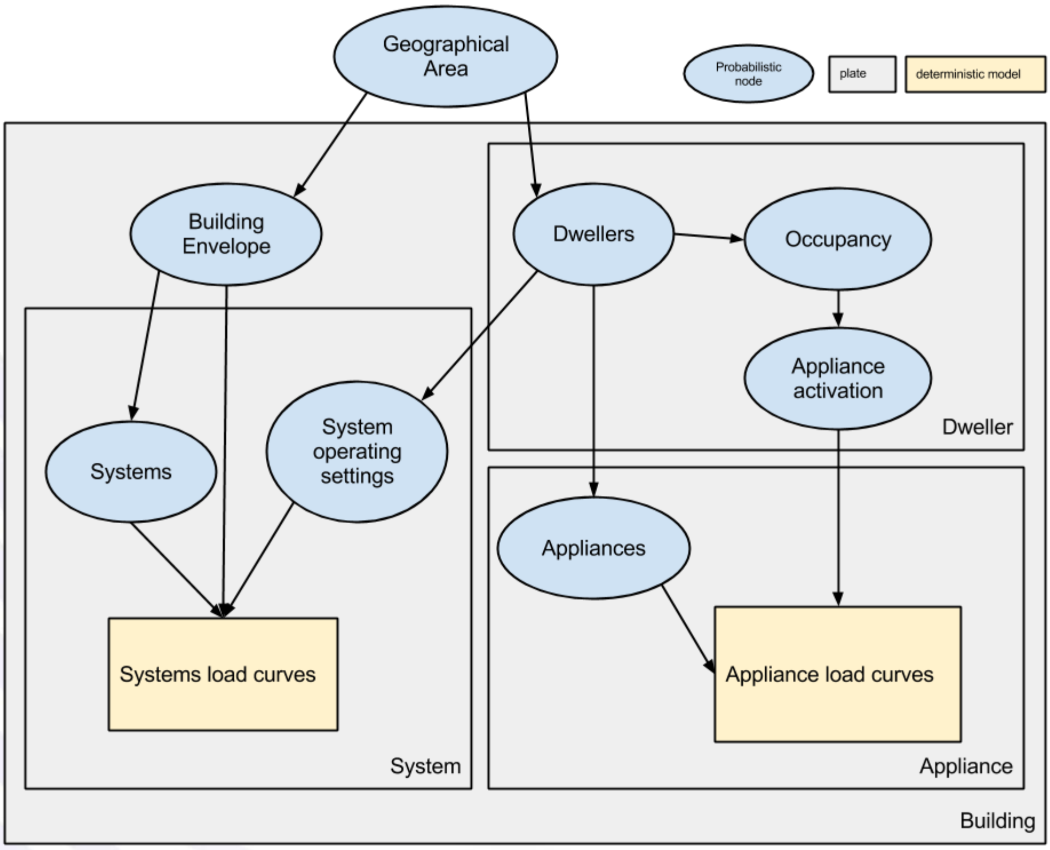

Figure 13: Probabilistic modelling of the district (plate notation).

Figure 5 shows an example of joint probability of 4 variables in Paris(INSEE 2013) : number of rooms, type of housing, occupant status and socio-professional category.

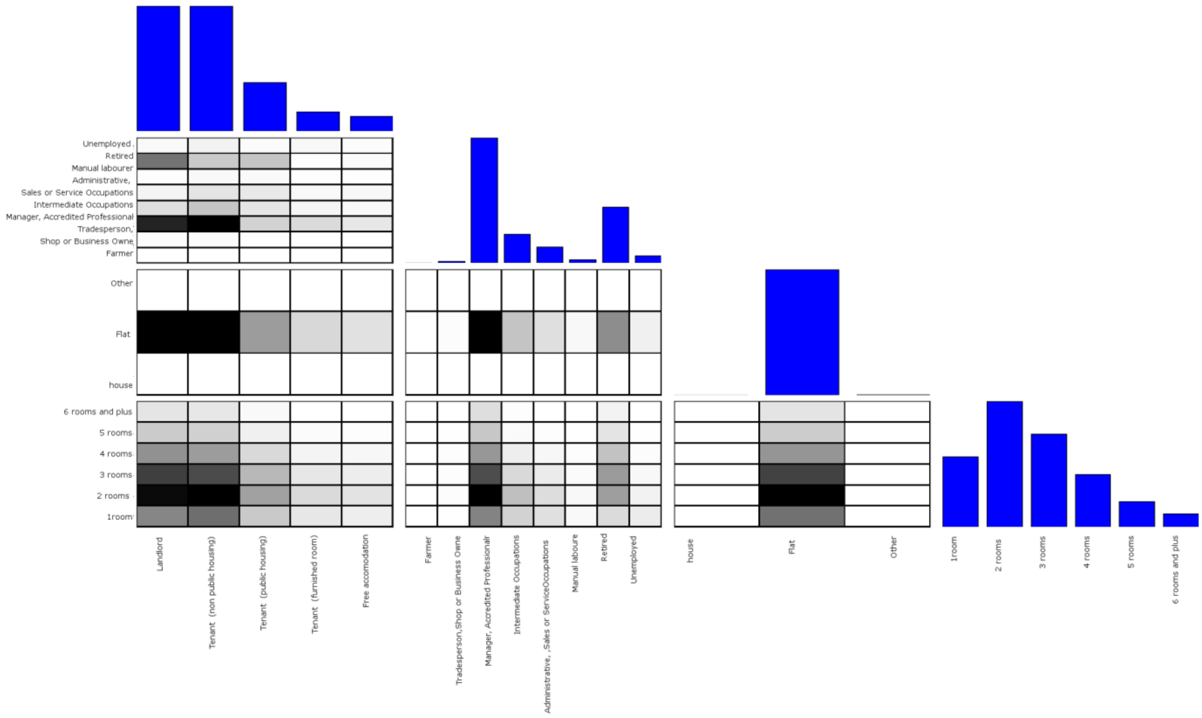

Figure 14 : Joint distribution (Paris, 2010).

3. Behavioural load curve model:

Appliance model

The appliance model generates the electrical appliances available in each building. The distribution model takes into account the level of equipment. This criterion will inform us about the presence or absence of an appliance in the building. The device must then be defined from its main characteristics (technology, energy class, size ...).

The bottom up approach used to generate the global load curve of the building (residential and commercial), requires the simulation of each appliance load. As a comprehensive list of all type of appliances is out of reach, a subset of devices of interest is selected based on their level of instantaneous active power, annual energy consumption and market penetration rate. This approach insures the simulation consistency in term of both power (instantaneous active power) and energy (annual energy consumption).

Active and reactive load curve is thus generated for a given device (clustered by technology, energy class, size, etc.) and a given use case scenario (duration, number of cycle, etc.).

Selected devices models are of two kinds:

- Physical model (i.e. : fridge consumption calculated from set point and external temperature)
- Fixed load profiles drawn from a database

Three categories of appliances have been identified:

- Trigger type appliances following a well-defined cycle (ON - Cycle). In this case, the occupant activity must be correlated to the start time.
- ON – OFF type appliance where user intervention is required to start and stop it. Between these two time intervals, the power profile can be variable.
- The last category is devoted to units functioning throughout the day (daily cycle). For these devices, the activity of the occupants can influence the final load profile through variations of instantaneous power level, or through the variation of the duty cycle of the control (i.e. a fridge)

A first choice of appliances to model for residential buildings has been selected. The list of devices modelled to date is as follows:

- Washing machine
- Clothes Dryer
- Dishwasher
- Refrigerator
- Freezer
- Oven
- Hob
- Television
- Computer
- Stand-by consumption

Activity model

As part of the work associated with the generation of the building electrical load curve, occupant's activity in the building occupies a special place. Indeed, Richardson (Richardson et al. 2008) shows the relationship between the average occupancy profiles and mean profiles of electricity demand.

The main objective of this model is to generate a profile of occupants' activity in the building as representative as possible of the reality. In making the assumption that an electrical device can only be activated if the occupant is active, the occupant activity allows to build an electrical load curve close to the reality.

Among the available model in the literature, Richardson has particularly attracted our attention for the following reasons:

- The Markov chain approach used in the model is light weighted compared to the computationally intensive agent-based approach
- It is built to accurately render the statistical properties of experimental data
- Its parameters can be set directly from experimental data
- an open source implementation of the model is readily available (excel spread sheet)

The model is based on a first-order Markov Chain. For each time step in a day (every 10 minutes), a transition matrix describes the probability to transit between activities.

The transition matrices are fitted on a database of TUS English study (Ipsos-RSL and Office for National Statistics 2000), where 2,000 homes were instrumented to identify the occupancy by residents. Distinction between weekdays and weekend days is done.

The Richardson model was implemented in Matlab, allowing the simulation from 1 to 5 occupants in a single housing.

Activation model

The bottom-up approach requires the identification of the times at which the appliances are activated. The appliance activation model can perform this task for different devices, depending on the profile of occupants and type of housing.

The main objective of the activation model is to generate an annual probability profile to activate the appliances for different occupant's categories and housing types. Thus, by performing a random draw at each time step of this probability profile, it will be possible to generate pulses that determine the starting up of the appliances.

The appliance list for which the annual probability profiles of activation were modelled is the following:

- Washing machine
- Clothes dryer
- Dishwasher
- Oven
- Hob
- Television
- Computer

Note that for cold positions, the activation profiles are not generated. The reason for this is intrinsic of the device mode (continuous operation, managed by the hysteresis).

First results

The first result from the coupling of the different models (Appliance model, activity model, and activation model) is illustrated through an example.

Occupants are classified into three categories: single, a couple without children, or a family. The age of the occupants is used as input into two categories: 26 to 64 and 64+. The devices are then defined according to their criterion of energy class, size (size, volume and capacity) and technology use.

The housing and its occupant were all arbitrarily chosen. Thus, we present here an apartment, occupied by a couple with no children in the age category of 26 to 64. The housing component units must in turn be defined by the model generation of electrical equipment of the building. The latter being in the development stage at the moment, electrical equipment has also been chosen arbitrarily.

The following charts and tables shows the simulation results obtained using the current global model (the tool interface is in French).

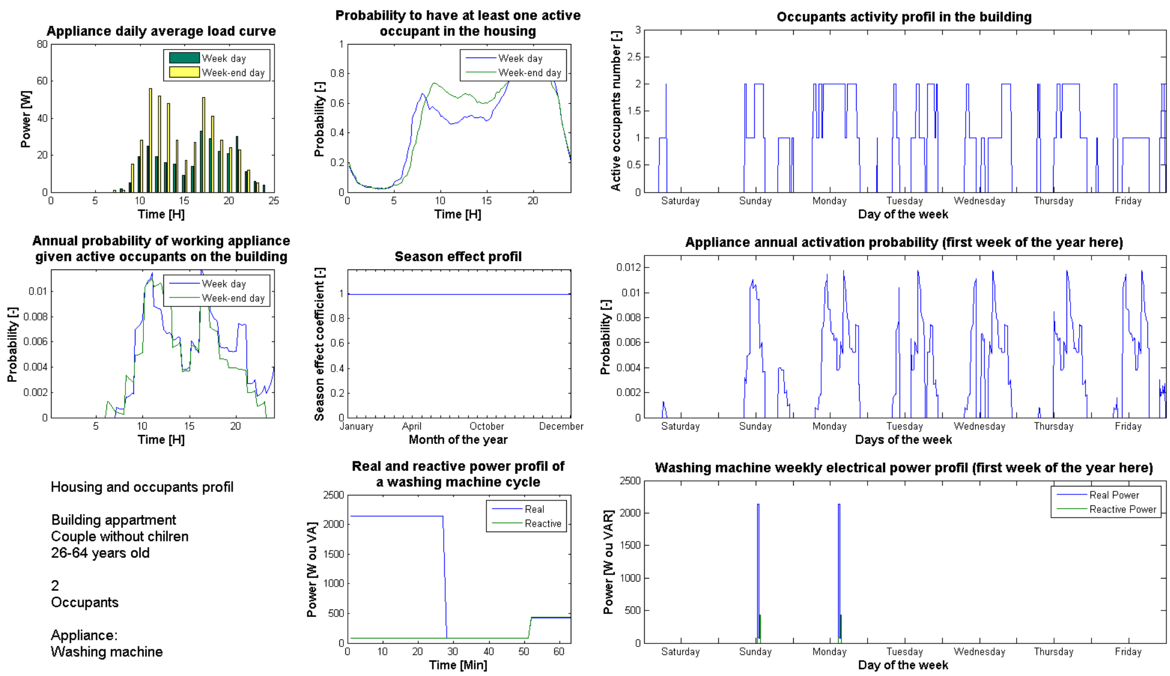

Figure 15: Intermediate stages of the construction of the other uses annual load curve (by appliance).

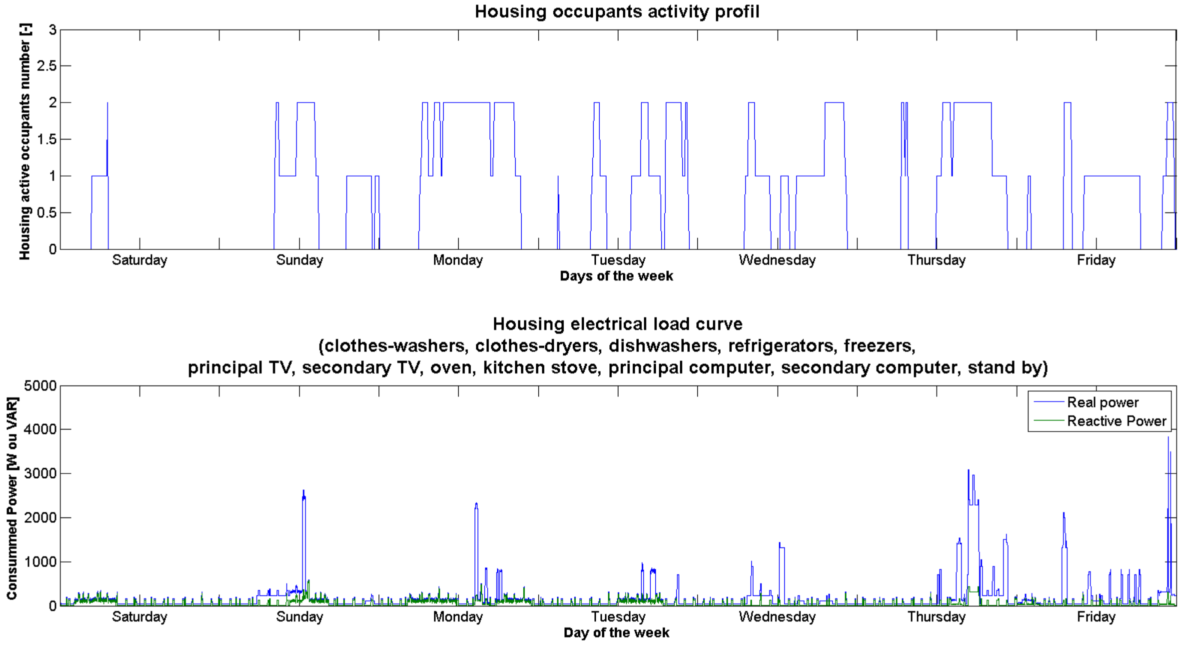

Figure 16: Example results for a given building (occupants' activity curve and load curve), represented for a week.

Conclusions

A general framework for a high resolution load curve simulation has been proposed.

Its generative data model, based on the statistical modelling of the district has been designed to overcome the lack of available data. This kind of approach, while much less data hungry than a comprehensive description of a district, might still be hindered by a lack of statistical data. Fortunately, probabilistic graphical network parameter represents actual probability. It is therefore always possible to incorporate expert knowledge in a given network in case of missing data. Once a population is sampled, it can readily be stored in the standard BIM format for interoperability purpose.

The behavioural part of the load curve model has been presented. The chosen model behaviour is based on stochastic modelling derived from Richardson work. Contrary to agent based methods, parameters can be set from actual experimental data and is much less computationally intensive. Though still a work in progress, a first example of simulation results has been shown.

Future work will emphasize on a finer grained activity model encompassing multiple states of activity. Validation based on the criteria listed in the introduction (statistical representatively, peak time statistics, etc.) will require further attention, especially in order to gather the relevant experimental data.

Acknowledgments

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References

1. Aigner, D.J., Sorooshian, C. & Kerwin, P., 1984. Conditional Demand Analysis for Estimating Residential End-Use Load Profiles. The Energy Journal, Volume 5(Number 3), pp.81–98. Available at: http://ideas.repec.org/a/aen/journl/1984v05-03-a06.html [Accessed August 21, 2013].

2. Bartels, R. et al., 1992. An end-use electricity load simulation model: Delmod. Utilities Policy, 2(1), pp.71–82. Available at: http://econpapers.repec.org/RePEc:eee:juipol:v:2:y:1992:i:1:p:71-82 [Accessed August 21, 2013].

3. Capasso, A. et al., 1994. A bottom-up approach to residential load modeling. IEEE Transactions on Power Systems, 9(2), pp.957–964. Available at: http://ieeexplore.ieee.org/articleDetails.jsp?arnumber=317650 [Accessed August 21, 2013].

4. Granjean, A., 2013. Introduction de non-linéarités et stationnarités dans les modèles de représentation de la demande électrique résidentielle. l'école nationale supérieure des mines de Paris.

5. Husaunndee, A. et al., 1997. SIMBAD: A simulation toolbox for the design and test of HVAC control systems. In Proceedings of the 5th IBPSA Conference. pp. 269–276. Available at: _http://www.ibpsa.org/\proceedings\BS1997\BS97_P022.pdf.

6. INSEE, 2013. Chiffres clés - logement. Available at: http://www.insee.fr/.

7. Ipsos-RSL and Office for National Statistics, 2000. United Kingdom Time Use Survey 3rd Editio., Colchester: Archive, Essex: UK Data.

8. Judkoff, R. & Neymark, J., 2006. Model validation and testing: the methodological foundation of ASHRAE standard 140. … -American Society of Heating Refrigerating and Air …. Available at: http://www.nrel.gov/docs/fy06osti/40360.pdf [Accessed August 20, 2013].

9. Kollar, D. & Friedman, N., 2009. Probabilistic graphical models: principles and techniques, The MIT Press.

10. Labeeuw, W. & Deconinck, G., 2013. Residential Electrical Load Model based on Mixture Model Clustering and Markov Models. IEEE Transactions on Industrial Electronics, PP(99), pp.:0–9. Available at: https://lirias.kuleuven.be/handle/123456789/375520 [Accessed August 21, 2013].

11. Ljung, L. & Söderström, T., 1983. Theory and Practice of Recursive Identification, Massachusetts and London: The MIT Press.

12. Richardson, I. et al., 2010. Domestic electricity use: A high-resolution energy demand model. Energy and Buildings, 42(10), pp.1878–1887. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0378778810001854 [Accessed August 7, 2013].

13. Richardson, I., Thomson, M. & Infield, D., 2008. A high-resolution domestic building occupancy model for energy demand simulations. Energy and Buildings, 40(8), pp.1560–1566. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0378778808000467 [Accessed October 30, 2012].

14. Rife, D. & Vanderkooy, J., 1989. Transfer-Function Measurement with Maximum-Length Sequences. journal of audio english society, 37(6), pp.419–444. Available at: http://www.aes.org/e-lib/browse.cfm?elib=6086 [Accessed January 2, 2013].

15. RTE, 2012. Consommation, production échnages commerciaux et contenu CO2 de l'électricité française. Available at: http://www.rte-france.com/uploads/media/pdf_zip/eco2mix/eCO2mix_RTE_Annuel-Definitif_2012.zip.

16. Walker, C.F. & Pokoski, J.L., 1985. residential load shape modelling based on customer behavior. Available at: http://www.lw20.com/201107163734781.html [Accessed August 21, 2013].

17. Widén, J., Nilsson, A.M. & Wäckelgård, E., 2009. A combined Markov-chain and bottom-up approach to modelling of domestic lighting demand. Energy and Buildings, 41(10), pp.1001–1012. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0378778809000978 [Accessed November 7, 2012].

2.3. Using a BIM flow for the design and operation of Building Energy Management Systems

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Abstract

This paper reports our experiences using the Building Information Modeling (BIM) approach within the FP7 project SEEDS (Self Learning Energy Efficient Buildings and open Spaces). SEEDS focuses on the development of an optimized Building Energy Management System (BEMS) that reduces the energy consumption and the CO2 emission of the building services during its operation phase based on self-learning techniques. One of the core components of the SEEDS architecture is the Building Model which calculates the energy consumption of the building at building operation time. In this paper, we introduce an approach for the automatic creation of this SEEDS' Building Model from an IFC data model. For an application case, the ability of IFC data models to describe building services is discussed. The introduced methodology was implemented for the energy management of an HVAC system using the CAD tool DDS-CAD 7.3.

1 Introduction

Buildings consume over 35% of energy in the EU. An optimized control of the installed building services using Building Energy Management Systems (BEMS) is a promising possibility to sustainably reduce their energy consumption. The aim within the SEEDS[4] FP7 project (Self Learning Energy Efficient Buildings and open Spaces) is to develop such a Building Energy Management System (BEMS) that reduces the energy consumption and the CO2 emission of the building services during the operation phase. A main part of the BEMS will be a Building Model, which includes the considered building services elements, especially the HVAC equipment and their energy consumption information. The Building

[4] http://www.seeds-fp7.eu

Model allows the calculation of the energy demands of the operating building services as part of the performance optimization techniques which are involved in the BEMS. For the development of the BEMS Building Model and the adaption of the BEMS to a specific building it is intended to use the methodology of Building Information Modeling (BIM).

This paper reports our experiences with the Building Information Modeling approach within SEEDS. The purpose of the work was to analyze the Industry Foundation Classes (IFC) data model in terms of its ability to describe building services and to setup a flow for automatic creation of SEEDS Building Model. In this paper, we introduce the energy management for a HVAC system of a helicopter garage as an application case. For this application case we describe all steps to create a running SEEDS Building Model from the IFC. These steps include an IDM (Information Delivery Manual) based requirement analysis. The outcomes of the IDM are used to define a specific view of the whole IFC schema and provide the basis for a validation of the IFC regarding its ability to represent the building services including their energy properties. The specific view is defined in an IFC Model View Definition (MVD). For the complete description of the building service system and its control we have derived IFC extensions which are currently not available in the IFC standard.

The proposed methodology was implemented for the energy management of an HVAC system using the CAD tool DDS-CAD 7.3.

The paper is organized as follows. After a short introduction, an overview on SEEDS is given. Section 3 introduces the development steps of the proposed BIM flow. In section 4, the results of the performed IDM requirement analysis are presented. Based on that, the specification of the MVD is shown in section 5. Subsequently, the enrichment of the IFC schema to fulfill unsatisfied exchange requirements is discussed in section 6. In section 7, the implemen-tation of the proposed BIM flow is presented for an application case. Finally, a conclusion is given in section 8.

2 Overview on SEEDS

The objective of SEEDS is the optimization of the energy behavior of the operating building services – especially the Heating, Ventilation, and Air Conditioning (HVAC) equipment, which is by far the largest energy consumer in buildings – using an innovative model predictive control strategy based on measurements and self-learning techniques.

The SEEDS BEMS architecture is divided into three layers: the controller layer, the data management layer, and the process interface layer (Figure 1). Each layer consists of one or several main components. The controller layer comprises the *Building Model Evaluator (*composed by the components *Building Model* and *Energy Calculator*), *Building Model*

Library, *Optimizing,* and *Self-learning*. The component *Archiving* stores and manages the historical and runtime data and is located in the data management layer. The process interface layer includes the *WISAN* (Wireless Intelligent Sensors and Actuators Network) communication server and the *Graphical User Interface* [1].

This paper focused on one of the core components in SEEDS: the *Building Model Evaluator* which includes the *Building Model (BM)* and the *Energy Calculator*. The *BM* describes the building services structure including their energy behavior of a residential or commercial building. It facilitates the calculation of the energy consumption of the installed equipment during its operation.

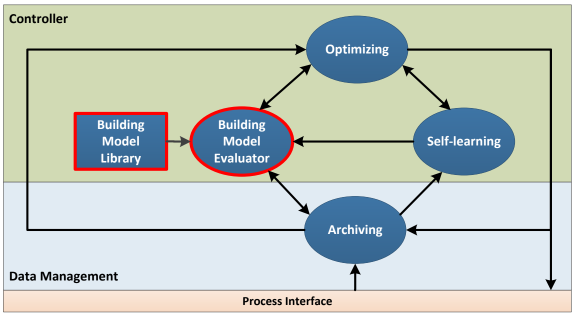

Figure 17: Simplified SEEDS BEMS architecture.

In the paper, we focus on HVAC components. It is created from instances of the *Building Model Library* (*BM Library*) which provides a portfolio of building services components. The structure of the *BM Library* will be discussed in section 6.

Helicopter garage - HVAC system

The first developments of SEEDS have been validated in a test bench which is a Helicopter Garage (located in Barajas airport in Madrid). The Helicopter Garage includes two building storeys and several office rooms. For the air conditioning of individual rooms an HVAC system is operating in cooling mode (because the validation was applied in summer time). The HVAC system consists of four sub-systems: the Thermal Energy Distribution System, the Heat and Cool Thermal Energy Plant, the Cool Thermal Energy Plant, and the Heat Thermal Energy Plant. Specifically, the HVAC system contains the following components: 12 fan Coils, chiller, heat pump, boiler, 3 pumps, and 3 water storage tanks.

SEEDS plays special emphasis to HVAC systems. References [2] and [3] provide some information on the energy modeling applied in SEEDS. A *Device Model Table* was included in Annexes C and D of [2]. For each device, its model table includes a schematic representation and a functional description together with the mathematical relationships among comfort, health, safety, and energy consumption. This information allows to model/determine, the energy behavior of each HVAC device. Furthermore, the operating limits and the local control system are also included in this document.

3 Development methodology

In order to implement a successful BIM based workflow [4] for the design and the operation of the SEEDS BEMS several steps are necessary. Basically, the required data exchange among the BIM and the entire BEMS or the individual component respectively must be determined. Table 1 gives an overview on the required BIM data of each BEMS component.

SEEDS BEMS Components	Required BIM data
Building Model Evaluator (*Energy Calculator*, *Building Model*) *Building Model Library*	Building Services Equipment ▪ HVAC equipment (Device Model Tables) – Energy properties (e.g. calculation specification, load table) – Physical and logical connection – Local control system – Operation limits ▪ BA equipment Interface definition ▪ Comfort and environment variables (and value ranges) ▪ Comfort settings ▪ Sensor data, data types, measuring units
Optimizing	Comfort settings Control settings
Self-Learning	Control settings Environment variables
Archiving	Sensor and actuator data, data types, measuring units
Process Interface (*WISAN*, *GUI*)	Sensor and actuator data, data types, measuring units

Table 1: Required BIM data exchange

To interface the SEEDS BEMS into a BIM process a comprehensive requirement analysis and interface specification have to be performed for each BEMS component. Therefore, in the following only the design and operation of the BEMS-EC which comprises the *Building Model Evaluator* and the *Building Model Library* is considered. Figure 2 illustrates the BIM based workflow for this desired use case.

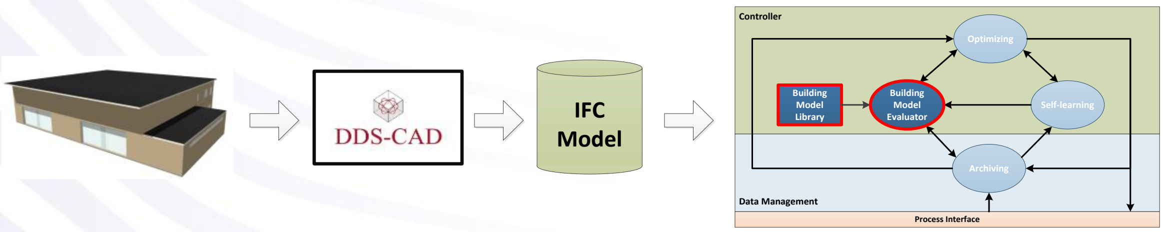

Figure 18: BIM based workflow.

For the purpose of this paper the following tasks are performed:

(1) Identification of the data that must be exchanged within a BIM process: By means of a requirement analysis according to the Information Delivery Manual (IDM), the Exchange Requirements (ER) are identified and specified. The ER describes the information that has to be exchanged in a model independent way. The ERs are the basis for integration of the BEMS-ER into a BIM process and therefore they are important for the specification of the IFC interface.

(2) Specification of the IFC interface of the BEMS-EC: The next step is the mapping of the model independent requirements to the Industry Foundation Classes (IFC), an Open BIM data exchange format. The mapping is defined in an IFC Model View Definition (MVD). A MVD basically represents a subset of the whole IFC schema specification. Furthermore, with the definition of the MVD the IFC schema is validated regarding its ability to represent the Helicopter Garage example including its HVAC equipment and its energy properties.

(3) Enriching the IFC data schema: In case the IFC cannot fulfill all the required data exchange, it is necessary to enrich the IFC schema. However, there are several options to extend the IFC, e.g. external or internal enrichment. The extensions that have to be done are added to the specified MVD afterwards.

(4) Design and implementation of the BEMS-EC: To estimate the energy behavior for the operating reference example the components *BM* and *BM Library* as well as the IFC interface are implemented. Thereby, the IFC interface implementation bases on the specified MVD. Furthermore, the instantiation of IFC data model of the helicopter garage is done. For this purpose, DDS-CAD 7.3 [5] is used.

Sections 4-7 below explain details on the implementation of the four tasks above into the SEEDS Project and its validation in the Helicopter Garage test bench.

4 IDM requirements analysis

As mentioned above, the first step of BIM based workflow is the determination of the information that must be exchanged within a specific business process. Therefore, a requirement analysis according to the Information Delivery Manual (IDM) [6] was performed for the business process “BEMS Engineering”. In the paper it was assumed the business process describes the interfacing of the already developed BEMS-EC into a BIM process. The basis for this IDM requirement analysis were the outcomes of the IDM in [7] and [8]. In [7], the IDM was performed for the more general business process of interfacing the whole SEEDS BEMS into the building life cycle. In this case, the business process “BEMS Engineering” was divided into the four sub-processes: i) *BEMS Planning and Design,* ii) *BEMS Commissioning, iii) BEMS Operating,* and *iv) BEMS Retrofitting.*

For each of those sub-processes, a process map[5] was developed. The process maps assisted to identify the actors which are involved in the process, the activities of the actors, the dependencies of activities, and the exchange requirements among the actors. The specifications of the exchange requirements in [9] describe the information that have to be exchanged to interface the SEEDS BEMS into a BIM process in a non-technical form. For the developments shown on this paper, the process maps were summarized and the specifications of identified exchange requirements were reworked.

The main outcomes were the Exchange Requirements from BIM to BEMS (ER *BIM2BEMS*) and from BEMS to BIM (ER *BEMS2BIM*). The ER *BIM2BEMS* specifies the information that has to be exchanged to generate the BEMS-EC automatically during the planning and design phase. The required data exchange while operating the BEMS-EC is described in the ER *BEMS2BIM*. The ER *BIM2BEMS* is structured as follows (for details see [9]):

- Project Information
  - Project Attributes
  - Unit Assignment
  - Project Decomposition
- Building Structure
  - Site, Building, Building Storey, Space
  - Spatial Decomposition
  - Spatial Containment
- Building Services Equipment
  - HVAC Equipment (including energy properties)
  - BA Equipment
- Building Services System
  - HVAC System, BAS
  - Component System Assignment
  - Service Spatial Element

5 Specification of the IFC interface

On the basis of the outcomes of the IDM requirement analysis, the specification of the IFC interface is done by mapping the identified exchange requirement to the corresponding IFC schema representation. The following section gives an overview of the development of the Model View Definition *BIM2BEMS* (MVD *BIM2BEMS*) which is based on the mentioned ER *BIM2BEMS* and the specified MVD in [10].

[5] For developing the process maps the Business Process Modeling Notation (BPMN) was used. The BPMN is provided by the Object Management Group (OMG) and offers a widely used standard for specification of business processes.

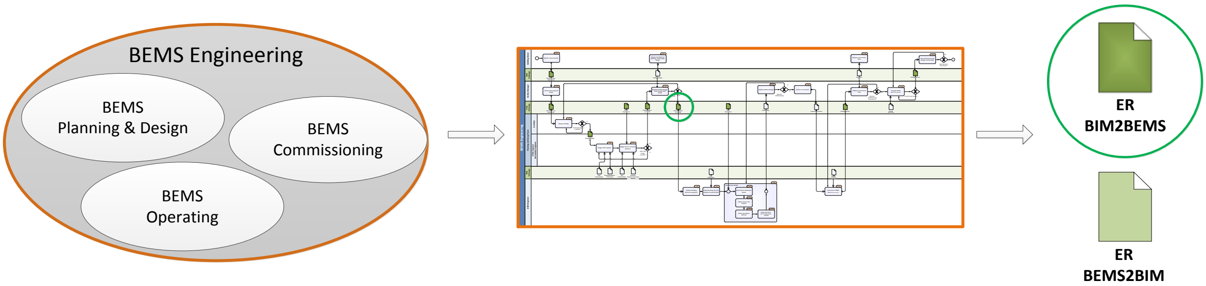

Figure 19: IDM workflow.

In general, a MVD represents a specific view of the comprehensive IFC schema specification. In the context of this paper, the IFC Model View Definition format [11] is utilized. The main idea of developing a MVD is to reuse standardized Concepts and their generic relationships. Whereby, each Concept represents a subset of the whole IFC schema and is defined in a Concept Definition. The generic relationships among different Concepts are specified in the Binding Concept Model. Figure 4 shows the Overview Page of the Binding Concept Model of the MVD *BIM2BEMS*. It demonstrates the correspondence between the MVD *BIM2BEMS* and the ER *BIM2BEMS*.

The Concepts in Figure 4 are composed of other Concepts. For instance, the Concept *Fan-Coil* consists of several Concepts which fulfill the exchange requirements regarding a fan coil within the MVD *BIM2BEMS.* This includes, the:

- General identification of the fan coil
- Assignment of specific product data using type and property set definition
- Representation of physical and logical connections using ports
- Assignment of the local control equipment
- Realization of the decomposition of the fan coils
- Relation to the HVAC system level and the basic building structure.

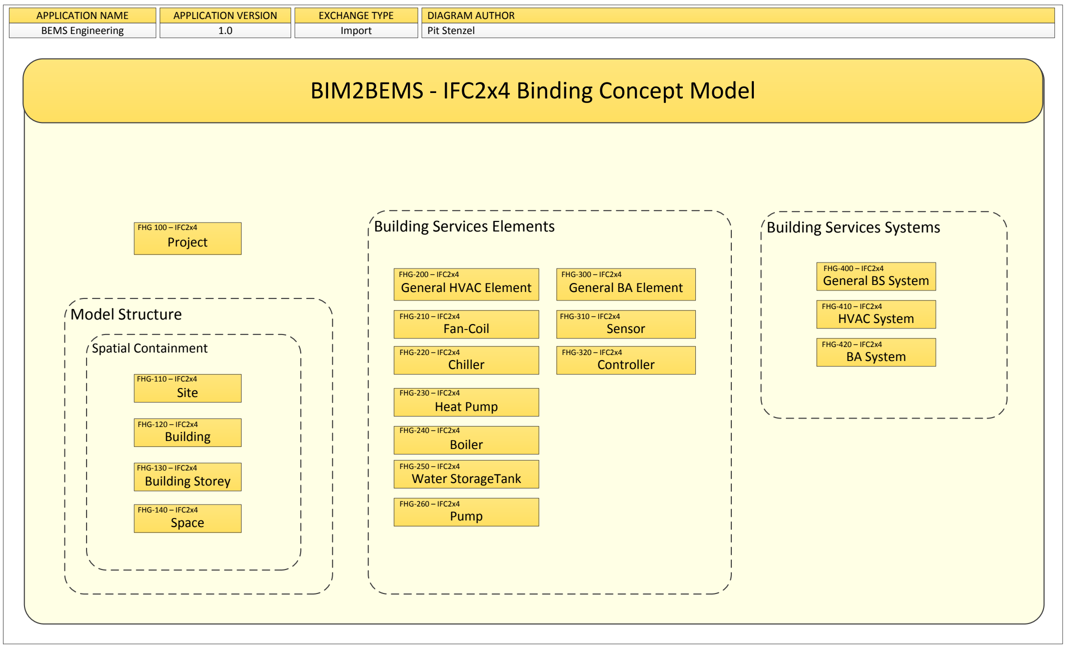

Figure 20: MVD BIM2BEMS - Binding Concept Model.

The general identification of the fan coil is done by the IFC object occurrence *IfcUnitaryEquipment* and the corresponding IFC object type *IfcUnitaryEquipment*. A further refinement of the fan coil is done by the direct attribute *PredefinedType*, which is set to AIRHANDLER. An overview of the specified IFC representation of the remaining HVAC equipment of the reference example is given in Table 2 and Table 3.

Besides the pure representation of the fan coil, the MVD specifies some relationships. For instance, the assignment of the IFC object type (*IfcUnitaryEquipmentType*) is made by means of the relationship object *IfcRelDefinesByType*. The IFC schema specification provides a range of predefined property sets which can be assigned either to *IfcUnitaryEquipment* using the relation *IfcRelDefinesByProperties* or to the direct attribute *HasPropertySets* of *IfcUnitaryEquipmentType* [7, 12].

BS Equipment Helicopter Garage	IFC object (occurrence)	IFC type	PredefinedType
HVAC components			
Fan coil 1-12	IfcUnitaryEquipment	IfcUnitaryEquipmentType	AIRHANDLER
Pumps	IfcPump	IfcPumpType	CIRCULATOR
Heat pump	IfcHeatPump	IfcHeatPumpType	AIRCOOLED
Water storage tanks	IfcTank	IfcTankType	STORAGE
Chiller	IfcChiller	IfcChillerType	AIRCOOLED
Boiler	IfcBoiler	IfcBoilerType	STEAM
BA components			
Two-point controller	IfcController	IfcControllerType	TWOPOSITION
Temperature sensor	IfcSensor	IfcSensorType	TEMPERATURESENSOR
Humidity sensor	IfcSensor	IfcSensorType	HUMIDITYSENSOR
Mass flow sensor	IfcSensor	IfcSensorType	FLOWSENSOR

Table 2: IFC representation component level.

HVAC systems Helicopter Garage	IFC object (occurrence)	PredefinedType
Air Conditioning System	IfcDistributionSystem	AIRCONDITIONING
Thermal Energy Distribution System	IfcDistributionSystem	AIRCONDITIONING
Heat and Cool Thermal Energy Plant	IfcDistributionSystem	-
Cool Thermal Energy Plant	IfcDistributionSystem	COOLING
Heat Thermal Energy Plant	IfcDistributionSystem	-

Table 3: IFC representation system Level.

However, in the context of the paper it is not possible to introduce the whole content of the MVD *BIM2BEMS*. The remarks regarding the MVD specification are intended to present only the idea. Further details are descripted in [9].

6 Enriching of the IFC data schema

During the development of the MVD *BIM2BEMS* it was found that the IFC schema [12] does not meet all requirements of the ER *BIM2BEMS*. These include the description and the identification of the heat pump (which is one of the HVAC components) as well as the representation of the specific energy behavior of all HVAC equipment. Because the latter plays a significant role regarding to the energy calculation, the IFC data had to be enlarged.

Pset_FanCoilEnergyProperties	(Type and Occurrence driven)	
Property Name	**IFC Object**	**IFC Data Type**
CalcModeThermalPower	IfcPropertySingleValue	IfcInteger
CalcModeElectricalPower	IfcPropertySingleValue	IfcInteger
CalcSpecThermalPower_Air	IfcPropertySingleValue	IfcText
CalcSpecThermalPower_Water	IfcPropertySingleValue	IfcText
ElectricalPowerMassflowTable	IfcPropertyReferenceValue	IfcExternalReference
ThermalCoolingPowerTable	IfcPropertyReferenceValue	IfcExternalReference
ThermalHeatingPowerTable	IfcPropertyReferenceValue	IfcExternalReference
FixedElectricalPowerValue	IfcPropertySingleValue	IfcPowerMeasure
ControlMode	IfcPropertyEnumeratedValue	IfcLabel
CommandVariable	IfcPropertyEnumeratedValue	IfcLabel

Table 4: Property Set Definition - Pset_FanCoilEnergyProperties.

There are several options to extend the IFC schema. Basically there are two possibilities, the internal and the external extension [9]. To overcome the mentioned issues both options were used. In order to represent the heat pump, the entities *IfcHeatPump* and *IfcHeatPumpType* were defined in the HVAC domain of the IFC schema. These entities are defined as specializations of the entity *IfcEnergyConversionDevice* and *IfcEnergyConversion-DeviceType* respectively and inherit the corresponding attributes [9].
To represent the energy behavior of the HVAC equipment for each component, a user defined property set was specified. Table 4 shows the property set definition for a fan coil. Besides the specific energy properties which are represented as single values or external references, it includes configuration data, e.g. control mode or command variable. Furthermore, the property set facilitates the choice of the calculation mode of the energy consumption.

7 Design and implementation of the BEMS-EC

The following section describes the design and the concrete implementation of the BEMS-EC. The structure of the *BM Library* and the architecture of the whole BEMS-EC are introduced.

The *BM Library* consists of three main sections *Flow Component*, *Control Component,* and *Spatial Structure Element*. The section *Flow Component* provides the components of the

HVAC equipment, such as chiller, heat pump, and fan coil. The components of the Building Automation System (BAS), e.g. controller and sensors, are provided in the section *Control Component*. The section *Spatial Structure Element* facilitates to represent basic spatial structure of the building within the *BM*.

The target of the design of the *BM Library* was to develop a generic data structure to help modeling a fundamental building structure and the building services equipment. For this purpose, the Industry Foundation Classes (IFC) [12] was the basis for the design of the *BM Library*. In particular the schemes *IfcSharedBldgServiceElements*, *IfcHVACDomain,* and *IfcBuildingControlsDomain* served as an orientation for the hierarchy of the building services components. As reference for the section *Spatial Structure Element,* the IFC entity *IfcSpatialStructureElement* and their specializations were used.
In terms of the energy calculation of the operating building services the components of the HVAC equipment are most important. Besides the simple HVAC components and their inheritance hierarchy the *BM Library* facilitates the representation of relationships. The class structure in Figure 5 clarifies these relationships. A detailed description of *the BM Library* structure is given in [9].

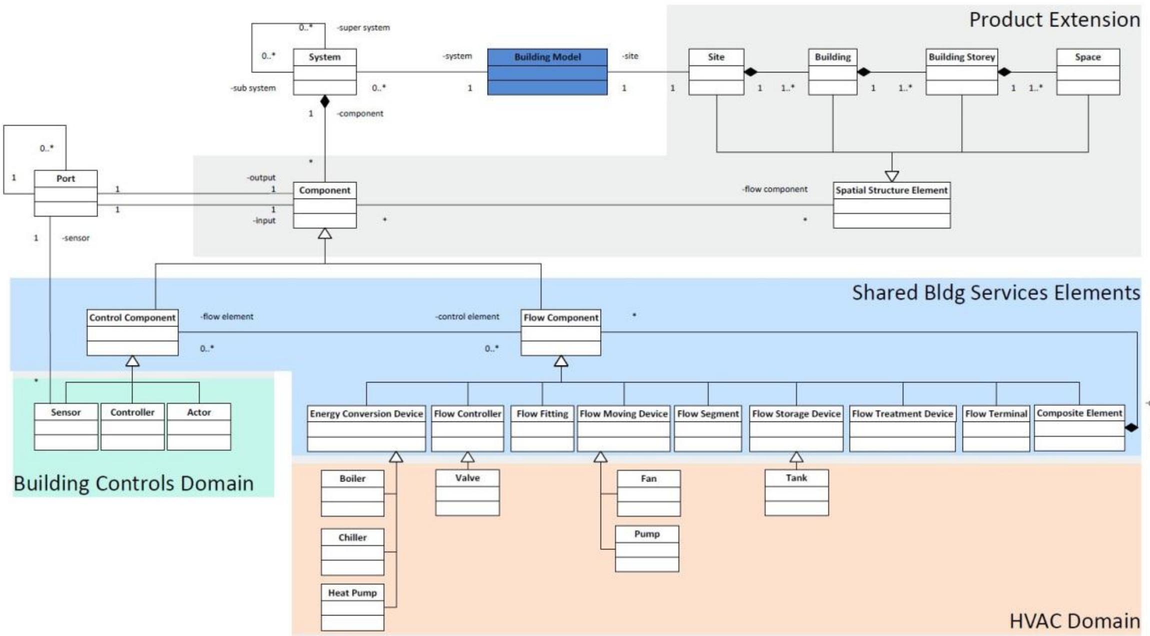

Figure 21: Class structure according to IFC structure.

Architecture of the BEMS-EC

Besides the components *BM Library* and *Building Model Evaluator* of the SEEDS BEMS architecture (Figure 1), the architecture of the BEMS-EC comprises further components to implement the BIM based workflow. Figure 6 illustrates all involved components of the BEMS-EC.

The components *IFC Parser* and *Inter Container* represent the IFC interface and facilitate the reading of an IFC data model in STEP Physical File format (SPF) [14]. Both components are implemented based on MVD *BIM2BEMS*.
The *Inter Container* is an internal data structure. This data structure is nearly equivalent to the subset of the IFC schema which was defined in the MVD *BIM2BEMS*. On the basis of the *Inter Container* the *Model Builder* creates the executable *BM*. For this, the *Model Builder* uses the *BM Library*, which provides a set of building services components and spatial building elements including their relationships and creates the corresponding instances. Among others, the *Model Builder* gets external references to the specific datasheets of the HVAC equipment. These are used for the final configuration of the HVAC components for the energy calculation. Finally, the *Energy Calculator* component is created. This part of the *Building Model Evaluator* calculates the energy consumption of each HVAC component for a given time period. Furthermore, the *Energy Calculator* is able to estimate the energy consumption of the HVAC equipment on system level as well as for partial building structures.

Ultimately the internal architecture of BEMS-EC is hidden and its functionality is provided by executing a DLL (Dynamic Link Library) using the corresponding parameters.

IFC instantiation of the helicopter garage example

In order to generate the BEMS-EC, an IFC model of the Helicopter Garage including the HVAC equipment is needed. Therefore, the necessary instantiation of the IFC data model is done using the already mentioned BIM tool DDS-CAD 7.3 [5]. This step within the proposed BIM workflow is equivalent to the planning and design phase of the building and the building services.
The implementation of the Helicopter Garage using DDS-CAD 7.3 was not easy. Some difficulties have to be overcome.

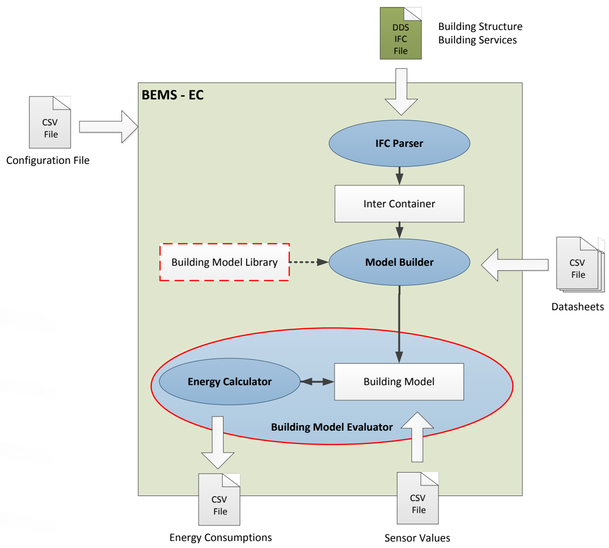

Figure 22: BEMS-EC architecture.

Firstly, the strict separation of the trades caused problems. For instance, the fan coils had to be modeled using two DDS devices, because a fan coil can be assigned to the plumping domain as well as to the air conditioning domain. Furthermore, the limited expandable product database was difficult to handle. Nevertheless, it was possible to model and instantiate the Helicopter Garage example by means of DDS CAD 7.3. The following figures show the results of the architectural design and the planning of the air conditioning system.

As well of the above design difficulties, other problems arose regarding the implementation of the purposed BIM based workflow. The DDS IFC export did not satisfy the exchange requirements. This was found in a comparison of the DDS IFC model and a resumed IFC model. The resumed IFC model was instantiated using the MVD *BIM2BEMS*. In order to use the DDS IFC model for the generation of the BEMS-EC, it has to be reworked manually. Some of the modifications performed are listed below:

- Achieving an unique representation of the HVAC as well as BA components
- Adding the user defined property sets including the energy properties to HVAC components
- Adding representations of the air conditioning system at system level
- Adding relationships of the HVAC components to the air conditioning system and the spatial structure.

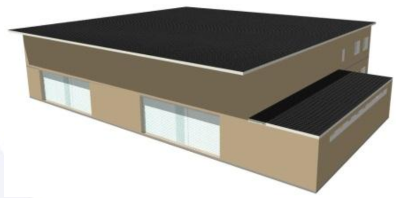

Figure 23: Building structure.

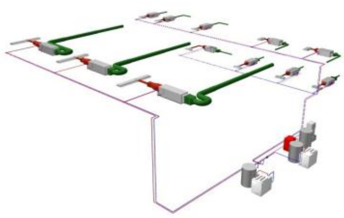

Figure 24: Air conditioning system.

Operating the BEMS-EC for the Helicopter Garage example

The inputs (DDS IFC model and sensor values) and the outputs (energy consumptions) as well as the values of the operating parameters (simulation time and sampling time) required to operate the BEMS-EC are provided using a configuration file such as the one shown in Table 4. The sensor values were generated by means of a corresponding Modelica model of the Helicopter Garage [15], because there was no real sensor data available.

The results of the energy consumptions were validated. It was, therefore, proved the performance of the BEMS-EC for several HVAC components.

BEMS Config-File	
Input	
DDS IFC-Modell	HelicopterGarage.ifc
Sensor Values	SensorValues.csv
Output	
Energy Consumption	EnergyConsumption.csv
Operating Parameter	
Simulation Time	259200 sec
Sampling Time	120 sec

Table 5: BEMS-EC Configuration file

8 Conclusions

This paper presents the main steps for the development of the BEMS Energy Calculator (called BEMS-EC throughout the paper) which comprises the core components *Building Model Evaluator* and *Building Model Library* of the BEMS developed by the on-going FP7 project SEEDS. The proposed BEMS-EC was developed using a BIM based workflow for the design and the operating phase. In order to interface the BEMS-EC into a BIM process, an IDM requirement analysis for the business process "BEMS Engineering" was performed. The main outcome of the IDM was the ER *BIM2BEMS*. Subsequently, the MVD *BIM2BEMS* was specified on the basis of the ER *BIM2BEMS*. It was noted that the IFC schema specification (IFC2x4) could not fulfil all requirements. As a consequence, the IFC schema had to be extended. Furthermore, the concrete design and implementation of the BEMS-EC was presented. The structure of the *BM Library* and the final architecture of the implementation were presented in detail.
The feasibility of the developed workflow was demonstrated into a test bench based on the Helicopter Garage example. The application of the IFC model to this example was instantiated using DDS-CAD 7.3. Because the DDS IFC export did not meet all the requirements of the BEMS-EC, the exported IFC model had to be reworked manually. Finally, the calculation results were validated and the ability of the BIM based workflow for the design and the operation of the BEMS-EC was demonstrated.

Within the paper we discussed the BIM based workflow only for the BEMS-EC. In a further works it has to be performed the same development methodology for the remaining components (see Table 1) to interface the entire SEEDS BEMS into a BIM process and to facilitate a continuous data exchange in design as well as operation. Furthermore, the representation of a BEMS within a BIM should be addressed. It has to be investigated whether the BEMS is represented as a kind of "Black Box" and only the external interface is defined or the BIM comprises the whole description of the BEMS architecture.

Further works regarding the proposed BIM based workflow are:

- Perform the proposed BIM flow for the other SEEDS BEMS components

- Rework of the IDM and MVD
- Defining the MVD *BIM2BEMS* using the mvdXML format [16]

- Investigate the representation of a BEMS within a BIM
  - Component based representation
  - Representation using "Black Box" approach

Acknowledgments

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References

1. N. Jimenez Redondo, et al.. *A Building Energy Management System based on Measurements, Self-learning and optimization techniques and Wireless technologies. Preliminary results of the SEEDS project.* ICT4SP Conference, Nice , 2013.
2. A. Barragan, et al.. *Development of a methodology for the modeling of BEMS for a wide spectrum of construction types.* SEEDS D1.1 Report, 2012. www.seeds-fp7.eu
3. A. Barragan, et al.. *Relevant energy affecting operating parameters for the systems and subsystems.* SEEDS D2.1 Report, 2012. www.seeds-fp7.eu
4. C. Eastman, et al.. *BIM handbook : a guide to building information modeling for owners, managers, designers, engineers, and contractors*. Inc. John Wiley & Sons, Ed. Hoboken, New Jersey, USA, 2008.
5. Data Design System. *Building Information Modelling (Open BIM) Solutions*. Online: http://www.dds-cad.net/index.php (last visited on 14.12.2012).
6. J. Wix and J. Karlshøj (2007). *Information Delivery Manual: Guide to Components and Development Methods*. Online: http://iug.buildingsmart.com/idms/methods-and-guides/IDMC_004_1_2.pdf (last visited on 25.10.2012).
7. P. Stenzel. *Analyse und Bewertung des IFC-Projektmodells im Bereich der technischen Gebäudeausrüstung als Grundlage für die Ableitung von Automatisierungsstrukturen in der Gebäudeklimatisierung.* Study Thesis, Enclosure Diploma Thesis, Dresden University of Technology, 2012.
8. B. Bort, et al. (2011). *HESMOS Deliverable D1.1: Gap Analysis, Use Case Scenarios and Requirements Specification*. © HESMOS Consortium, Brussels.
9. P. Stenzel. *Validierung und Anwendung des IFC-Schemas für eine raumlufttechnische Anlage zur Generierung einer Energiebedarfsberechnung im Rahmen der Open-BIM-Initiative.* Diploma Thesis, Dresden University of Technology, 2013.
10. T. Liebich and M. Weise (2009). *Model View Definition - Basic Handover to Facility Management*. Online: http://www.blis-project.org/IAI-MVD/MVDs/GSC-

001/IFC2x3.pdf. (last visited on 08.10.2012).

11. J. HIETANEN (2006). *IFC Model View Definition Format.* http://buildingsmart-singapore.webzfusion.net/news/ news-docs /IFC_MVD_Format.pdf. (last visited on 10.12.2012).

12. BUILDINGSMART INTERNATIONAL, MODEL SUPPORT GROUP (2011). *IFC Schema Spezifikation IFC2x4*. Online: http://www.buildingsmart-tech.org/ifc/IFC2x4/rc2/html/ index.htm. (last visited on 13.12.2012).

13. T. LIEBICH, et al. (2011). *HESMOS Deliverable D2.1: BIM Enhancement Specification*. © HESMOS Consortium, Brussels.

14. ISO10303-21. *Industrial automation systems and integration -- Product data representation and exchange -- Part 21: Implementation methods: Clear text encoding of the exchange structure,* International Organization for Standardization, 1994.

15. S. TUCH. *Modelbasierte Minimierung des Energieverbrauchs einer raumlufttechnischen Anlage*. Diploma Thesis, Hochschule für Technik und Wirtschaft Dresden, 2012.

16. T. CHIPMAN, et al. (2012). *mvdXML - Specification of a standardized format to define and exchange Model View Definitions with Exchange Requirements and Validation Rules*. http://www.buildingsmart-tech.org/downloads /accompanying-documents/formats/mvdxml-documentation/mvdXML_V1-0.pdf
(last visited on 15.11.2012).

3. Session: Smart Appliances

3.1. Towards standardization of M2M communication in Smart Appliances

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Abstract

Smart appliances are appliances that are networked with their ambient and use information from the home environment to autonomously make decisions, e.g. to switch a service off to save energy. While communication at physical layer is supported by a variety of standards (e.g. X10, ZigBee, KNX, Z-Wave, WLAN, LON), communication at the semantic layer lacks agreed and applicable standards. This has become a major showstopper for the market success of smart appliances.

This paper gives an overview of the outcomes of the discussions developed during the 3rd VoCamp on "Energy Using and Producing Products Management", introducing objectives, requirements, and existing standardization efforts. Particular focus is put on joining the different views by which the semantics of M2M communication can be organized, device-centric or service based, typically. The firs approach describes the composition of appliances and their integration within the home ecosystem; the second, instead, represents appliances as set of services contributing to different home tasks, e.g., energy management.

1. Introduction

In this paper we give an overview of the topics discussed during the 3rd VoCamp on "Energy using and producing Products (EupP) Management". We first introduce the general definitions and describe potential scenarios. In section 2, we give requirements for M2M communication. In section 3, we give an overview of standardization efforts, and in section 4 we describe a new approach for organizing ontologies for M2M communication as discussed during the 3rd VoCamp [1]. In section 5 we discuss the outcomes related to standardization efforts.

Smart Grids and Smart Appliances

The increasing share of renewable energies has caused increasing needs to re-structure the power distribution grid. Currently, the power distribution grid is organized and controlled in a centralized way. However, increasing feed-in from distributed, small-scale renewables such as photovoltaic or wind turbines requires a more distributed control of feed-in and maybe even of consumption. To achieve Europe's ambitious 20-20-20 targets, consumption of appliances in households and commercial buildings has to be considered as reflected by several research efforts trying to tackle this challenge (e.g., as in [2], [6], [8], [9]). Objectives of *energy management* in appliances (more: [5]) is

1. To contribute to stability of the local and global power distribution grid.
2. To enable integration of renewables in the distribution grid with existing infrastructure.
3. To reduce power consumption and increase efficiency by switching low-priority and/or not-needed services (e.g. light in unoccupied rooms, HVAC when home inhabitants are on vacation, etc.) off, or reducing them to a level that is appropriate for a recognized scenario.

In such scenarios, appliances are assumed to become more and more "smart". A *smart appliance* is an appliance that plays an active role in energy management. Based on awareness of a situation, it may autonomously take decisions and act consequently.

In particular, autonomy is a very important property of smart appliances: the appliance is expected to act without requiring a user's knowledge, decision, or presence. Users can always takes the ultimate decision – if they want, however, it is expected that home inhabitants will seldom consider to take all decisions regarding energy management, either because a they do not have the needed know-how, or because they do not want o to be bothered about every single, tiny, aspect of real-time energy management, whereas they might want to focus on high-level, general objectives.

Autonomous operation of smart appliances is of key importance for information hiding. Information hiding reduces the complexity and the information distributed to the outside of appliances. The reduction of information offered to the outside world is important for manufacturers, because they often don't want others to interfere with validated and maybe confidential processes in appliances. It is also desirable from the point of view of privacy to limit distribution of information that is not required to fulfill the purpose of energy management. However, the desirable co-existence with other use cases like ambient-assisted living or multimedia makes the distinction between useful and not-required information difficult.

Smart appliances in future homes

As emerging from current standardization efforts (see [3], [4], [5] for an overview), future homes will see smart appliances coexisting with other home subsystems providing the following functionalities, either integrated in one box or distributed among the home area network:

- *Gateway*; provides communication capability between the outside world, in particular internet, and the inside world, and also between the appliances (especially if appliances use different communication standards at the physical layer).
- *Smart meter;* supports power and consumption exchange between the power distribution grid, the home-grid, and provide relative information to both the grid and the home IT.
- *Energy management*; aggregates data from appliances in a home and manages or co-ordinates use of energy

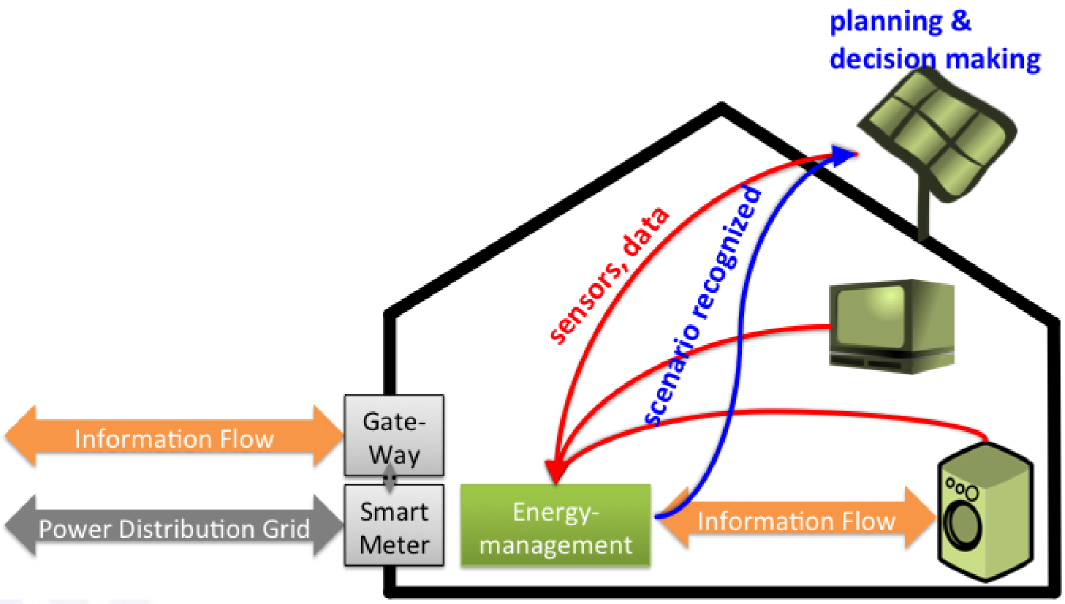

Figure 1: Future home (logic architecture): de-centralized, distributed approach of decision making.

Figure 1 shows a scenario in which (smart) appliances are networked with the energy management (service, e.g., running on the home gateway). A gateway handles the (physical) communication between appliances, energy management, smart meter, and the outside world, and coordinates the information flow between the home devices, be they " dumb", e.g., traditional appliances, or "smart", i.e., capable of taking autonomous decisions. Smart appliances autonomously plan their own use of energy, based on scenarios communicated to them by the energy management, which in turns interacts with the grid operator via the smart meter.

Abstracting from the example shown by Figure 1, we distinguish 2 different approaches to energy management: centralized and distributed energy management, with different requirements; combinations are clearly possible:

Centralized control: The typical building automation and control and related standards for communication focus on rather centralized control: appliances announce availability of sensors, actuators, data, etc. Based on values measured by sensors, centralized control methods determine settings for actuators that are then sent back to the appliances.

The centralized approach is typical, and well-suited, for building automation processes such as HVAC where many simple sensors (e.g. temperature, humidity) need to combined to get optimal control settings (e.g. for heating).

However, the centralized approach does not offer any information hiding: all information is transported to the "central management" that has appropriate knowledge in terms of software, and context, to control the overall system. For "smart appliances" such a centralized control is not generally applicable for the following reasons:

- *Information hiding:* most appliance manufacturers won't disclose processes, sensor data, actuators, etc. to users and 3rd party software to control and modify washing processes.
- *Reduced dependability:* in distributed systems, dependability of communication is a major issue. This is in particular the case for wireless (e.g., ZigBee, Z-Wave, WLAN) or power line communication (e.g., X10, see next section). If communication fails in a centralized control scenario, an appliance could not operate in the best case; in the worst case there might even be safety issues.

De-centralized (distributed) control: De-centralized control is well-suited for "smart" appliances. In contrast to the centralized control scenario, the energy management service (see Figure1) only provides information about specific or general objectives. Examples for such objectives can be

- Reduce peak load below threshold, or
- Shift demand by some time.

In the de-centralized scenario, smart appliances take the decisions, in autonomy, using (or not) the above information. However, a minimum of "centralized" control is required: this can be a controller that observes voltages and limits in the local distribution grid or a controller operated by the grid operator that does planning of demand and consumption of energy. While the de-centralized approach seems to solve the problems with information hiding and dependability, there are open issues:

- How can the global „controller" ensure stability and Quality of Services?
- How can additional services be realized if the

Arguably, the global controller needs not to be at home. However, having aggregators at home is mandatory for information hiding and aggregation of data, increasing both privacy and dependability.

2. Objectives of and Requirements for Standardization

Objectives of standardization: Currently, there is a clear need for smart appliances and energy management. Also, energy management by smart appliances is technically feasible and proven by a variety of research projects and case studies. Unfortunately, at the current situation there is a variety of physical communication channels (WLAN, ZigBee, KNX, Z-Wave, PLC, X10, etc.), but a lack of agreed standards at semantic layer.

The objective of standardization is to

1. Pave the path for the upcoming smart appliances and for energy management in Europe and the world, to reach Europe's 20-20-20 target,
2. Enable Cross-Manufacturer interoperability between smart appliances,
3. Limit the risk of manufacturers when developing smart appliances, and to ease the market entry at reasonable additional cost per appliance,
4. Consider privacy concerns of consumers.
5. Be compatible with existing standardization efforts, to avoid falling in the "Yet Another Standardization" trap, and to exploit validated solutions and approaches, e.g., ZigBee profiles, which are likely to be widespread in the future appliances market.

Requirements of standard: In the 3rd VoCamp, the main requirements of standards for M2M communication have been summarized starting from current standardization efforts ([3], [4], [5]) and from the current state of the art ([2],[8],[9] are just a little sample of the extensive research efforts carried in this field). These requirements cover a wide set of different, and possibly contrasting aspects, and designing a single standard effectively covering each peculiarity is clearly unfeasible. Nevertheless, the ambitious goal of the EuPP initiative (and of the 3rd VoCamp) is to aggregate consensus on the requirements to identify a minimum, yet significant subset of them to enable effective M2M interoperation, on energy data. The initial "wish list" can be described as follows:

(1) **(Scope, high priority)** The standard shall specify communication between appliances and energy management at syntactic and semantic layer. Appliances shall include white goods, HVAC, lighting, micro renewable home solutions [3].
(2) **(Scope, medium priority)** The standard shall be independent from physical communication means; however some restrictions would be acceptable. Major current standards like must be supported.
(3) **(Information hiding, high priority)** The standard shall enable (not necessarily enforce) information hiding to enable and ensure privacy and dependability.
(4) **(Future applications, high priority)** The standard shall enable (not necessarily provide itself) also support for additional and future services such as Ambient Assisted Living or surveillance applications.

(5) **(Easy deployment, very high priority)** The set-up/deployment process shall be automatic without need for user interaction while ensuring privacy and information security.
(6) **(Lifecycle, medium priority)** Support energy management and related aspects during whole life cycle of product and planning of a building [3].

The requirements (1), (2), and (6) are derived directly from the objective to enable energy management in smart appliances as described in the objectives. The requirement (2) results from the fact that is technically easy to build bridges between different communication media; however, a common semantic understanding is required that shall be focus of the future standard. Requirements (3) and (5) are of very high importance from a user's perspective and to enable market success. It has to be noted, that objectives and requirements are partially contradictory regarding automatic set-up/deployment process at one hand and privacy/information security at the other hand.

3. An overview of standardization efforts

Related standards that are of relevance or target M2M communication are

- uPnP [7] is a relevant standard for service discovery that has currently focus on AV appliances and services. However, it might be extended towards "smart" appliances.
- ZigBee Smart Energy Profile 2.0 can be seen as the first standard that describes M2M communication at semantic layer. It is agreed by a variety of other standards as semantic layer on top of arbitrary data layer communication.

Furthermore, there are a number of ongoing standardization efforts for which excellent overviews were given by Baumeister [4] and Arndt [5]. These standardization efforts are taking place at national (e.g. DIN), European and international level. Figure 2 summarizes the ongoing activities in IEC TC 56 (WG21) that rather focuses communication to the outside world, and TC 56 (WG15) which has focus on in-home communication. In addition, ETSI and other standardization bodies have started the OneM2M initiative targeting a rather multi-purpose („Internet of Things"), service oriented layer.

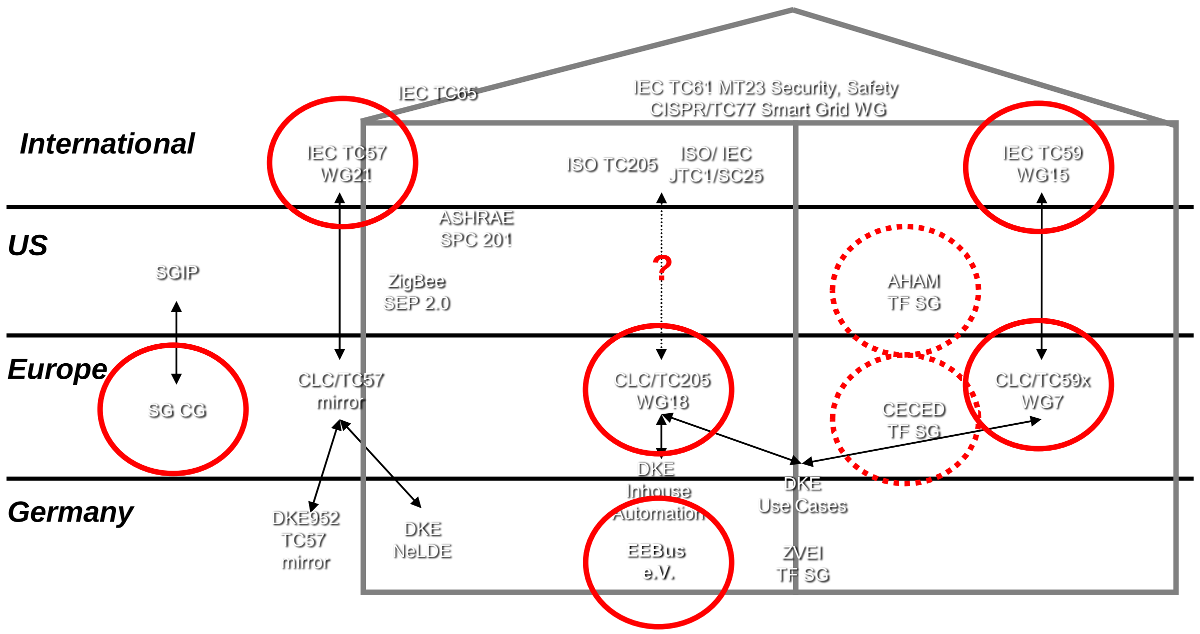

Figure 2: Overview of ongoing standardization efforts for M2M communication in the SmartGrid (may be incomplete) from Baumeister [4].

The discussion in the IEC standardization is (similarly to ZigBee) focusing on a number of use-cases that are analyzed, and for which appropriate commands are defined. This procedure is very conservative (as standardization is mostly), as it guarantees robust and dependable operation in these use-cases in the future.

However, future development might show other and additional use-cases. Smart Grid and energy management are just at the beginning of a development that might lead us to more general visions such as ambient intelligence, e-Health or surveillance applications, most likely combinations of this all. For this reason, it makes sense to reason about extendibility and general applicability.

4. Research: A proposal for joining ontologies for M2M

The approaches in state of the art building automation ontologies and standardization approaches can be seen from different aspects:

1. Device-oriented, bottom-up aspect - In this approach, as e.g. in DogOnt [8], things are given names and are classified according their functionality in a building, e.g. door-sensor, lighting switch, actuator. This approach is mostly taken for giving an application-and-network independent (abstract) structuring and operation of the home environment (and of smart appliances "living" within the same ecosystem).
2. Scenario-based, ad-hoc aspect - In this approach, use-cases and scenarios are defined. To handle these use-cases, commands are defined such as "switch XXX on", "load-control", etc. This approach is mostly taken by standardization bodies as it

offers a clear path from requirements to commands. A good example is the definition of ZigBee Smart Energy 2.0 profiles

3. Service oriented, top-down aspect – This approach particularly focuses on services and on how to coordinate to fulfill specific optimization objectives. Appliances are classified on the basis of how they can contribute to an optimization objective. A good example is the abstraction of a refrigerator, but as well as of an HVAC, to a "shiftable, thermal service".

The three classes described above are not isolated or contradictory to each other. Instead, there are likely to give their best when properly combined; in fact **each of the approaches describes particular aspects that, when combined with the others provide very meaningful semantic assets.** As an example for the "bottom-up" approach we would consider the DogOnt ontology [8] and extensions (e.g., reconciling ZigBee profiles to the device-centric approach[6]); even if it already includes aspects of both other approaches as well as shown in Figure 3: A "Building Thing" also provides functionalities and commands.

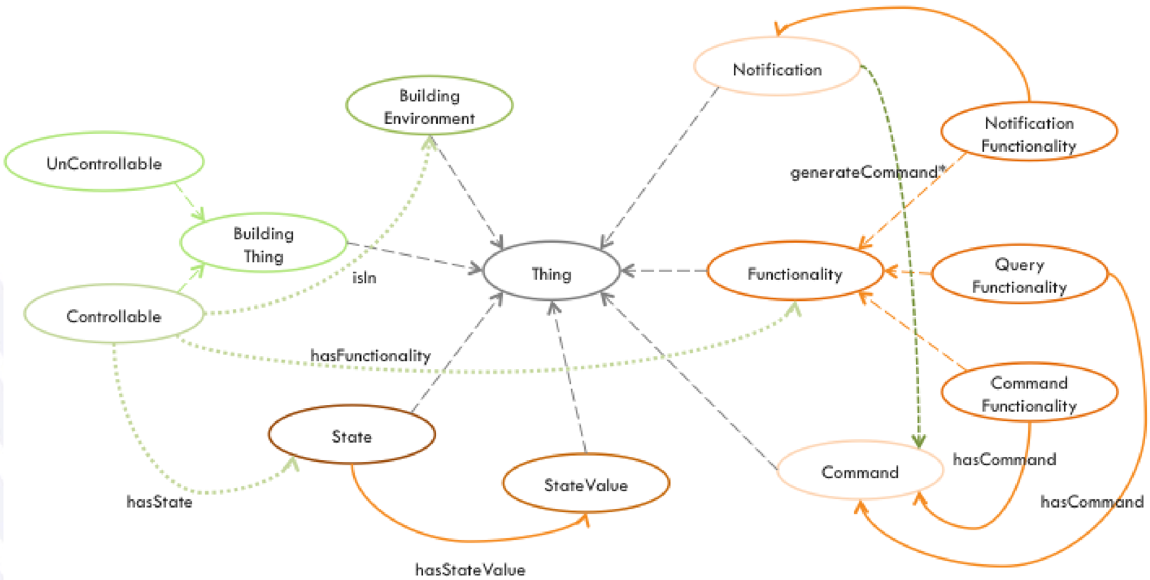

Figure 3: Top-level part of DogOnt ontologies.

SmartCoDe services are shown in Table 1 as an example for the service-oriented aspects. They offer a well-suited framework for very powerful and generic power management using all kind of smart appliances. It has to be noted, that different appliances can also combine different services. For example, a washing machine can be a schedulable load (e.g. by defining starting time autonomously), but also includes when running a thermal service for the water in the machine.

[6] Available to download on http://elite.polito.it/dogont

Class	Description	Configuration	EM-Strategy	cost	Examples
VARSVC	**Variable Service:** The appliance provides a user-variable service which is balanced with sensor input.	tolerance bounds	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 an inert, thermal service which can serve as a virtual storage.	temperature bounds / hysteresis	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	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	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	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	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	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: Services of smart appliances to energy management [2].

During the 3rd VoCamp the combination of the mostly device-oriented approach from DogOnt with the service-oriented classification from SmartCoDe has been discussed, and its feasibility has been considered through collaborative design.

From the DogOnt standpoint, abstract services defined by SmartCoDe approach (Table 1) can be seen as a special kind of functionality:

SmartService is-a functionality

In contrast to a pure functionality, a SmartService also includes the autonomous actions and decisions of a "smart appliance". For the special case of energy management we can specialize this class further:

EnergyMgmtService is-a SmartService

Then, all energy management services from SmartCoDe can be added. However, the services can also be assigned to "things" that also provide other properties to the energy management beyond just service: this can be the possibility to offer sensor values for other use cases, but as well information required for the management of the appliances during its whole lifetime from manufacturing over deployment, operation, and after-use.

Once the Services are present in such an ontology, they can also be connected with appropriate objects that represent possible messages and bring-up of services, but as well location, energy consumption, materials, etc. of the associated appliance (not shown in figure 4).

All together, such combined ontologies are a suitable and complete information model that covers for full lifetime of an appliance as part of a building.

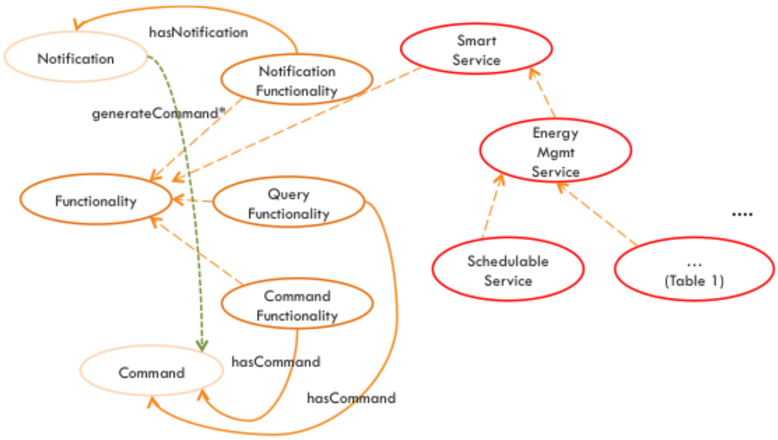

Figure 4: Services merged easily with bottom-up ontologies.

5. Discussion and Conclusions

We have analyzed requirements for standardization, given an overview of standardization approaches, and introduced and classified existing approaches from research.

Comparing the requirements and objectives formulated in Section 2 with the use-cases used in the ongoing standardization efforts (ZigBee Smart Energy 2.0, Cenelec), many objectives can be fulfilled:

(1,2) Scope – good match between requirements and ongoing standardization activities.

(3) Information hiding – Focus is on encryption; it is unclear how privacy shall be achieved as e.g. grid operators would need (at least partially) access to encrypted communication. Here privacy might be in risk depending on use of aggregation.

(4) Future applications – As the approach of standardization is focused on analysis of (current) use-cases, the support for future services beyond the analyzed use-cases is limited to the use of the defined commands fort he use-cases.

(5) Easy deployment – The deployment is supported by standardization in progress and additional standards, but in particular distribution of keys or pairing could become issues for unexperienced consumers.

(6) Life cycle – Current standardization focuses use cases.

In summary, objectives 1, 2, and partially 3 and 5 are well covered by the ongoing standardization activities. However, ongoing standardization activities should also clearly integrate data aggregation techniques and information hiding to reduce amount of data and to improve privacy to fully achieve the very important objective 3 with impact on privacy and dependability. The objectives 4 and 6 can be achieved by abstracting from concrete use cases (as currently the case in standardization) to more abstract and general classes of appliances, and merging them into ontologies. We recommend standardization to go a similar approach as shown in section 4.

References

1. Dario Bonino, Christoph Grimm, Dimitrios Tzwovaras: Proceedings of 3rd Vocamp „Energy using and producing Products (EupP) and it’s Management“, TU Kaiserslautern, June 2013.
2. Markus Damm, Stefan Mahlknecht, Christoph Grimm, Tamás Bertényi, Tom Young, Christian Wysoudil: A partially decentralised forecast-based Demand-Side-Management approach. In: Innovative Smart Grid Technologies (ISGT Europe) 2011.
3. Rogelio Segovia: M2M Semantics for Smart EE-Appliances. In: [1].
4. Josef Baumeister: SmartGrid–Smart Home Standardization. In: [1].
5. Marlyn Arndt: ETSI M2M and OneM2M. In: [1].
6. Christoph Grimm, Peter Neumann, Stefan Mahlknecht (Eds.): Embedded Systems for Smart Appliances and Energy Management, Springer, ISBN 978B1B4419B8794B5.
7. Golden G. Richard: Service and Device Discovery: Protocols and Programming. McGraw-Hill Professional, ISBN 0-07-137959-2.
8. D. Bonino, F. Corno: DogOnt - Ontology Modeling for Intelligent Domotic Environments. 7th International Semantic Web Conference. October 26-30, 2008. Karlsruhe, Germany. Ed. Springer-Verlag, Lecture Notes on Computer Science, pp. 790-8031.
9. D. Bonino, F. Corno, F. Razzak: Enabling Machine Understandable Exchange of Energy Consumption Information in Intelligent Domotic Environments. Energy & Buildings 43 (2011), Elsevier, ISSN 0378-7788, pp. 1392-1402.

3.2. French AGORA and Other Initiatives to foster Smart Home ecosystem development

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Abstract

The Smart Home landscape today is composed of siloed solutions, which results in various types of devices and different communication technologies being proposed to the end-user. This situation may not be satisfying when targeting a real take-off for the Smart Home market. It was indeed realized that the end-user would require warranty on long-term usability of his Smart Home system. This raises the question of interoperability among the various devices deployed in the end-user's home, which in turn points out the necessity for a common data model as an enabler for various actors of the Smart Home domain to make their systems interoperate. The paper will present some initiatives (and their status) aiming at solving this question.

In particular, the French industrial forum "AGORA des réseaux domiciliaires" (Agora of the domestic networks) creation was impulsed by a set of 9 industrial companies[7], to encourage the synergy required among Smart Home industrial actors to define the "homebus".

Also the Home Gateway Initiative (HGI) is actively working on the Smart Home architecture and on defining data models for the Smart Home particular needs, which data models will be made available via standardized APIs (Application Programming Interfaces).

The paper will also mention the ongoing standardization activity around abstraction and semantics in the M2M domain, pointing out the aspects that are relevant for Smart Home ecosystem. Examples will be given through details of the ETSI M2M guideline mapping a "home area network" e.g. ZigBee, to the ETSI M2M abstract data model. Moreover ETSI M2M had begun a study on Semantics that is re-used in oneM2M Abstraction and Semantics work item. Last, the present paper will globally explain the relationship of this work item not only with "verticals" (such as HGI or the Continua Alliance), but also with European Research projects (such as FI-WARE, and projects coordinated by IERC AC4).

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[7] The nine companies who initiated the AGORA are : Bouygues Telecom, EDF, France Telecom, Legrand, Numéricable, Sagemcom, Schneider, SFR, Technicolor

1. Introduction

From Home Automation to Smart Home, via the Digital Home, all the technological and applicative assets have been ready for several years; yet the real mass market is not that much developed. While some "vertical" dedicated packages are available, the end-user often hesitates to deploy these systems that do not give him any guarantee of flexibility when he wishes to evolve to new Smart Home services without changing the whole system.

Technologies supporting smart home services have indeed been developed specifically for particular segments of this market and use either proprietary communications protocols or a domain specific solution. As a result, such systems were not deployed at a large scale due to their cost, the lack of the interoperability with systems from other segments, and the lack of standardized solution hence a lack of flexibility.

In order to go beyond these limitations, national initiatives have been undertaken in the world in parallel to regional research projects and international standardization steps towards more interoperability via the definition of data models for devices and for the data to be shared among the various segments of the Smart Home. This paper describes the French initiative AGORA that works in this direction, as well as some international standardization aspects worked out in HGI (Home Gateway Initiative) and in the more generic ETSI M2M and oneM2M bodies, bridging with research projects already well advanced in the activities related to Abstraction and Semantics, i.e. FI-WARE and IERC AC4.

2. The "AGORA" initiative

In France, a group of industrial actors composed of the telcos, few manufacturers and some services providers, have created in 2009 a non –profit organization: the "AGORA des réseaux domiciliaires" (that could be translated into "AGORA of domestic networks").

The Smart Home sector was indeed beginning to emerge as a promising sector with a great economical opportunity to develop new products, and new jobs. But to fulfill these promises, the industrial actors needed to collaborate all together towards a coherent global solution, that would encourage always more services, and more products, still satisfying interoperability criteria for full adoption by the end-users.

Today, a total of 19 companies are active in AGORA technical work, and are defining a common way to share information among the various equipment installed in a house. The major goal here is to enable domestic devices and "vertical" sets of devices (e.g. set of devices for energy consumption management, set of devices for comfort, set of devices for entertainment, set of devices for security,…) to communicate, interact and cooperate, thanks to the "homebus" concept, illustrated by Figure 1. It consists in a kind of new household language, that shall also verify the protection of personal data.

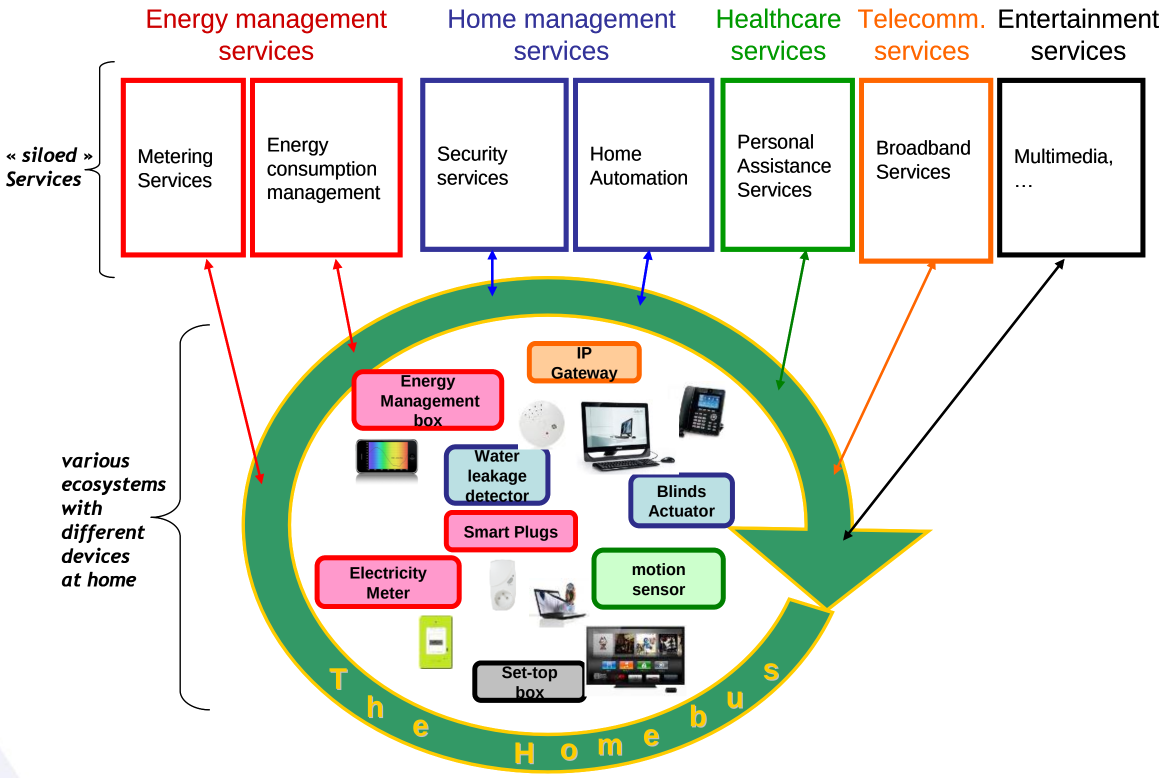

Figure 1 – Homebus concept from AGORA.

The homebus challenge resides in distributing data that are very different in nature and volume between the various silos. AGORA focuses on facilitating the sharing of data and events among the various ecosystems of the smart home, as a first step to leverage the current siloed deployments. For that purpose, it has defined this afore-mentioned homebus, based on IP protocol, as an enabler for heterogeneous ecosystems connected to the local home network to keep each other informed about the status of each ecosystem, hence more globally of the house.

AGORA high-level architecture, shown on Figure 2, was built upon the basic definition of an AGORA Node, which was defined as a smart element connected to the homebus on which it exposes information (status, measures, state…) to share with other Agora nodes. The AGORA fully decentralized architecture is deployed over local IP network, where all AGORA nodes can operate independently with a plug and play concept. Several kinds of devices are considered: IP devices which directly link to the bus, sensors and actuators which communicate within a Home Area Network (e.g. Zigbee, KNX, X10,…) linked to the Homebus through "ecosystem gateways", and the telecommunication operator box which provides internet gateway function (without extending yet AGORA functionalities to the WAN external network, for security reason).

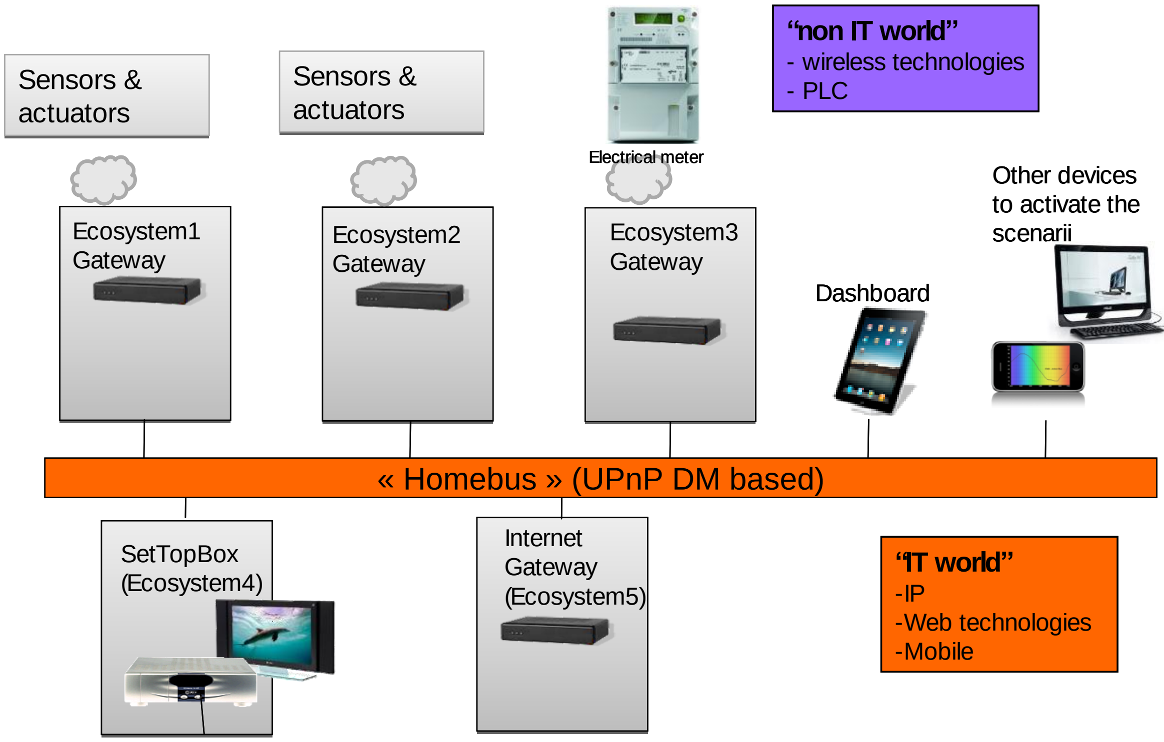

Figure 2 – AGORA architecture overview.

The first version of the AGORA demonstrator was officially shown in April 2012 (a video is available on http://www.reseau-domiciliaire.fr/editorial), as a result of several months of a fruitful synergy among the Smart Home French industrials to build a first example of such a homebus. For this initial version, the goal was to see whether it would be possible to commonly define a data model that the various ecosystems of the Smart Home could share. A list was drawn up of the relevant events to be exposed and used by each of these ecosystems through this homebus, which involved the expertise of each of the AGORA actors; it was indeed key to ensure what event could be expected on the homebus from which specific ecosystem, and what meaning each ecosystem will give to these events it will retrieve from the homebus. At this stage of AGORA, a model based on the UPnP DM v2 standard was used, keeping in mind this version of the demonstrator was not intending to be a mass-market product.

AGORA actors listed, for each of their own ecosystem, the characteristics (including types of variables and their values range) related to their devices, and the associated events they will be able to expose on the homebus. The UPnP/DM-like description was then used by all the ecosystems to retrieve the exposed information and to use it accordingly to their own rules. Thus, each actor keeps control of his core business domain and remains the responsible entity for this particular ecosystem; it is up to each ecosystem indeed to decide whether to use or not the data and/or event exposed by the other ecosystems on the homebus.

The choice for such a common data model, combined with regular technical synchronisations between the involved actors resulted in a robust and stable demonstrator, that has been shown at different seminars in Europe, e.g. at IDATE 2012 as shown in Figure 3.

Figure 3 – AGORA demonstrator at "Digiworld Summit" of IDATE 2012.

Each actor had built the software program needed to translate its particular HAN (Home Area Network) technology to the AGORA common data model based on UPnP DM, so that a new event happening in the house and detected by one ecosystem can be exposed to the homebus, and vice-versa: by translating back the AGORA common data model to its specific technology an ecosystem can choose to retrieve and to use an information (related to a new event in the house) that has been exposed by another ecosystem, and can consequently command adequate actions within its domain perimeter.

As an example, the “multimedia” scenario (out of the 4 scenarios) demonstrated by AGORA tells the story of a family who decides to watch a good film on their IPTV at home. Once they have selected the film out of the list provided by their multimedia service provider, they press on the “HomeCinema” button of their remote control (or on the corresponding icon of the home dashboard), so that their smart home system automatically prepares the best conditions for watching the film. It is this particular “HomeCinema” status message, adapted and transmitted by the Multimedia ecosystem onto the Homebus, that is captured and analysed by the various other ecosystems, so that each of them can react adequately (following its own rules) to this status, i.e.:

- the “Lighting” ecosystem will reduce the main lighting in the room, and will switch on the fill-light just above the TV screen;

- the “Opening” ecosystem will command the rolling shutters to close them halfway so as to avoid any reflection of the external light on the screen

- the “internet access” ecosystem will request the IP gateway to filter the telephony calls so that the non-priority calls are directly forwarded to the vocal-messaging server whereas the priority ones will be announced, additionnally to the normal ringing, via a message written on the TV screen while the film is paused during the duration of the call. Once the person has finished the call and after he has hung up, the film will resume from where it had been paused for the call received.

At the end of the film, the family just presses on the « HomeCinema End » button of the telecommand (or on a specific icon of the home dashboard), to have the house go back to its normal working mode. This scenario shows that the simple action of pressing on a button of the telecommand has generated a message on the homebus that each of the ecosystems was able to interpret so as to perform, within its own perimeter, the tasks it has associated with this message.

Among the various ecosystems taking advantage of this common data model, the smart home dashboard was specifically designed to make the customer aware of the status of this house, through the events exposed by the various ecosystems. A first version of this dashboard is shown on Figure 4.

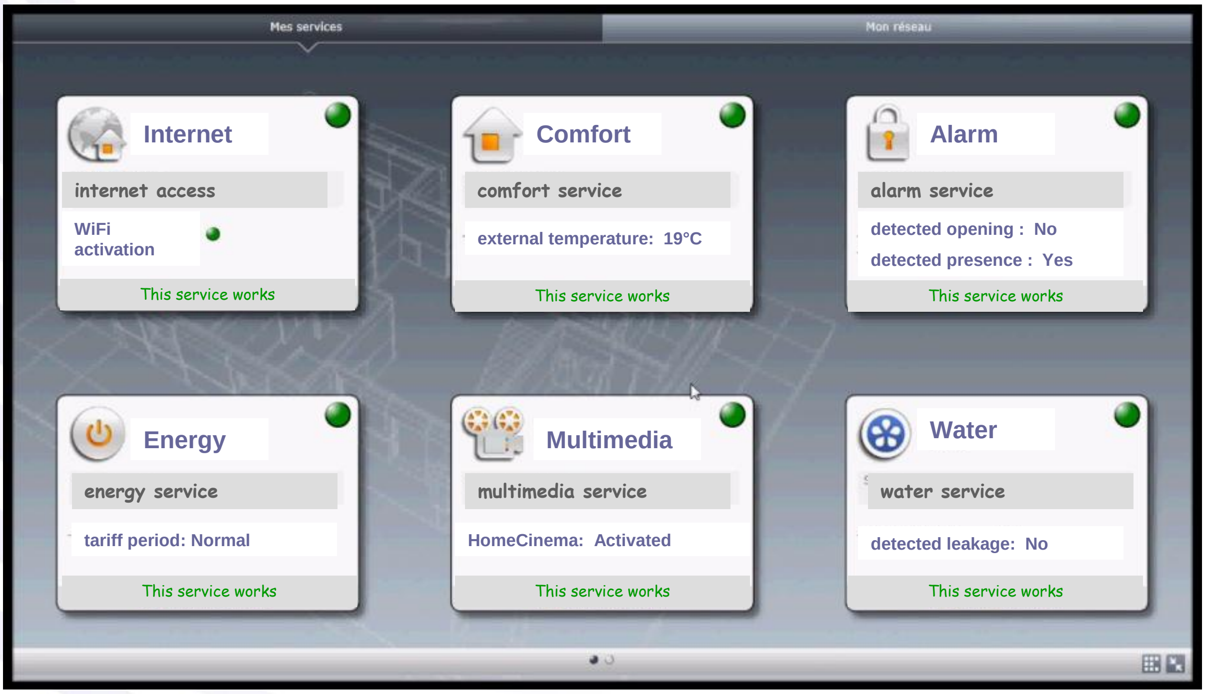

Figure 4 – AGORA dashboard for customer awareness about the status of his home.

Through this dashboard, the different ecosystems having executed their tasks send onto the homebus the associated execution information e.g. "rolling shutters halfway" or "N messages received on the vocal messaging server"… and this information is then showed on the dashboard, either by being explicitly displayed or by updating the corresponding icon.

This first AGORA demonstrator constitutes not only a great technical achievement but also a beautiful success in terms of different smart home industry actors converging to a common data model. The latter allows each actor to share useful information with others while keeping the responsibility for actions to be decided within his own core business domain.

This synergy is growing with more actors who have recently joined the AGORA to participate in the realization of the second version of a demonstrator that will meet additional requirements such as scalability, secured communication, data protection, implementability on resource-constrained objects, and possible interfacing to application servers in the Cloud. This second version of AGORA demonstrator mainly aims at reaching a further step towards a "smart home compatible" label that will guarantee interoperability of these smart home devices that will bear the label.

The choice for the technology to be used for the homebus in this 2nd version of AGORA demonstrator is currently under technical discussions, with some Plugfests organized to compare the candidate technologies such as IETF CoAP (the Constrained Application Protocol specified by IETF). Some more updated details will be given at the eeBDM 2013 Workshop presentation on the 10th of September.

Eventually, it can be noted that some discussions have already been initiated between AGORA and other similar national initiatives in Europe so as to combine these national experiments into a possible European-dimension synergy.

3. Other initiatives towards data models for Smart Home

3.1 Energy@Home, Italy: focus on home energy consumption optimization

Among others, Energy@Home (E@H) is another national initative similar to AGORA in some way, although adopting a different approach in addressing the topic of interoperability among smart appliances, limited in the case of E@H to those involved in the energy consumption optimization.

In Italy, E@H started as a collaborative and spontaneous project between Electrolux, Enel, Indesit Company and Telecom Italia in 2009. Its goal was to promote the development and widespread deployment of products and services based on the interoperability and collaboration of the appliances within the household, targeting a coordinated electricity consumption optimization between all the appliances in a house.

E@H defined an interoperable system composed of a Home Gateway, a smart meter and smart domestic appliances using ZigBee radio technology (IEEE 802.15.4). In particular, the Home Gateway is able to interface ZigBee-communicating Smart Appliances and other user's devices (e.g. PC, tablet) using IP/HTTP protocol, and provides a broadband connection to internet via a standard ADSL connection. Thus, the E@H Home Gateway is able to collect energy data from the 'Smart Info' (element provided by the Distribution System Operator that dispatches energy related information into the Home) and additional information from Smart Appliances. It uses all collected data to control Smart Appliances so that their energy-consumption behavior is optimized. For that purpose, the data modeling was designed so that it can integrate the concept of the Power Profile, defined as the estimation of the power that the appliance will need when running a specific cycle or program. In order to define the interaction model with the Smart Appliances, E@H adopted the CENELEC EN50523 standard "Household appliances interworking" as specified by CECED (European Committee of Domestic Equipment Manufacturers) and mapped it into specific ZigBee 'clusters' (ZigBee terminology for "functionalities").

The data model developed by E@H is then an extension of the ZigBee HA profile (Home Automation applicative profile from the ZigBee Alliance), with new clusters related to both appliance and energy management specific features that are needed for the different types of appliances considered by E@H. Thus the work performed in this project, including several ZigBee interoperability events in Italy and field trial among 100 users, resulted in actions to ZigBee Alliance for admendments to the ZigBee HA profile specification.

From these first deep technical analysis and achievements, E@H partners concluded that the domain required an eco-system approach based upon interoperability between much more vendors and larger systems. This is the reason why they built, in July 2012, a not-for-profit Association, the "Energy@Home Association", open to all interested partners.

3.2 FI-WARE, FP7 European Project: core platform for Future Internet

The previous sections presented AGORA and Energy@Home, as national initiatives addressing the near-future Smart Home market. Although far more generic in terms of scope, the FI-WARE Project is another initiative of interest for our investigation on data models currently used in technical studies towards interoperability of smart appliances.

FI-WARE has been indeed the technology foundation of the FI-PPP (Future Internet – Public Private Partnership) since 2011, being a 3-year large scale Integrating Project. It is working on the core platform of the FI-PPP. This novel service infrastructure is built upon elements called Generic Enablers (GEs), which offer reusable and commonly shared functions, as illustrated on Figure 5 (extracted from [4]). The GEs are expected to facilitate the development of Future Internet applications in multiple sectors, including the Smart Home sector.

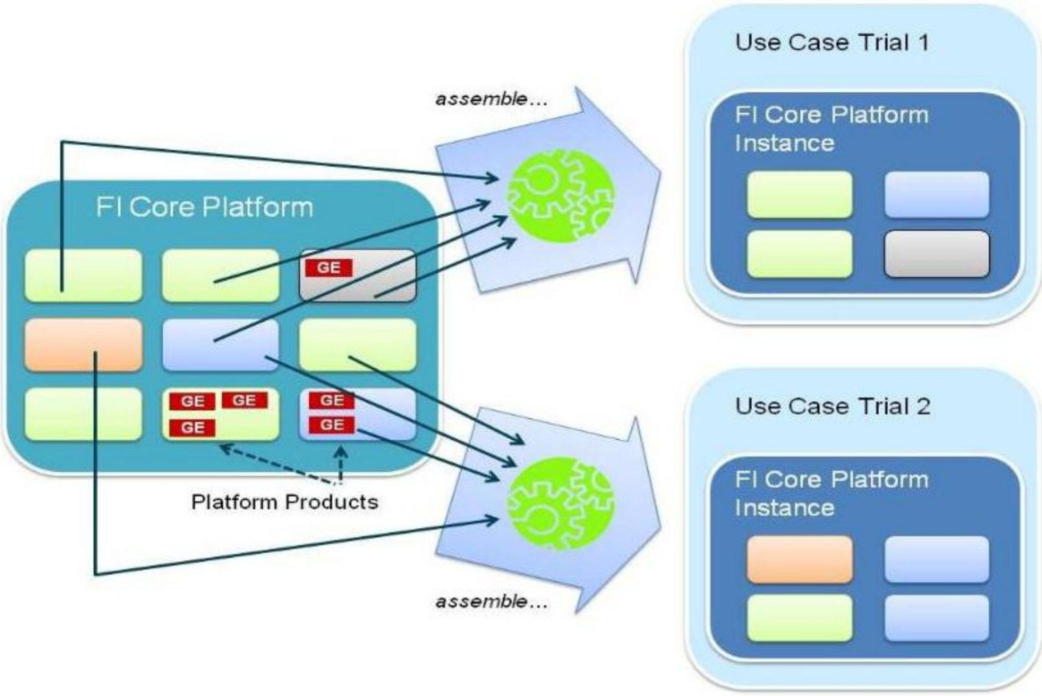

Figure 5 – FI-WARE Generic Enablers as the technology foundation for the Future Internet Core Platform.

FI-WARE identified that the difficulties found in the interoperability among applications running on different devices are often a big issue in the development of global Internet Applications. Hence FI-WARE decided to address these issues by defining Generic Enablers that implement a common and standard Interface to Devices. The basic assumption for the definition of Connected Devices Interfaces (CDI) is that they will be defined as independent as possible from specific technology implementation and programming paradigm. Thus an abstraction layer is defined on top of the technology dependent layer(s) of the devices; this abstraction layer communicates with the applications and the network service by means of a interface layer as shown in Figure 6.

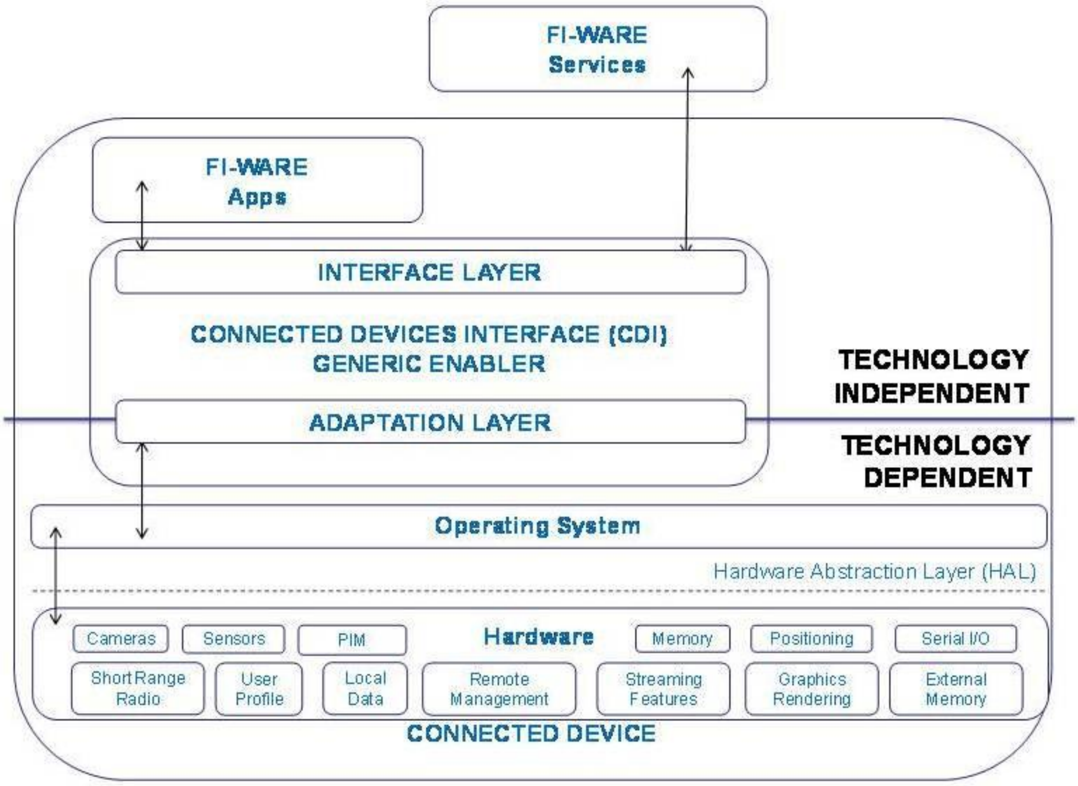

Figure 6 – FI-WARE Connected Devices Interface Generic Enabler (CDI GE).

The CDI GE interfaces the FI-WARE services and applications with the connected device capabilities. While the adaptation layer is technology-dependent, the interface layer relies exclusively on the required interfaces to support the various FI-WARE applications and services. This interface layer will be based, as far as possible, on the re-use of solutions from other initiatives, such as W3C.

Another part of FI-WARE studies deals with the Data/Context Management, that includes aggregation of data from various sensors through the use of a Gateway. In this part, several GEs are defined that are relevant to consider when looking for enablers to interoperability of smart appliances, such as the Publish/Subscribe Broker GE, which allows applications to interchange heterogeneous events following a standard publish/subscribe paradigm.

For the Publish/Subscribe Broker GE, FI-WARE refers to the OMA NGSI (Open Mobile Alliance - Next Generation Service Interfaces) technical specification and in particular re-uses the NGSI-10 interface, which is one of the interfaces associated to Context Management Functions defined by this OMA specification. FI-WARE Publish/Subscribe broker GE will just focus on the parts of NGSI-10 interface that are considered most useful to support development of applications in the Future Internet. On the other hand, it will extend the scope of NGSI-10 specifications to be able to deal with data elements, not just context elements. Several arguments were in favour of choosing the OMA framework, among which:

- the ability to keep memory of events while conditions for the duration of these events hold, independently of who connects as a consumer of the event
- the suitability for a wide range of potential implementations of the Publish/Subscribe Broker GE, not only on traditional servers but also on small devices
- the ability to define several alternative bindings, being particularly suitable to adapt to a REST binding, which is thought to be the most suitable communication style for heterogeneous devices
- the adaptability to handle data with no predefined structure
- the flexible subscription query language (being able to adapt for support of multiple query languages)

Thanks to this design, the FI-WARE Publish/Subscribe broker GE is useful to make all data types available through the same interface, following a pull or push style of communication.

The achievement of FI-WARE generic enablers related to Connected Devices Interfaces and to Data/Context Management seems to provide a valuable direction to the Smart Home sector towards facilitating the sharing of applications data among different types of devices / smart appliances.

Whereas AGORA and E@H initiatives are working at the elaboration of data models for their particular scenarios and pre-defined types of smart appliances, FI-WARE generic approach provides detailed clues to meta-data models and semantics-based solutions that are a step further to describe the meaning of the data as well as the relationships between them. The generic concept including the consideration of an abstraction layer to hide the specificities of each Local Area Network used for exchanging data among various devices was also the basis for some standardization technical groups dedicated to Smart Home (see section 3.3 below), and even to M2M wider scope (see Section 4).

3.3 Standardization of Smart Home data models

The initiatives described above pointed out that the main barriers to the interoperability of devices for Smart Home came from the variety of connecting technologies used by different "siloed" sets of devices, and from the lack of standardization in terms of data model.

Home Gateway Initiative (HGI) stands among the standardization bodies that had identified these barriers and created a dedicated Smart Home Task Force in order to fill the standardization gaps in this domain.

Historically, HGI was founded in 2004 by major broadband service providers (BSPs), and was joined by leading vendors of digital home equipment, and its global goal is about shaping the way that IP services are delivered to the home. Through its SH TF created in 2012, HGI aims at defining the reference architecture for Smart Home, identifying the relevant reference points to be standardized. A high-level representation of this architecture is showed on Figure 7.

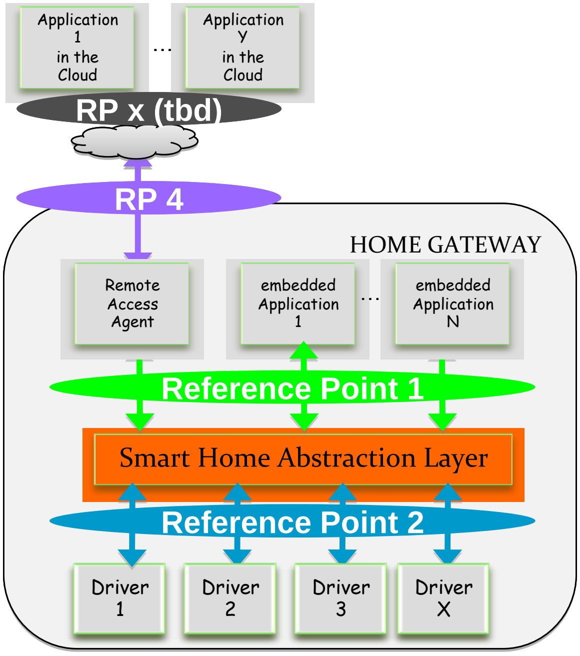

Figure 7 – HGI Smart Home Reference Architecture High-level representation

The Smart Home Abstraction Layer (SHAL) is a master element of this reference architecture, as an answer to the issue of the too various possible LAN (Local Area Network) technologies (represented by their associated drivers in the Home Gateway) used by siloed ecosystems. The SHAL is expected to provide unified APIs for application developers to command, control and query home appliances without having to know anything about the various LAN technologies.

Beyond the reference architecture, HGI identified Semantics for Smart Home as a key topic for standardization. Therefore it has recently created a new work item that aims at elaborating Device Models for devices involved in the Smart Home domain. A first template, HGI GWD-042 "Smart Home Appliance/Device Model Template", is being elaborated, which is expected to be circulated among other standardization bodies and industrial fora taking part in the development of enablers for Smart Home. It will capture a suggested template for modeling smart appliances from the point of view of applications making use of these devices. The template will be developed in coordination with at least BBF (BroadBand Forum), OSGi Alliance, ETSI M2M, and oneM2M. The Reference Point 1 identified in the reference architecture (shown in Figure 7) as the interface seen by embedded application modules on the home gateway, will make use of the template defined in GWD042. RP1 will be developed in consultation with interface technology liaison partners who will be asked to assist HGI with describing their available devices in the template.

Like industries involved in the initiatives described in previous sections, the Standardization bodies such as HGI have realized that the Smart Home required synergy among multiple actors, also in the standardization arena. From this observation, HGI and BBF decided to create a joint Smart Home Group, born in July 2013, so as to jointly work on the next international standards for Smart Home.

4. Leveraging on M2M standards

With the AGORA description in section 2, it is noticeable that numerous various ecosystems may have to coexist in the Smart Home domain. But the M2M domain covers even a far larger scope of ecosystems and applications. (Here M2M is meant in its wide sense, encompassing any kind of automation-based applications that facilitate the human life by limiting the human intervention to the minimum level wished by the human.

For service providers and operators, the need for mutualization of functionalities among all the M2M applications and for standardized unified interfaces able to expose these functionalities to the applications became obvious in a wish to optimize M2M infrastructure deployments. This was the starting point for ETSI M2M Technical Committee to develop Release1 of M2M specifications [6], published end of 2011. These specifications define the first end-to-end M2M architecture independent from the connectivity technologies, thanks to the standardization of an abstracting service layer that hosts service capabilities commonly required by most of M2M applications. The exposition of these service capabilities to the M2M Applications is performed via APIs specified by the ETSI TS 102 921 Specification [6]. Vertical applications are then expected to leverage on this M2M generic standard when designing their deployable solutions. In particular, for the Smart Home domain the possible integration of an M2M agent on the Home Gateway is under discussion in the HGI Smart Home Task Force. The high-level illustration of such an instantiation is given in Figure 8.

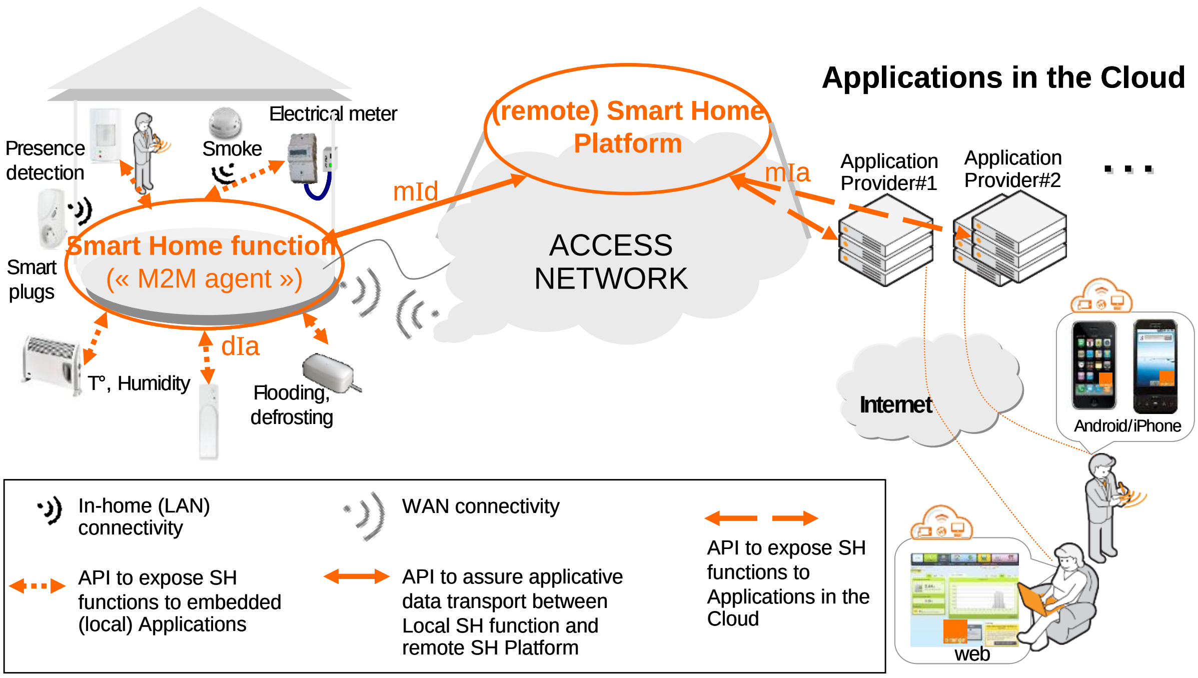

Figure 8 – Service layer M2M-based Agent for Smart Home.

Of the three REST-based APIs specified by ETSI M2M, the dIa interface is the one of particular interest for the smart appliances. ETSI M2M provides a guideline, TR 102 966 Technical Report, on the way to implement and use this API for enabling interworking between LAN technologies such as ZigBee, and ETSI M2M; as an example, according to this guideline the ZigBee network is dealt via an « Interworking Proxy Application » (local application) which maps ZigBee network characteristics (devices, clusters, attributes, commands) into the REST-based ETSI M2M structure, as illustrated in Figure 9.

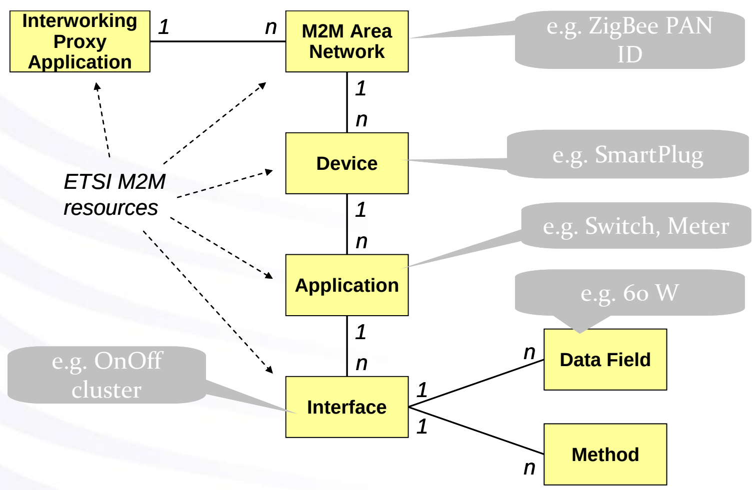

Figure 9 – (from an Actility contribution to HGI) Generic interworking model from TR 102 966.

ETSI TR 102966 describes separately the syntax (e.g. XML) and via 'tags', the semantics (e.g. "a lamp profile"). Semantic tags identify the semantic idiom used (e.g. OASIS.OBIX_1_1 for OASIS oBix conventions, or ASHRAE.CSML_1_0 for BACnet Control

System Modelling Language conventions) while Application tags identify a logical node profile (e.g. « a dimmable lamp »). It currently conveys existing data models (e.g. ZCL ZigBee Cluster Library, KNX e-Mode). From this basis, it is expected to specify some technology independent profiles.

As a matter of fact, TR 102 966 provides a way to abstract LAN technologies in a homogeneous service layer that encompasses some mutualized functionalities and that any Smart Home Application can access via unified standardized APIs. The latest version of the Draft TR 102 966 even extends the solution to address resource-constrained devices.

Beyond this abstraction inherent to ETSI M2M standard through its REST-based service capabilities layer accessible by unified standardized APIs, studies on Semantic support for M2M data had been initiated in order to go one step ahead towards interoperability. Draft TR 101 584 Technical Report describes some use cases demonstrating the need for Semantic support :

- to make M2M data understandable without prior knowledge about the data or devices that produced them,
- to make M2M data / devices discoverable by generic description, and
- to offer interaction on higher level of abstraction (physical entity modeling)

Since M2M encompasses various vertical applications, a key hint for performing these studies is to keep in mind that these 'verticals' may have their own ontology already defined; this is the reason why ETSI M2M study on Semantics was guided by thoughts about how to provide a meta-ontology that verticals could mapped to. This is where IERC AC4 (Internet of things European Research Clusters, Activity Chain 4) coordinating the European Research Projects related to "Service openness and inter-operability issues / semantic interoperability" was identified as a key partner to discuss with.

In parallel, the oneM2M standardization partnership was created, in July 2012, with ETSI M2M being one of the 7 co-founders, which was a great opportunity for the M2M community to pursue efficient work on M2M international standardization with even more partners. Within oneM2M, several Working Groups have been created, which include WG5 dedicated to 2 main items i.e. the device Management item on one hand, the Abstraction & Semantics item on the other hand which is the item under which the discussions initiated by ETSI M2M through its Semantic support for M2M data study with IERC AC4, but also HGI, BBF, and Continua Alliance (for the eHealth sector) can continue.

The oneM2M Draft Technical Report "Abstraction and Semantic Capability Enablement in oneM2M" proposes to explicitly distinguish Abstraction aspects from Semantic support aspects, as roughly illustrated on Figure 10, and leverages on ETSI M2M TR 101 584 so as to anticipate abstraction requirements as well as semantic-based solutions from the early stages of the design of oneM2M architecture and protocols.

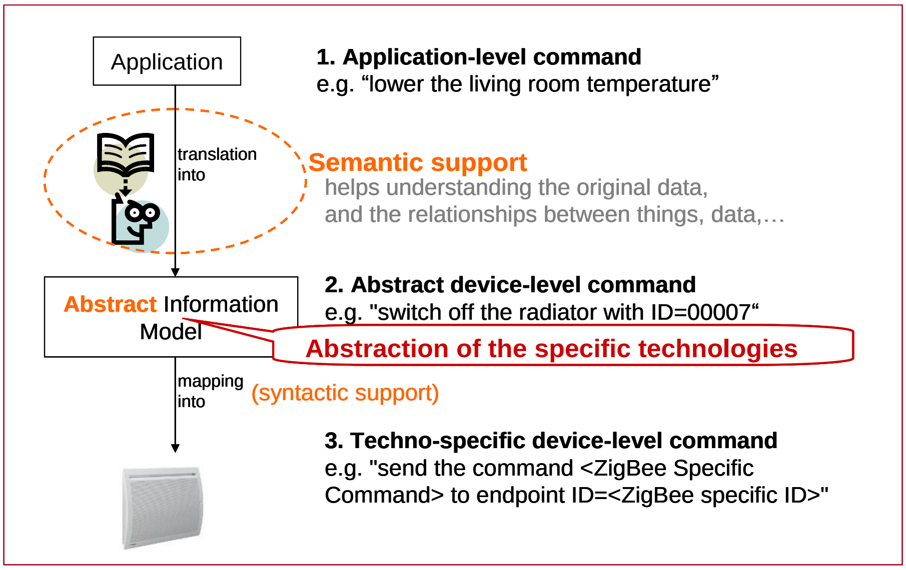

Figure 10 – Abstraction versus Semantic basic illustration.

M2M standard provides a standardized way of storing and accessing data through unified interfaces so that different applications can exchange data in an interoperable manner. ETSI M2M / oneM2M allows for a first level of abstraction to hide the heterogeneity of underlying access networks. The next step consists in finding a kind of meta-ontology into which any vertical domain, including Smart Home, could plug its own ontology and leverage on deployed generic M2M infrastructure.

5. Conclusion

This article presented some examples of initiatives from the Industry, Research, and Standardization worlds towards solving the interoperability issues, due to initial lack of standards and to existence of fragmented paradigms, between smart appliances. Although the list of examples is not exhaustive, the goal of the article is to give some clues on complementary data modelling approaches relevant for the Smart Home domain in particular.

French AGORA initiative was deeply described, as a good example of a multi-ecosystems multi-LAN-technologies approach to define a “Homebus” to which each ecosystem agrees to connect in order to share data with all other ecosystems. The AGORA Homebus concept includes the definition of a common data model understandable by all the pre-identified devices of the involved ecosystems. AGORA first demonstrator is based on a UPnP/DM-like data model, that already enables a real synergy among all the ecosystems at home. The second demonstrator ongoing challenges this first data model in order to better fit additional requirements identified by AGORA.

Another initiative, the Italian Energy@Home project, has a different approach compared to AGORA, as it focuses on the particular ecosystem of electricity consumption optimization. For this specific domain, E@H decided to agree on a single radio technology for the appliances, with the home gateway collecting the data from all the devices through this radio protocol, which is ZigBee, and worked on the applicative layer of the stack for an enriched data model particularly suitable for the considered application of energy consumption optimization. E@H deep studies on the different types of energy-consuming devices have resulted in extending the data model of the ZigBee Home Automation Profile (from the ZigBee Alliance) so as to integrate new relevant functionalities. E@H initiative is a perfect example of how the industry can help, thanks to their implementation feedbacks, enhancing particular standards.

The European FI-WARE Project was then mentioned to show current trends in defining an abstraction layer to facilitate interoperability of applications. This showed a more generic vision, which tends to prepare the global Future Internet, of which the Smart Home is one instantiation. FI-WARE studies on ontologies also constitute valuable hints that may be put in synergy with international standardization activities ongoing in ETSI M2M and more globally in oneM2M.

The generic M2M standard, i.e. published Release1 of ETSI M2M, was described in the perspective of being possibly beneficial to the Smart Home specific arena. For the latter, the Smart Home Task Force of Home Gateway Initiative, after having elaborated the Smart Home reference architecture and associated Reference Points, is now particularly focusing on the specification of data models with the collaboration of all other relevant standardization bodies and industrial fora.

All of these collaborative actions aim at defining open standards for a mass-market Smart Home, providing standardized enablers that would stimulate the market to evolve from verticalized solutions to a horizontal, more homogeneous and interoperable approach.

The most important message behind this article is that close cooperation is mutually needed between initiatives from the industry, the research collaborative projects and the standardization bodies. The industry expects to find answers to their needs in the existing standards and when the industry identifies gaps in standards, the latter need to be enhanced/updated by industrial implementation feedbacks and by solutions that were anticipated by focused experts involved in research projects.

Acknowledgments

This article was written thanks to the collaborative work undertaken by AGORA, Energy@Home, FI-WARE, IERC AC4, HGI, BBF, ETSI M2M, and oneM2M. Yet, the information provided here reflects a personal interpretation from the discussions ongoing in these different groups.

References

1. AGORA site: http://www.reseau-domiciliaire.fr/home .

2. Energy@Home site: www.energy-home.it

3. FI-WARE site: http://www.fi-ware.eu/

4. General FI-WARE presentation "fi-ware, The Core Project" available on http://www.fi-ppp.eu/projects/fi-ware/

5. Home Gateway Initiative site: www.homegatewayinitiative.org

6. ETSI M2M Release 1:
   M2M service requirements TS 102 689 v1.2.1
   http://www.etsi.org/deliver/etsi_ts/102600_102699/102689/01.02.01_60/ts_102689v010201p.pdf
   M2M functional Architecture TS 102 690 v1.2.1
   http://www.etsi.org/deliver/etsi_ts/102600_102699/102690/01.02.01_60/ts_102690v010201p.pdf
   mIa, mId and dIa interfaces TS 102 921 v1.2.1
   http://www.etsi.org/deliver/etsi_ts/102900_102999/102921/01.02.01_60/ts_102921v010201p.pdf

4. Session: ee Beyond the Building

4.1. CITYGML digital mock-up to support sustainable cities

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Abstract

In a context where sustainability becomes a crucial factor for cities and citizens, experts underline the confusion of decision-makers confronted to the mass of criteria to manage. Thus those need to change their practices involving plan, design and management. They seek for new powerful tools supporting their decisions, through an integrated multi-criteria evaluation tool. CSTB has worked for the last years on the potentiality of using a centralized and standardized data model to accommodate and support the different aspects of an urban project during its lifecycle, in a close connection with city experts, decision makers and citizens. CityGML, as an OGC standard, offers interesting features to share and manage the complexity of a city. Its model describes geometry and semantics at different levels of detail and can be expanded natively to new items thanks to generic elements. The paper illustrates how we developed our tool eveCity to implement and use a CityGML exclusive model. It describes some of its hosted "expert modules" that interoperate in real-time by picking and enriching the model. It also focuses on new automatic geometric reconstruction methods to speed up the acquisition process and an application offer of local authorities.

1. Introduction

In a context where sustainability becomes a crucial factor for cities and citizens, experts underline the confusion of decision-makers confronted to the mass of criteria to manage. Thus they need to change their practices involving planning, design and management, especially by seeking new powerful tools to support their decisions, on both environmental and societal stakes, within a crisis context and a hard locked legislation. In this context innovative tools coming from the Information and Communication Technologies (ICT) can

(i) manage growing complexity due to the mass of criteria and information linked with sustainable development and (ii) better communicate with citizens using new ways of visualizing and simulating our reality.

Considering the city scale, using the digital mock-up appears to be a very good way to gather the actors around a shared and unified digital model and to support a sustainable urban planning. Indeed this tool is aimed to be perennial, easy-to-update, and built to capitalize all pieces of information needed to address all sectors of the urban scale. Thus CSTB has been working over the last years on the potentiality of using such a centralized and standardized data model to accommodate and support the different aspects of an urban project during their lifecycles, in a close connection with city experts, decision makers and citizens. This article will present some of our results, and will insist on their transfer to the operational world of local authorities.

2. Extending the BIM concept to the district scale

2.1 BIM for construction

There are several definitions for the notion of BIM. The Acronym BIM is sometimes interpreted into "Building Information Model" or "Building Information Modelling", the former capturing essentially the concept and the latter the approach.

On Wikipedia[8], the following definition is given to BIM: "Building information modelling covers geometry, spatial relationships, light analysis, geographic information, quantities and properties of building components (for example manufacturers' details). BIM can be used to demonstrate the entire building life cycle, including the processes of construction and facility operation. Quantities and shared properties of materials can be extracted easily. Scopes of work can be isolated and defined. Systems, assemblies and sequences can be shown in a relative scale with the entire facility or group of facilities. Dynamic information of the building, such as sensor measurements and control signals from the building systems, can also be incorporated within BIM to support analysis of building operation and maintenance."

This definition presents several important facets of the BIM notion:

- It covers the whole life cycle of a building project;
- It creates a single information node that simplifies updates and synchronisation mechanism among actors of the same construction project.

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[8] http://en.wikipedia.org/wiki/Building_information_modeling

- It is a structured collection of building and construction objects including physical components, spaces, processes, actors involved, and relationships among these objects. All of these objects may be enriched by shared or specific properties. As a consequence, quantities or values stored in these properties can be extracted and reused as the source of information to perform calculations, analysis or simulations.
- It is a mean of enabling heterogeneous actors to work together in an efficient way and for better results;
- The BIM is a proven example that systemic usage of models leads to more efficient exchange and speeds up collaboration between projects. Let's see how to expand it at the city level.

2.2 Extending to the city scale: the example of energy management

The system at the level of a city (or even at the level of a neighbourhood) is very complex even considering only the energy aspect. One approach that has been chosen in the Odysseus[9] project is to consider all concepts of the system as energy nodes that can be described with a set of characteristics. The architecture of such network is a mesh of so called "E-Node" which are characterised by their dynamic Energy Profile Card (dEPC) that describes their energy-related capabilities to generate, consume and/or store energy over time.

In the Odysseus approach, a neighbourhood is composed of a set of E-Nodes that can potentially exchange energy through the energy network for an improved global efficiency. Typical nodes are buildings, power plants such as PV (Solar panel electricity systems), geothermal, CHP (Combined Heat and Power) plants, storage plants, civil infrastructures including roads and tunnels with their lighting systems, electric vehicles and charging stations, etc.

A complementary approach to manage the complexity is also to consider different levels in order to represent this composition of E-Node in a kind of "Russian Doll approach". Odysseus defines four different logical levels of granularity for the E-Nodes:

- **The "Building Energy element" level** corresponds to the first aggregation level. For instance, it is supposed to represent zones of a building (simple room, areas in a building) but also houses and flats as a composition of E-Nodes. It could also represent a whole building as a composition of sub zones/ rooms / corridors / flats / etc.
- **The "Neighbourhood" level** corresponds to an aggregation of "Energy elements" of the energy network (e.g. buildings, streets likes, electrical vehicles)
- **The "District" level** corresponds to an aggregation of "Neighbourhoods". The border between the notion of neighbourhood and the notion of district is established by considering that a district corresponds to an administrative denomination of an area (which comprises several buildings & neighbourhoods) while a neighbourhood

[9] Odysseus project : See http://www.odysseus-project.eu/

is the aggregation of buildings that are in the same geographic area (for instance, in the same block or in the same residence).

- **The "City" level** corresponds to the aggregation of "Districts". It is the upper level in the frame of Odysseus but we can imagine easily that there are of course other levels above like "Region" or "Country"…

2.3 Key usages of urban digital mock-up

The urban digital mock-up could be considered as an ICT tool that is built to help conception, decision and communication for local authorities, citizens and even research and design offices. It is dedicated to support the whole life of a planning project. All usages do not need the same quality: the objective is to make the project and the levels of detail of the mock-up evolve together. Main usages are:

- **To promote the territory**, as physical mock-ups did long ago.
- **To conceive and plan**: the mock-up allows inserting a projection of a past or future project, and supporting urban planning like a new linear infrastructure.
- **To manage the city**: the mock-up, as a centralized data container is an innovative and visual way to pilot, monitor and interact with sensors, even in real-time. This is known as the "Smart City" concept. For example, local authorities can decide to decrease the speed limit in case of air quality sensors indicate a negative trend.
- **To predict, analyse, and evaluate**: this is our main topic of decision and conception helping tools. Indeed expert applications need a standard to interoperate and profit from each other. We can quote here the environmental or societal impacts of such projects. In this case, the digital mock-up is very pertinent as a real scientific object allowing managing a multicriteria approach and visualizing it in an intuitive way. See section 4.2 for some examples in eveCity.
- **To communicate and participate**: this is a very useable aspect, linked in France with the growing « participative democracy » and linked with the internet and digital revolution. Citizens meet together with their representatives around a projection (in an immersive way eventually) of the project mock-up integrated in their district in order to take decisions together to better understand a project. The other side of the coin is that every local authority is not always ready to give this transparency to its projects. Information is (still) power!

2.4 Adapted model and supporting format

To support the use in real life applications of the aforementioned concept for cities and districts management, we have to rely on a suitable data model. Moreover, the model has to be linked in close relation with a format, to ensure exchange and interoperability with a wide variety of (end-)users. Thus, we chose to use an already existing, well adopted and recognised standard: CityGML which is maintained by the Open Geospatial Consortium (OGC).

CityGML has now been developed for more than 10 years by the members of the Special Interest Group 3D (SIG 3D). Based on GML3 (Geographic Markup Language version 3.1.1), its version 1.0.0 has been adopted by the OGC as a **standard** in 2008. CityGML is now broadly recognised as the virtual 3D city models storage and exchange format. In 2012, version 2.0 has been released and is considered as a major revision introducing new thematic features (bridges and tunnels) and substantial additions (buildings LOD0 representation among many others …). Currently, this is still a standard which needs to be developed, but it is now accepted and a large user community has emerged. Major GIS tools (ArcGIS, FME …) have integrated this format, thus allowing its use by all actors of urban management. Moreover, CityGML is the only recognised standard at this scale, which is not the case of LandXML, not recognised as such.

In a few words, CityGML can model the main geographic and city objects (terrain, buildings, transportation networks …), together with their appearance, their semantics and their relationships. Its flexibility also comes from the fact that objects can be modelled at several Levels Of Detail (from LOD0 to LOD4: regional to architectural models with interiors). Moreover, for a given object, multiple LODs representation can be given (but also generalisation relations between them), which allows the user to select the one which best fits his needs.

At last, CityGML is "open". Here, "open" means that the standard, which defines the core of CityGML, can be extended if one needs to. This can be achieve through the Application Domain Extensions (ADE) mechanism which enables to enrich existing modules of the CityGML standard, but even to create new features. This is particularly useful to develop special applications for which data modelling are not directly embedded in the standard. For instance, EU FP7 funded projects, such as Ecodistr-ICT and Odysseus, focusing on energy efficiency at district scale, work on the development of a specific ADE dedicated to such a problematic.

All these contextual elements have confirmed our choice to rely on this format / data model.

3. The "Digital City Project[10]"

This project brings together five high-level national research centres (CSTB, ENPC, IFSTTAR, IGN, and METEO-FRANCE) under the global assignment of French Ecology Ministry. CSTB has been leading this project for the last 3 years, focusing on the potentiality of using a centralized and standardized data model to accommodate and support the different aspects of urban projects during their lifecycle, in a close connection with city experts, decision makers and citizens.

[10] In french : Ville Numérique

The project aims to bring together the various expertises in (picture and geometrical analysis, data standard and sharing, mesh generator, scientific computing, software engineering, scientific visualization…) within a common software platform. This implies the interoperability of various mathematical models and data.

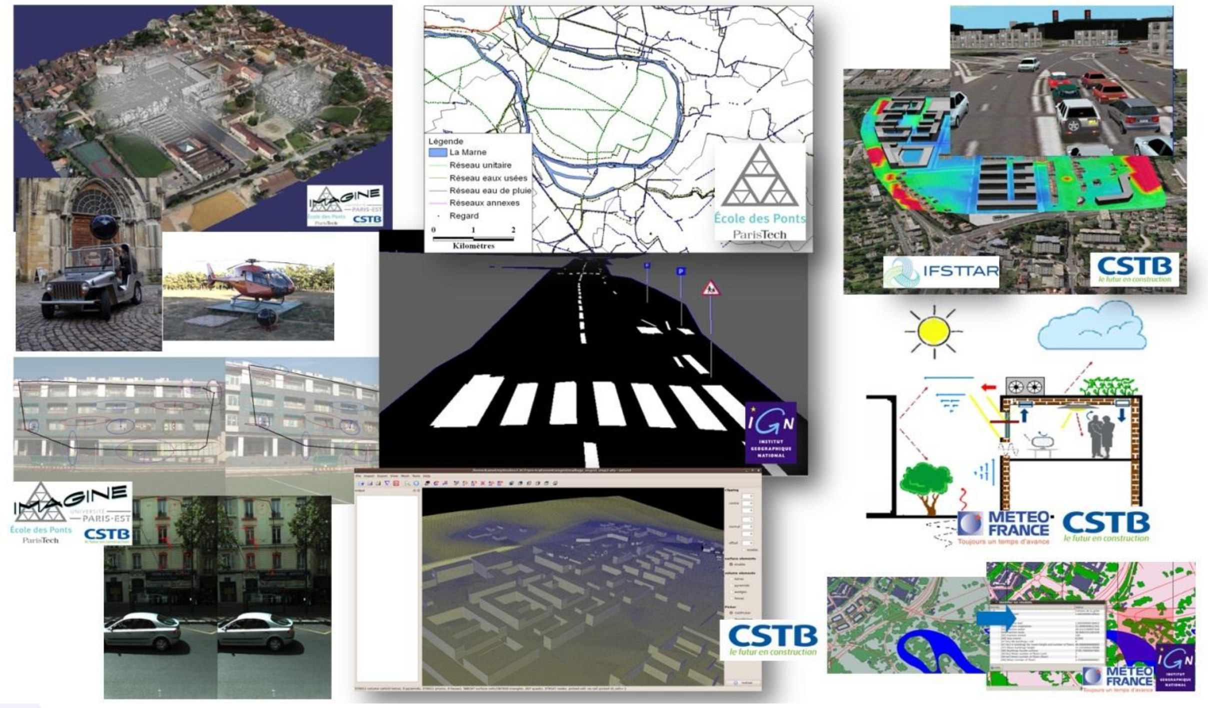

Figure 25: Some results of "Digital City" project. Left: 3D Automatic acquisition and recognition. Top/middle: GIS hydrologic information. Top/right: Coupling traffic and noise simulation. Middle: automatic recognition of road elements from pictures. Bottom/middle: Deduction of air volume from digital mock-up. Middle/right: link between urban meteorology and building energy. Bottom/right: link between GIS information and Weather meshing. Credentials: CSTB, IFSTTAR, IGN, METEO France, ENPC.

One of the main outcomes of this project is that the federation is a really difficult and long term mission: indeed mathematical models have their own data format, vocabulary, working scale, uncertainty, validity model, etc. They are not all sufficiently mature to be implemented in an integrated platform. Thus, making them work together can quickly become a vocation.

To overcome that barrier, it is still possible to follow some simple rules, in terms of data format and transparency, to allow a better exchange, especially at the conception phase of a modelling or a simulation. In order to do that, partners decided to build together a charter called "Digital City Charter[11]" designed to gather all these good principles and

[11] In French : Charte Ville Numérique

practices, and lay the foundations of an integrative software platform in order to connect, share and add value to their research work. This charter is an open initiative which has just started, and which will form a major outcome and continuation of the project.

The aim is to propose it to every institution interested in being interoperable with others. Advantages are significant for members: visibility, cost reduction for data transformation and connection with others, common promotion possible in the software community platform.

The main principles for a model or a digital simulation are interoperability (glossary, variable listing, standard formats…), transparency (objectives, added value, precision, documentation, hypothesis, validity domain…), cooperation (sharing, OpenSource, collaborative research…), value-creation (common platform and promotion, certification…) and promotion.

4. eveCity : a software integrative platform to manage digital urban mock-up

We implement CityGML within a software integrative platform called eveCity [12] dedicated to research (prototype versions) and/or more operational offers (release versions) at the city or district scale. It is based on the Model View Controller architecture, and an Open Source base independent of proprietary technologies. Its main goals are to help and support conception, decision and finally dialogue and communication, for project stakeholders.

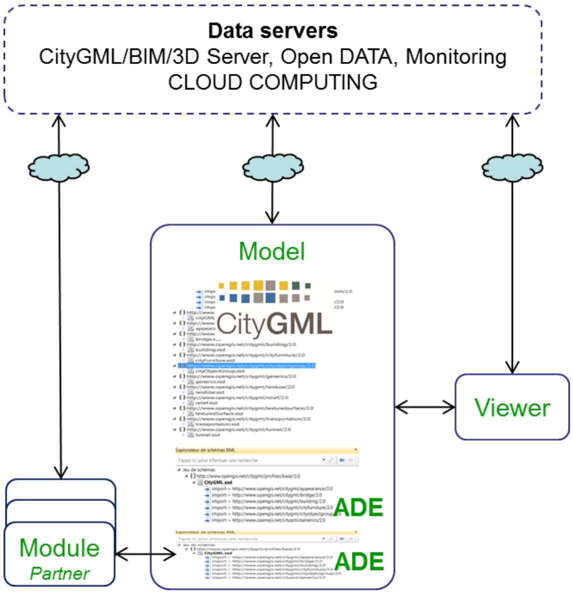

Figure 26: Main principle of eveCity platform

To do so, it hosts several "expert modules" that interoperate in real-time by picking and enriching the model. The results can be displayed within a virtual scene in an integrated, interactive and pedagogical way in order to address non-experts. We will focus in this article on usages related to sustainable issues in a technical point of view (see "Predict, analyse, and evaluate" in section 3.3)

[12] eveCity for "Enriched Virtual Environment for the City".

4.1 Issues and thematic of research

There are obviously a lot of scientific bottlenecks and issues to address in order to build such an integrated platform. Those challenges constitute our main thematic of research within the eveCity platform:

- Hosting and managing a heavy city model on a cloud server (current work is on the API Degree3D, used in the FP7 Odysseus project to host the experiment on two test cities). eveCity then can connect the server to operate on local and smaller data extractions.
- Automatic generation and validation: the release of CityGML as XML Schema Definition (XSD) is of major interest for software developers and data exchange. Indeed, this formalism can be used to automatically generate APIs, and enables files validation which is of great interest for data exchange to ensure integrity and interoperability.
- Human-less 3D acquisition (see 4.3)
- Semantic recognition of those 3D models to enrich the digital mock-up with the data needed for expertise (identify and separate roads for traffic simulation for example)
- Interoperability between expert modules through the digital mock-up to support a multicriteria analysis essential to reach sustainability: this includes technical sectors like comfort, health, environment, energy.
- Integrative and harmonious 3D post-treatment representation of model and simulations for non-expert (metaphors like colour maps, 3D strips, immersive or augmented reality, realistic sound).
- Scales compatibility: models have to be consistent especially at their limits to fit the upper or lower scale. The Level Of Detail (LOD) of CityGML is then used to ensure a fluid transition between scales.

4.2 Expert modules

EveCity aims to gather and federate the large variability of parameters, and scales of each domain of expertise (like noise, environment, traffic, energy, etc.). Thus it introduces the concept of "expert module" capable of extending the main model with its specific variables/parameters and sharing them with other subscribing modules. CityGML offers a generic way to do that through the Application Domain Extension (ADE), formalism from which new modules are built (see 2.4).

Each "expert module" can embed a specific simulation engine led by one of our partners. To be integrated, this "brick" has to follow the principles of the "Digital City Charter" (see chapter 3) to ensure interoperability and coherence between domains and scales of expertise.

Today eveCity manages several prototype expert modules from research, and three operational ones listed here that can interact with each other: (i) Traffic model designed for both macroscopic and microscopic scales, with 3D representation (ii) Noise propagation model with colour map and audio restitution (auralisation) and (iii) pollution dispersion with 3D representation.

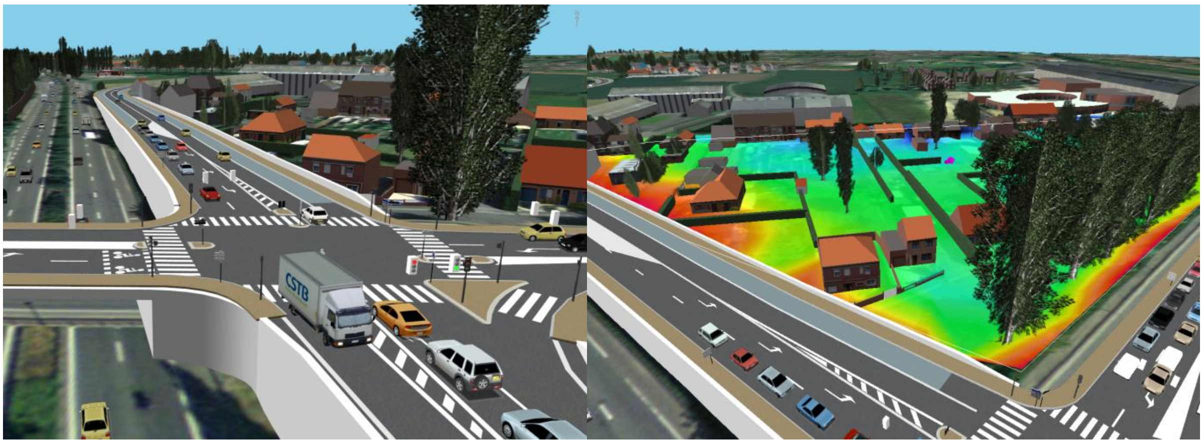

Figure 27: Example of an eveCity R&D work for local authorities in the north of France (Credentials: Conseil Général du Nord, CSTB). The acoustic impact of traffic on a new road is dynamically rendered both with a color map and direct audio restitution (auralisation).

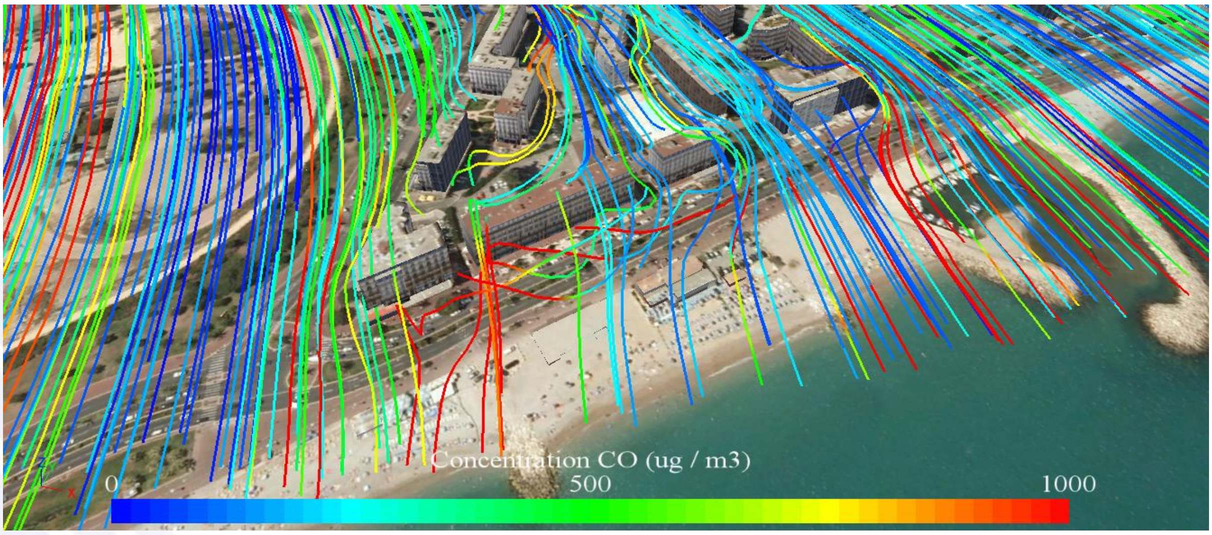

Figure 28: Example of pollutants propagation through a city digital mock-up (eveCity 2012)

Following this process, we plan to develop other expert modules in the frame of European funded research projects: especially Odysseus (dEpC, ICT, smart grids) and Ecodistr-ICT (ICT, renewal taking into account energy efficiency at district scale).

It is worth mentioning the presence of a nearly operational module which aims to evaluate solar energy potential at the district scale. It will help local authorities to map the exact localization of potential solar panels on buildings' roofs. To do so, the module needs an accurate model representing every detail such as trees, chimneys or dormer windows to take every shadow in account (the next paragraph explains how it is now possible to obtain such a level of detail in a short time).

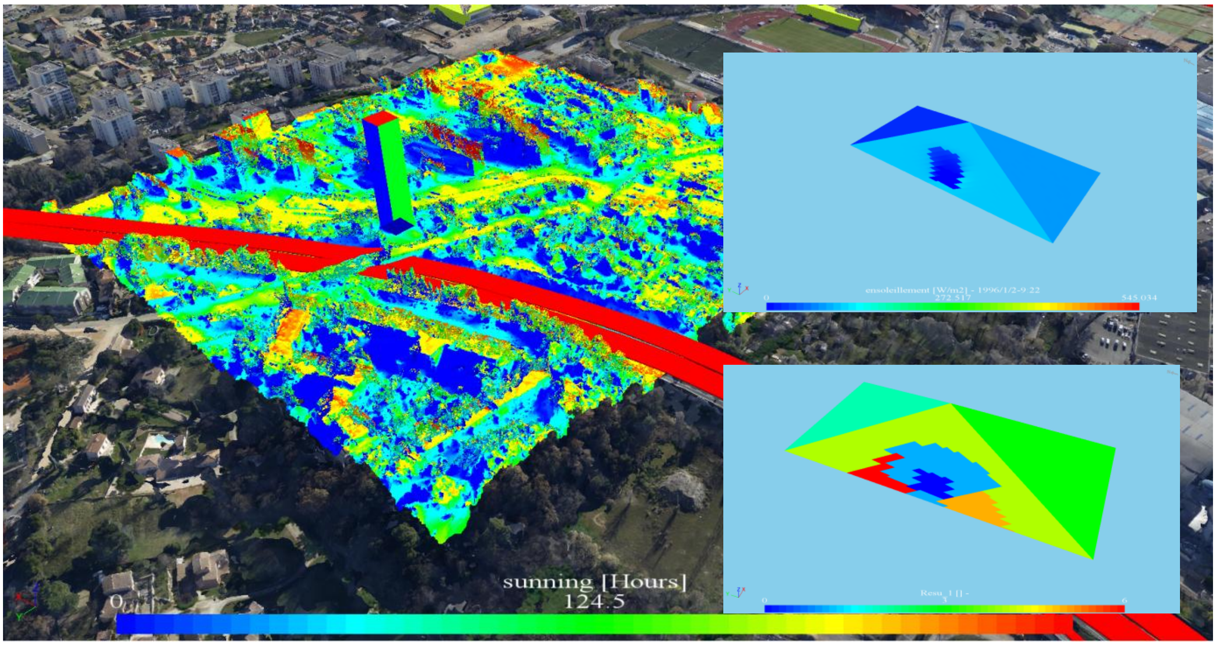

Figure 29: Example of the use of a decision3D[13] 10cm/pixel mock-up to compute solar potential on a district, and on a specific roof. Top-right: Instantaneous incident total solar flux on a 4-panel roof: chimney shadow is clearly visible (chimney meshing cancelled on this view). Bottom-right: Automated meshing group dedicated to calculate homogeneous spatial and temporal area before PV module layout step (light and dark blue area are not exploitable). Credentials: CSTB, Technicom, Acute 3D.

CSTB incites design offices, research units to develop such modules with CityGML interfaces to become compliant with integrated platforms like eveCity, or even simply to facilitate interoperability with others.

4.3 Focus on automatic digital acquisition

To manage urban and district landscapes, a 3D digital representation of the area of interest is required. This is the first step of urban modelling. To do so, we can rely on existing GIS databases. However, they are often out-dated, suffer from discrepancies with the actual environment and some objects (infrastructures or vegetation) are not represented. Thus, to rely on an exhaustive and reliable modelling, we need to build a digital model. To do so, we use a classical computer-vision technique, namely, multi-view reconstruction.

Automatic 3D geometry reconstruction from images has been a key topic in computer vision for a few decades. In the scope of urban area management, producing a model of the area of interest is a crucial step as it provides (i) the base of the visualization and (ii) the required geometry for simulations. Among many others, our method to reconstruct the

[13] See chapter 5 and www.decision3d.com

environment from multiple uncalibrated images (aerial or terrestrial) has been presented and has proven its performances on international datasets [VU 2009]. Thanks to these innovative qualities, a spin-off, Acute3D [14], has been created in 2011, transferring algorithms from academic research to an industrial process. Although it is not in the scope of this paper to describe in details our reconstruction process, let us describe its main steps to have a global overview:

1. Images are first calibrated and the geometry of the scene is reconstructed. A sparse point cloud can thus be obtained from the matched interest points across image pairs
2. From this point cloud, a 3D triangulation is built. It gives a first raw version of the surface
3. The raw surface is then optimized and iteratively refined taking into account geometric constraints and consistency between images
4. The final model is then textured using images, taking into account visibility constraints to get a clean seam line

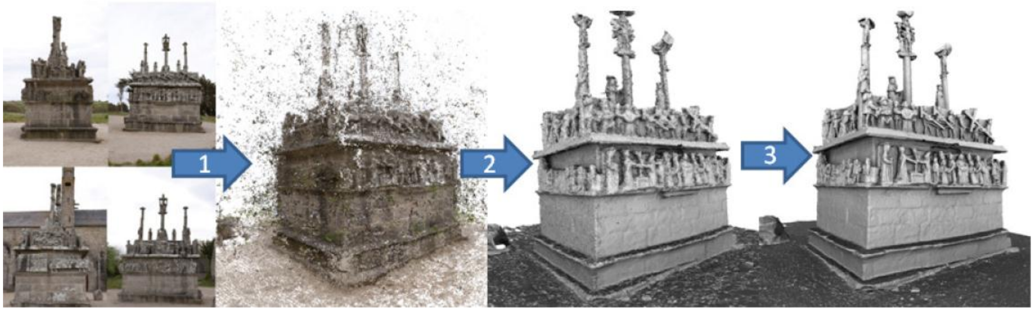

Figure 30: 3D Reconstruction pipeline. 1) Point cloud generation from multiple images; 2) Raw mesh; 3) Refined mesh (Credentials: Vu, Hong-Hiep, Stéréo multi-vues à grande échelle et de haute qualité, 2011)

Naturally, we use this technology with aerial, satellite or ground based images to reconstruct man made environments, but it is not limited to this particular topic [PONS 2011]. Our algorithm can handle every type scene and can thus be used in digital heritage conservation, virtual tourism … Moreover it is able process detailed areas as well as large areas. Thus, we can easily handle several scales, from single buildings to city scale. Once the images acquisition is available, wherever they come from (terrestrial or aerial, with a DSLR widely available camera), the process is fully automatic to reconstruct a 3D model and does not require any human input. From the acquisition to the raw 3D representation, there is no intervention, which provides very reasonable to production costs.

[14] www.acute3d.com

Figure 31: Example of 3D automatic capture using Smart3DCapture technology from ACute3D (Credentials: InterAtlas, Visuel3D, and Acute3D).

However, this first representation of the environment is not sufficient for urban analysis and management. In fact, the output of this first step is a raw 3D representation of the territory: it is a georeferenced textured triangles collection, but it does not carry any semantic information. Semantic interpretation is the process which consists in recognising objects (namely trees, buildings, ground …) and labels them. It provides high level information required for further works using digital models. Thus, the next – crucial – step is to bridge the gap between geometric and semantic modelling. This is currently a work in progress, but, using external GIS databases, we can provide an overview of the global process that is involved in this task. In fact, GIS layers are easily available from National Mapping Agencies and other providers (i.e. OpenStreetMap, Google, Yahoo and Microsoft). Combining this GIS databases with the 3D geometric model is a solution to build semantic information. For example we have combined these data sources for the buildings' layer, as a proof of concept, and are able to label each triangle of the 3D reconstruction as building / non-building.

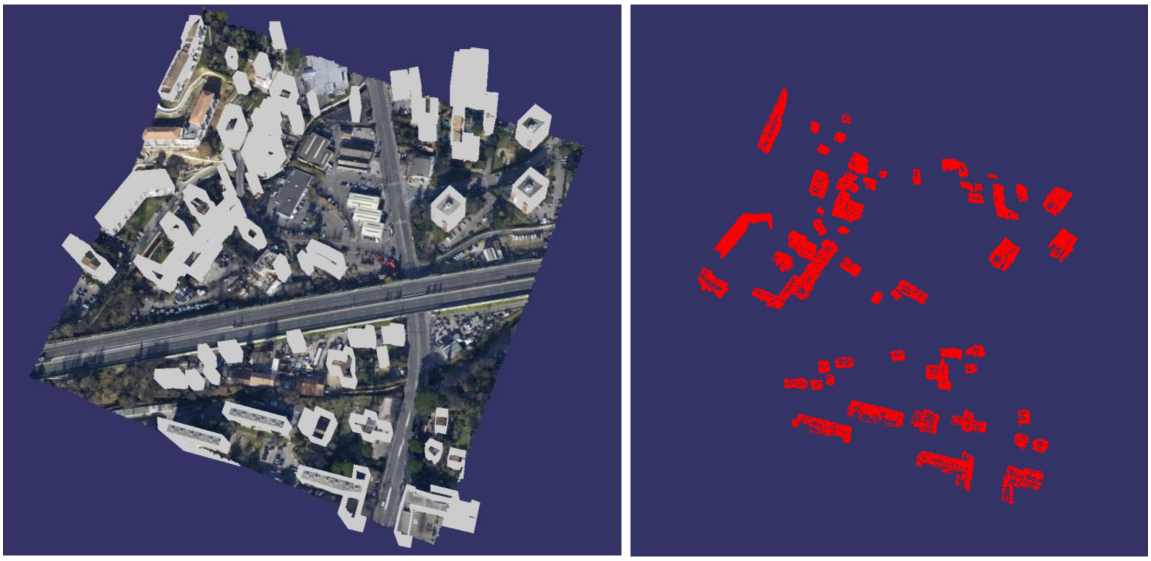

Figure 32: Raw mesh semantization. From left to right: Buildings footprint (from an external GIS database) projections on the raw mesh; Buildings extraction result. Credentials: CSTB, Acute3D, Technicom.

There is however one drawback when combining GIS databases with the 3D surface: both data have (often) not being acquired at the same time, and thus, discrepancies may exist. This can clearly be seen on the first image of Figure 8: input images to produce the 3D reconstruction of the environment are recent, whereas the GIS buildings database is several years old. Thus, some missing new buildings are not in the database, and consequently are not extracted in the mesh. A way to fix this would be to edit manually the GIS database to integrate missing buildings (this can be done quickly since generally only a few buildings are added / destroyed).

However the most reliable solution would consist in applying a process which would not require a GIS input and which works directly on the mesh to extract ground and above ground objects. Each object will then need to be classified to have a rich semantic interpretation of the scene (e.g., separate buildings from trees). Once the semantic information retrieval has been done, the scene interpretation needs to be further investigated. As a matter of fact, if we focus on buildings, they are extracted in the mesh as collection of triangles. Each building is composed of hundreds or thousands of small triangles. Generally, complex simulations computations cannot handle a so detailed geometry. Thus, an approximation has to be computed. This can be done by fitting primitives, like planes, to obtain a more simple representation suitable for simulations.

5 Innovative application for local authorities

A platform like eveCity is a very good way to speed up the R&D process from front-end academic research towards an operational system ready for dissemination. Following this objective, CSTB built a consortium with Acute3D and Technicom to gather their complementary knowledge and propose a unique all-inclusive solution dedicated to help local authorities in developing and managing sustainable projects at urban scale.

The idea is to use 3D automatic capture (see section 4.3) to quickly build a reference and affordable digital city mock-up, easily updated, able to address experts as well as citizens in many usages (listed in section 2.3).

This model will be made perennial by using CityGML (and IFC at the Buildings' scale) to store 3D geometry and semantics in a secured place (like a cloud server).

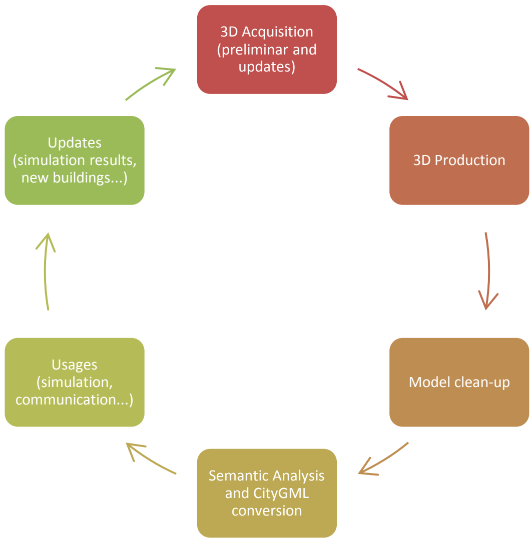

Figure 33: Decision3D schematic process.

City authorities dispose of a powerful digital clone, living along their territory. It will be updated, enriched, and will continuously benefit of enhancements coming from last research results (especially on improving semantics recognition),

They can use the mock-up as a permanent support and saving point to reduce their costs linked with various data needs, making profitable their first investment. They can even form their own collaborators to the mock-up management (as GIS services today). And to cap it all they can participate in dissemination by calling public tenders in a better way inciting candidates to work using standards like CityGML to directly address the mock-up without any heavy processes of conversion.

However Decision3D will already propose and expose a panel of innovative simulations (see some of the expert modules in section 4.2) coming from CSTB experts, public partners, or private companies compatible with the urban digital mock-up "best practices". This expertise will complete, exploit and enrich directly the Decision3D mock-up (results will be new model elements, available for other expertise) while offering 3D representation to make them understandable by the most. Each party will profit from this model, according to the urban authority demand.

6 Conclusions

In this paper, we explored how a well fitted digital mock-up can help local authorities in being more efficient and productive in its territory management, and to supply power tools to support sustainable projects.

But such new tools are of course not sufficient alone to reach sustainable objectives: a revolution in behaviours and governance is needed, especially from the public authorities, to impose better practices and usages. At this only price, these new tools will be gradually better accepted (they are still seen as constraining for the moment) and become the best choice to quickly design optimized solutions fitting every aspects of sustainable development without forgetting political orientation and public debates.

Moreover this new technology benefits of new communication vectors like Google glasses, augmented reality, and of course tablets and smartphones.

The digital mock-up will without any doubt unify in the long term the GIS and 3D data, as CAD replaced plans, to become the standard and shared repository. New businesses have already emerged using data made available by local authorities (OpenData): this is the beginning of a new paradigm where ICT tools allow every citizen to participate to the evolution of its own city.

CSTB takes an active part in the adoption and dissemination of this objective by developing innovative modules and tools supporting sustainable city services.

References

1. SOULA J., Mai 2013. *Maquette Numérique Urbaine : Etat des lieux et perspectives face au marché*. Projet de recherche Ville Numérique, CSTB/TIDS. MOD-EVE-12-187-RE.
2. BELZITI D. & al. , Janvier 2013. *Boîte à outils R&D CSTB pour l'évaluation intégrée des opérations d'aménagement urbain durable*. Rapport final de la tache 4 du projet de recherche « Evaluation des projets Urbains », CSTB/TIDS.
3. GRÖGER G., PLÜMER L., 2012. *CityGML – Interoperable semantic 3D city models*. ISPRS Journal of Photogrammetry and Remote Sensing.
4. BAILLY E., DURET H., Décembre 2012. *Quels apports des maquettes numériques urbaines dans les projets urbains durables ?* Tâche 1 du projet de recherche « Ville Numérique », CSTB/DESH.
5. AUGISEAU V., BELZITI D., BONETTO R., Novembre 2011. *Plateforme d'intégration logicielle*. Rapport final de la tache 4 du projet de recherche « Evaluation des projets Urbains », CSTB/TIDS.
6. SOUBRA S., Hans J., Picinbono G., October 2011. *Information modelling and simulation to support sustainable construction* CIB W078–W102 2011 Conference "Computer knowledge building".

7. SOULA J., LECLERCQ L., MAILLARD J., VAN-MAERCKE D., ZIBOUCHE K., Février 2011. *Couplage de simulations environnementales au sein d'une maquette numérique urbaine*. Colloque « La modélisation de la ville : du modèle au projet urbain », Ecole des Ponts Paris Tech, Marne La Vallée.

8. PONS J.-P., KERIVEN R., TOURNAIRE O., SOUBRA S., Février 2011. *Modélisation 3D Urbaine Automatique par Photogrammétrie Haute Résolution*, Colloque « La modélisation de la ville : du modèle au projet urbain », Ecole des Ponts Paris Tech, Marne La Vallée.

9. LECLERCQ L., BECARIE C., SOULA J., Avril 2010. *Maquette Numérique Urbaine : modèles, réseaux et simulation de trafic*. Rapport final de l'action de recherche « Maquette Numérique Urbaine », CSTB/TIDS.

10. LECLERCQ L., SOULA J., Février 2010. *Impact et modélisation du trafic urbain au sein des maquettes numériques. Prototype et scénarios d'utilisation*. Rapport final de l'action de recherche, CSTB/TIDS.

11. SOUBRA S., 2009. *Combining 3D models and simulations to meet the design challenges of the twenty-first century*. Collaborative Construction Information Management. ISBN 13: 978–0– 415–48422–0. Taylor & Francis.

12. VU, H-H. and KERIVEN, R. and LABATUT, P. and PONS, J.-P, Jun 2009. *Towards high-resolution large-scale multi-view stereo*. Conference on Computer Vision and Pattern Recognition (CVPR), Miami.

13. SOUBRA S., 2008. *The need for creativity enhancing design tools*, Virtual Futures for Design, Construction & Procurement. Peter Brandon (Eds) Blackwell Publishing.

4.2. An ee-district ontology to support the development of the ee-District Information Model of the RESILIENT project.

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Abstract

This paper presents the district information model (ee-DIM), that is being developed in the framework of the RESILIENT project. It describes both the methodology we adopted to design the ee-DIM and its architecture. An iterative process will lead to the design of the final ee-DIM. This process includes: analysing and conceptualising relevant scientific literature, re-using and aligning existing generic and domain ontologies, gathering and conceptualising the knowledge of production system operators and facility managers, collecting and analysing monitored data from pilot districts, and integrating European standards.

1. Introduction

The RESILIENT project aims to design, develop, install and assess the benefits of a new integrated concept of interconnectivity between buildings, distributed energy resources and grids at a district level. This approach requires a set of new ICT components adapted to the context of energy management at district scale.

RESILIENT relies on a comprehensive R&D and demonstration approach. The proposed concept is to be first modelled and simulated across various typologies of buildings and different climates. It will be installed, monitored and evaluated in three pilot projects – in the UK (wales), in Belgium, and in Italy. The solutions in RESILIENT, thus, will be proven here by assessing the energy and environmental benefits. It also allows validation of models and technologies which can be then replicated throughout all the differing European areas.

Many authors agree that development of domain-specific ontologies is an ad hoc process (Madrazo et al., 2012). However, that does not imply that the ontology itself must be built from scratch. It means that strategy adopted in order to build the ontology, the methodology, is case specific. The actual structure and content of the ontology can be constructed from a mix of both pre-existing and specifically made building blocks, as it is the case in any modern software development project (d'Aquin et al., 2008).

In Europe, some projects looked into developing a knowledge base to intelligently analyse the data collected by building automation systems. Project Intube developed a knowledgebase containing semantic building objects, their properties and relationships, which were developed in their energy management and integration platform (IntUBE, 2011). These Intelligent Building Management Systems developed enable real-time monitoring of energy use and optimisation. They also offer interactive visualisation of energy use and solutions to maximise comfort and optimise energy use . An intelligent monitoring system for energy consumption was also developed in the project AmI-MoSeS, which provides information about energy efficiency and knowledge- based decision support system for optimisation of energy efficiency (AmI-MoSES, 2011) .

Research projects have also investigated and developed ontology based approaches to the building automation domain. It has been used to control home automation devices by creating SWRL rules that regulate system behaviour (liente-Rocha and Lozano-Tello, 2010). Ontologies have also provided semantic representation of requirements, in requirement engineering of building automation systems. These contain possible and specific requirements and their casual dependencies. Ontologies help represent intelligent reasoning which can be used to support complex interoperation, generalisation and validation tasks in the building automation environment (Bonino et al., 2008).

The projects mentioned above are largely focussed at a building level. SEMANCO project, on the other hand, also involved energy management and ontologies but was focussed on a city level. It aimed to develop an ontology-based energy information system and tools which help stakeholders, involved in urban planning, to make decisions to reduce CO2 emissions at a city level (Madrazo et al., 2012). ee-DIM ontology and the associated tools developed is applied at a district level and its primary aim is to optimise the local energy production and consumption solely in the district.

The ee-DIM and its ee-district meta-model in particular, formalize a generic, yet capable of specialisation, description of district elements as a socio-technical system. This formalization allows then to produce machine-readable (and even machine understandable) models usable by software tools. In particular, the multi-agent based software tools also developed in the framework of RESILIENT require the ability to infer and extract rules from the ee-DIM.

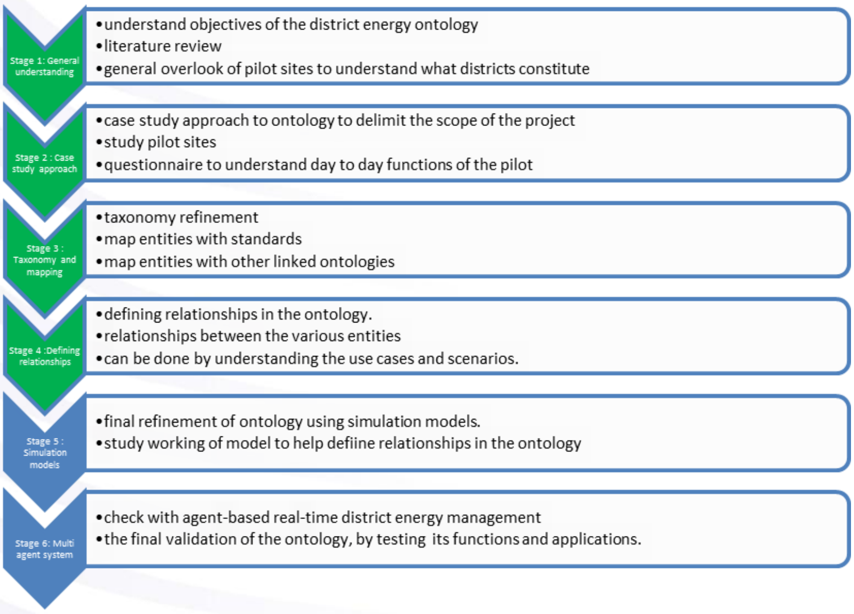
The ee-DIM itself is based on a network of ontologies that abstracts the elements of the district energy system, their characteristics and their relationships, as well as the constraints that apply to them. Some of these ontologies are built from UML models using best practices of the semantic knowledge field. The ontologies have been integrated into the network following novel alignment and modularisation methods.

Section 2 of the present paper presents the methodology adopted by the authors for the development of an ee-District meta-model. Section 3 presents the conceptualisation resulting from the early stages of the methodology and leading to the ontological structure presented in Section 4.

2. Development methodology

One of the key aspects to the RESILIENT project is the design and implementation of the district energy ontology, which would form the core for the ee-DIM. This section describes the strategies followed to develop the district energy ontology.

An OWL ontology was created and continuously developed to model according to the knowledge collected throughout the different stages of the methodology. Thus, it has inputs from literature such as (Cricchio et al., 2007), interviews with stakeholders, questionnaires, domain expert knowledge, various standards such as (IEC 61970-301:2011) and existing ontologies. It is an iterative process, because of the complexity of the project and the collaborative nature of the work between partners. The methodology is described in the following stages:



Understanding the application and scope of the district energy ontology.

Firstly, before starting to develop the ontology, it is crucial to understand how the ontology is to be used by a third party software or user in the scope of the project. The district energy ontology developed in the framework of RESILIENT is designed for district multi-energy coordination involving combinations of storage systems, generation units, cogeneration units and energy users, in order to:

- answer queries from real-time optimization software;
- ensure interoperability district coordination level entities and building/energy resource level.

The ontology would therefore model all the district entities (energy producers, distributors, consumers); the infrastructure for transfer of load (pipelines, power cables); the load schedules; the demand and supply trends or patterns; the major constraints of the overall system and some of individual entities; the objectives that are to be met. Most importantly, the relationships between these entities need to be incorporated into the ontology. Once the objectives are clearly defined, a general overlook at RESILIENT project's pilot sites is important to identify the different physical components installed in a district as well as the stakeholders. This produces an overview of how the district is currently operated.

This first site study helps define the scope of the information model. It is an iterative process and will be carried on throughout the development of the ontology. However, the initial analysis of district ought to identify the different components which constitute a district and how they are linked together. The work on district energy ontology continued then with basic literature review on these different components of a district. For example, it included looking into physical aspects of a district - energy sources (production) and its classification; consumption points; means of distribution of this energy… etc. The ontology also includes social aspects such as stakeholders. The functions and conditions set in the stakeholder entity would have an effect on running of districts and would contribute to laying ground rules for energy optimisation in the district. Hence this is a very important part of the district energy ontology which would look to define some of the boundaries for the various optimisation problems to be solved.

Some key elements of the District energy ontology that were concluded during this stage was:

- The ontology is to be used to model energy information at a district level.
- The ontology should support the development of tools, which enable real-time decision making for district energy optimisation.

- It is to be developed using the OWL Semantic Web Language, providing the ontology engineers with a good extension of modelling formalisms.
- The ontology needs to be linked with other standards and accepted ontologies.

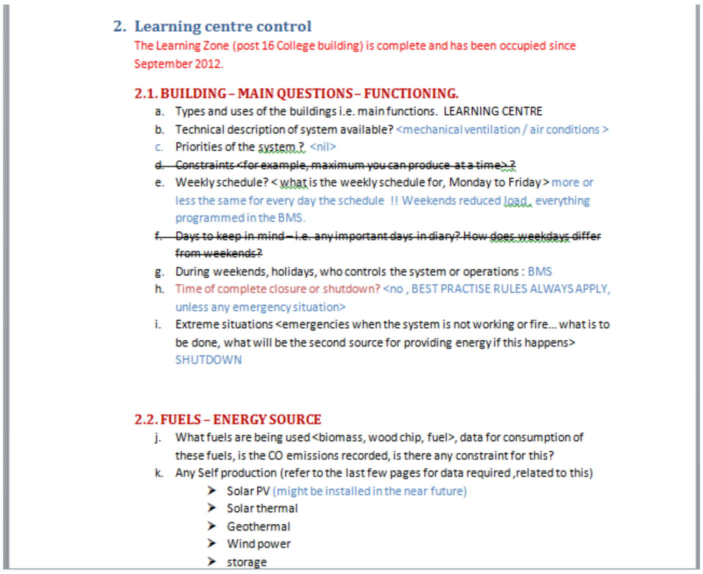
This can be considered as stage one of ontology development, which is largely based on literature review and constructed relying on a very general understanding of how a district works.

Case study approach to further develop the ontology.

Case studies attempt to understand more specifics of the actual working of the different pilots in the project. Their purpose is to get an idea of how the district works in the current real conditions. There can be significant differences in functional descriptions of districts in literature and how it would work in reality; hence, the importance of this stage.

One key part of this stage of ontology development is the questionnaire which was developed. The questionnaire was aimed at the UK site first. It collects information such as district energy scheme/layouts, informal description given by facility owners/managers, operational manuals of different entities of a district, understanding of the different functioning of buildings in the district and their demand and supply patterns. The questionnaire is split into different sets of questions, where each set is aimed at the different producers and consumers in the pilot site. A set of questions is also dedicated to the general day to day operations of the district. Screenshots of the questionnaire can be found below in Figure 34 and Figure 36.

The questionnaire prepared for RESILIENT project's pilot site in Ebbw Vale (Wales, UK) was answered through a series of interviews – both in person and over the telephone; further developed through site visits. Like stage one, the development of the questionnaire was also an iterative process. This then is fine tuned to fit the other two sites in the project as well. This was also followed in (reference seamnco project) mainly because it enables delimiting the scope of the research and to a certain extent also helps define the tools needed by stakeholders. Furthermore, use cases/scenarios may be identified during this stage which will help the development of the ontology from the application perspective (end use).



2. Learning centre control

The Learning Zone (post 16 College building) is complete and has been occupied since September 2012.

2.1. BUILDING – MAIN QUESTIONS – FUNCTIONING.

a. Types and uses of the buildings i.e. main functions. LEARNING CENTRE
b. Technical description of system available? <mechanical ventilation / air conditions >
c. Priorities of the system ? <nil>
~~d. Constraints <for example, maximum you can produce at a time> ?~~
e. Weekly schedule? < what is the weekly schedule for, Monday to Friday > more or less the same for every day the schedule !! Weekends reduced load , everything programmed in the BMS.
~~f. Days to keep in mind – i.e. any important days in diary? How does weekdays differ from weekends?~~
g. During weekends, holidays, who controls the system or operations : BMS
h. Time of complete closure or shutdown? <no , BEST PRACTISE RULES ALWAYS APPLY, unless any emergency situation>
i. Extreme situations <emergencies when the system is not working or fire… what is to be done, what will be the second source for providing energy if this happens> SHUTDOWN

2.2. FUELS – ENERGY SOURCE

j. What fuels are being used <biomass, wood chip, fuel>, data for consumption of these fuels, is the CO emissions recorded, is there any constraint for this?
k. Any Self production (refer to the last few pages for data required ,related to this)
   - Solar PV (might be installed in the near future)
   - Solar thermal
   - Geothermal
   - Wind power
   - storage

Figure 34 : Case study questionnaire, sample question.

Due to the iterative and collaborative natures of this methodology, the authors shall put in place a more effective way of collecting and sharing knowledge in the months ahead. Web based wikis such as Cicero (Suárez-Figueroa et al., 2008) or survey management systems such as the Bristol Online Survey will be considered (BOS).

Taxonomy development.

The taxonomy stage involves getting into details of the various entities already defined in the ontology, i.e. categorising the entities and finding generalisation/specialisation associations between them. Most of the taxonomy developed is backed by the literature review produced during stage one and the information gathered from pilot sites during stage two.

- Energy converters
  - Energy generation systems
    - Electricity source
      - Distributed energy resource
        - CHP source
        - Non-CHP source
    - Heating source

Energy storage systems

- Electricity storage system
- Heat storage system

Loads

- Load
  - Electricity load
  - Heating load

Energy distribution networks
Area power system (Main grid)
Local power system (Microgrid)
Control devices
Meter devices

- Sensor devices
- Communication infrastructure
- ICT infrastructure
- Stakeholders
  - Building manager
  - Building owner
  - Building user
  - Resource aggregator (VPP owner/manager?)
  - Resource maintainer
  - Resource owner
  - Resource operator
- Geospatial information
  - Object location
    - X,Y,Z coordinates or approved geo-referencing system
    - Line or curve coordinates

Figure 35: Early Categorisation of Concepts.

Once the taxonomy has been defined, this stage also plays a huge role in trying to map the entities defined in the district energy ontology with entities from other ontologies and the standards that are planned to be included. Figure 35 shows an early version of the categorisation and taxonomy. This might be a tedious task during the early stages of Ontology development, however, it is necessary to increase the potential applications of the ontology at a later stage, in other words, make it more robust.

Relationships in the ontology.

Relationships (other than taxonomical relationships) between classes of the ontology will be template against the socio-technical system ontological module presented below in Section 4. The authors are currently implementing the addition of rules on top of the ee-district ontology. These rules will represent local practices of the facility managers that are not machine-readable and thus not available to request from the district's individual energy management systems. Examples of such rules can be safety/emergency measures or manually set energy schedules.

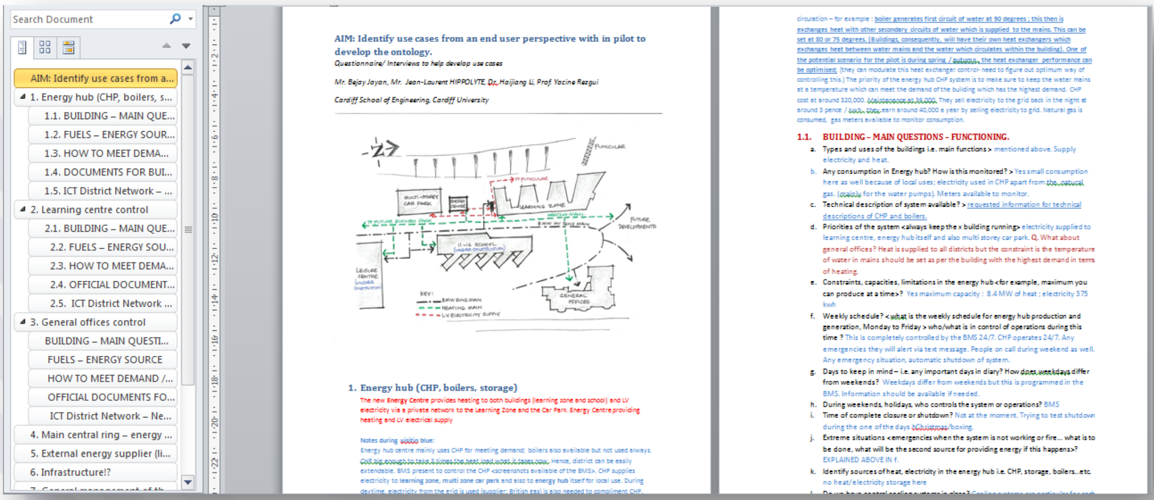


Figure 36 : Case study questionnaire.

3. Conceptualisation of an ee-district

In the recent years, various European communities/districts have developed new models of local energy production and supply. These new initiatives have been conducted by either public authorities or private companies or non-profit charity or entities resulting from an agreement between any of those three kinds. In all cases, they aim to deliver "energy efficiency, energy savings and/or sustainable energy" (Brodies LLP, 2007).

A district energy system is composed of networks of physical entities (buildings, energy systems, network, storage facilities…) as well as networks of social entities (stakeholders), all interacting with each other. Figure 37 illustrates a fictitious simplistic example of the multiple energy network structure of a district. The semantics of the horizontal links (depicted by plain lines) between entities is network-specific. The vertical links (depicted by dotted lines) are ownership/composition relations.

Figure 38 shows an abstracted viewpoint of district energy systems, mostly inferred from (Chaudury et al., 2009), although this book only deals with one particular form of energy (electricity). An intermediate abstraction has to be placed in the middle, in order to align the multi-network nature of a district energy system with such flat conceptual models. That is the purpose of the socio-technical ontology further presented in Section 4.

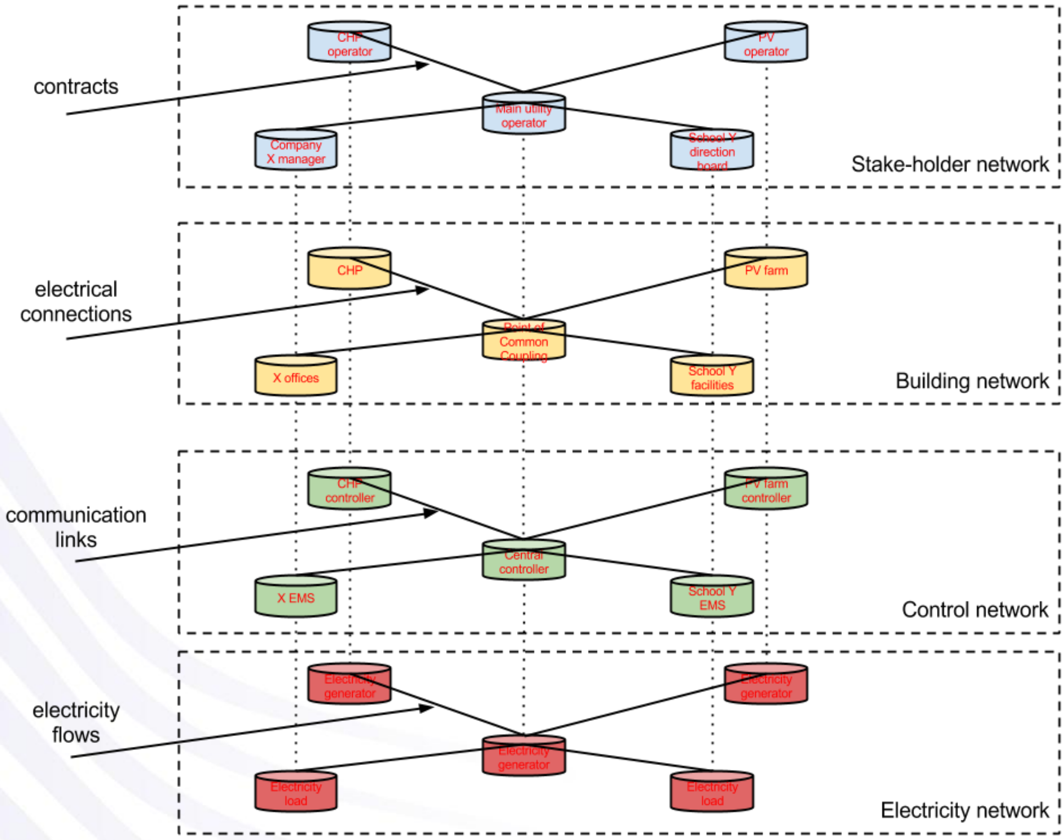


Figure 37 : A mock example of multi-network district energy system.

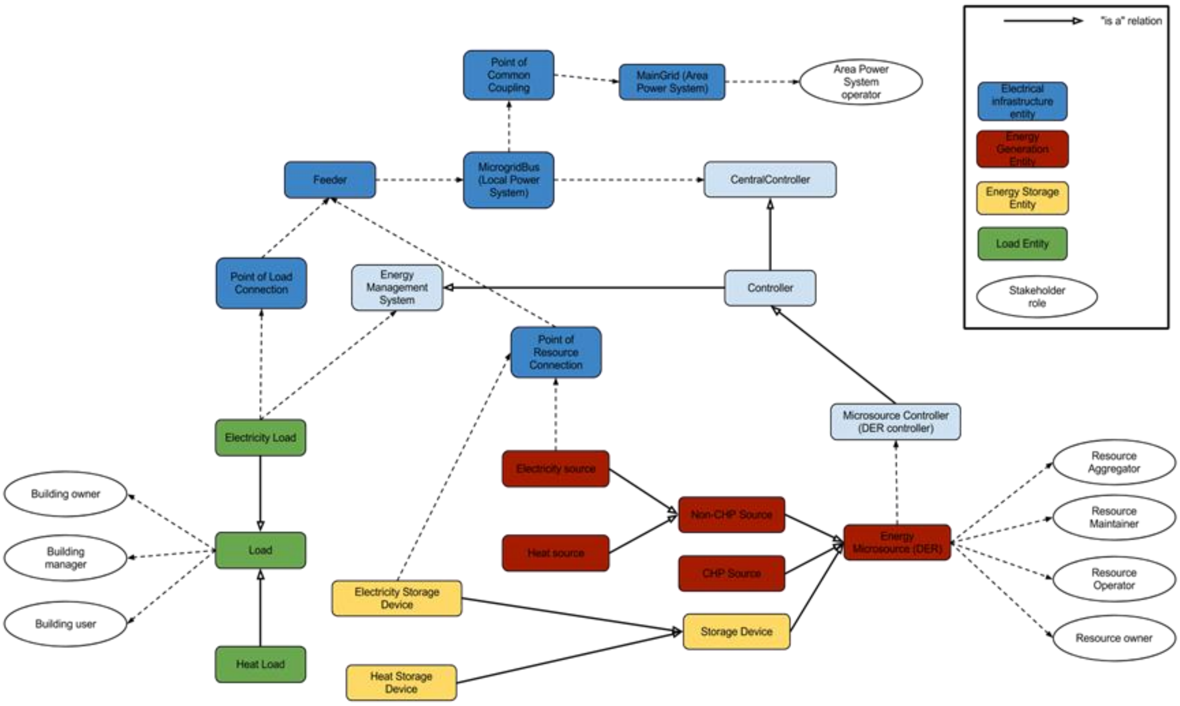


Figure 38 : Concepts in a district energy system.

4. Semantic structure

Building and energy being such fragmented interdisciplinary sectors, any knowledge management system intending to be deployed for practitioners of these sectors need to adopt a layered and modular approach (Rezgui, 2007). As a result, the two main aspects of the semantic structure of the ee-District Information Model are:

- district energy systems are modelled as socio-technical systems,
- a meta-model of district energy system relies on an organised set of diverse ontologies (interdependent or self-sufficient according to their level of abstraction).

Socio-technical systems have been modelled differently within different research fields (partially because different fields require different views and partially because the definition of the concept of a socio-technical system may vary from one field to another). The resulting field-specific tools are therefore not meant to be generic. (van Dam, 2009) tries to abstract the concepts of socio-technical systems across disciplines, as shown in Figure 39. That thesis views systems that contain both social and physical elements as nodes in networks. The social nodes make decisions about the physical nodes. The physical nodes are converters of particular physical or virtual goods (e.g. energy, information…). As shown in Figure 37, a district energy system is an instantiation of such a socio-technical system, where the social elements (stakeholders) are depicted in the top layer and the physical elements (buildings, monitors/controls, distribution connections) are depicted in the three bottom layers. A hierarchy of classes representing physical edges and social edges allow to model the connections between nodes of the same conceptual network.

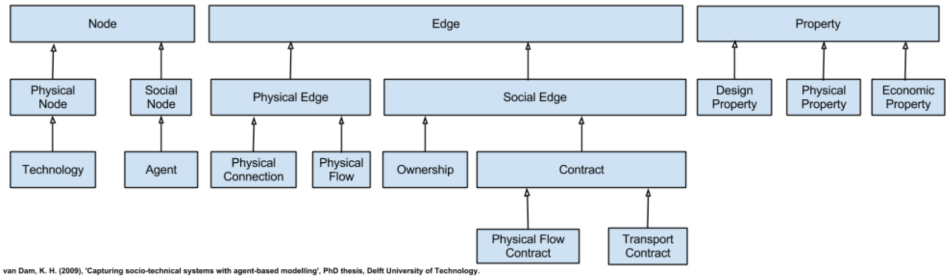


Figure 39 : Core classes of the Socio-technical System ontology.

Because the knowledge sources used in the RESILIENT project are so diverse in content and in format, building the ee-district information model also falls into one of the category of scenarios described by (Suárez-Figueroa et al., 2008): Building Ontology Networks by Reusing and Reengineering Non Ontological Resources. This deliverable of the European project NeOn provides recommended practices for transforming resource content (dictionaries, terminologies etc…) into ontological schemas. Normative documents regarding international and European standards are examples of such resources. In particular, the IEC/EN 61970-301 standard is essential to the ee-DIM, since it is supposed to facilitate the integration of Energy Management System (EMS) applications developed by different entities (IEC61970-301:2011). Thus, it could facilitate interoperability between RESILIENT's district coordination systems and the district's consumer entities (buildings) and the district's energy generation units. The integration of such a standard in the ee-district ontology shall make the support of different building automation and communication protocols such as BacNET (ISO 16484-5:2012) simpler.

The meta-model of ee-district ontology therefore adopts a modular architecture. Figure 40 shows the structure adopted by the authors, which is derived from OntoCAPE's meta-model (Morbach et al., 2007). OntoCAPE is a domain ontology developed for Computer Aided Process Engineering. Although the meta-model on which it relies was originally developed for this particular ontology, it has been successfully applied to the design of ontologies for other domains. The meta-model represents both explicit "underlying design principles" and establish "common standards for the design and organisation" of the considered ontology.

The ee-district meta-model approach is similar. It formalises a template that encompasses the domain ontologies required to support the definition of an ontology that would be specific to a district. Figure 40 shows the main modules that have been identified during the first 2 stages of the methodology presented in Section 2. The dashed arrows symbolize dependency relations between modules. It can be noticed that the above socio-technical system ontology, although it has been defined and implemented as self-contained by its authors (apart from the re-use of OWL language built-in elements), has been aligned with the OntoCAPE meta-model. In particular, the topology module (defining fundamental concepts from the theory of connectedness) and the mereology module (defining fundamental concepts from the theory of part-whole relations) are both essential in the standardisation of network and ownership concepts across the ee-district meta-model.

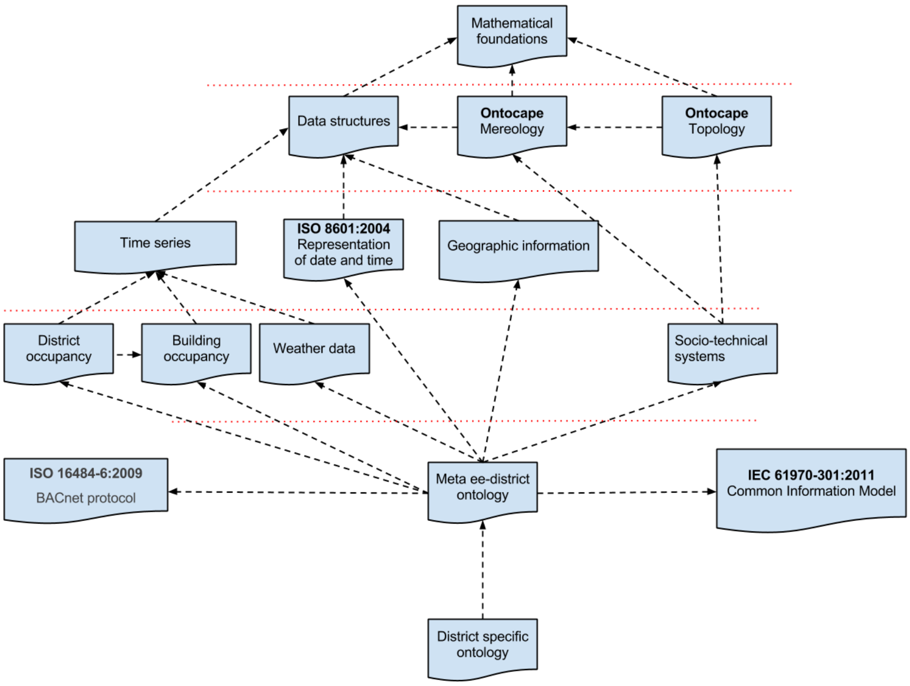


Figure 40 : Module hierarchy of the ee-distrit ontology

5. Application

The RESILIENT project will deliver a holistic framework to optimise both the design and the real-time operation of district energy systems. The ee-DIM's ontology formalizes the description of all district elements, expressing them in a coherent software-consumable representation and therefore usable by the components of the framework. *Figure* ***41*** depicts, as a BPMN collaboration diagram, the interactions between the ee-DIM (or more precisely, the central part of its realization, the ontology server) and RESILIENT real-time energy management optimization components. The ontology server providing static information about the district elements, their capacities, their topology is an illustration of how the ee-DIM can be applied. At the bottom of the diagram, the GIS information and the energy efficient rules editors are additional examples of ee-DIM application.

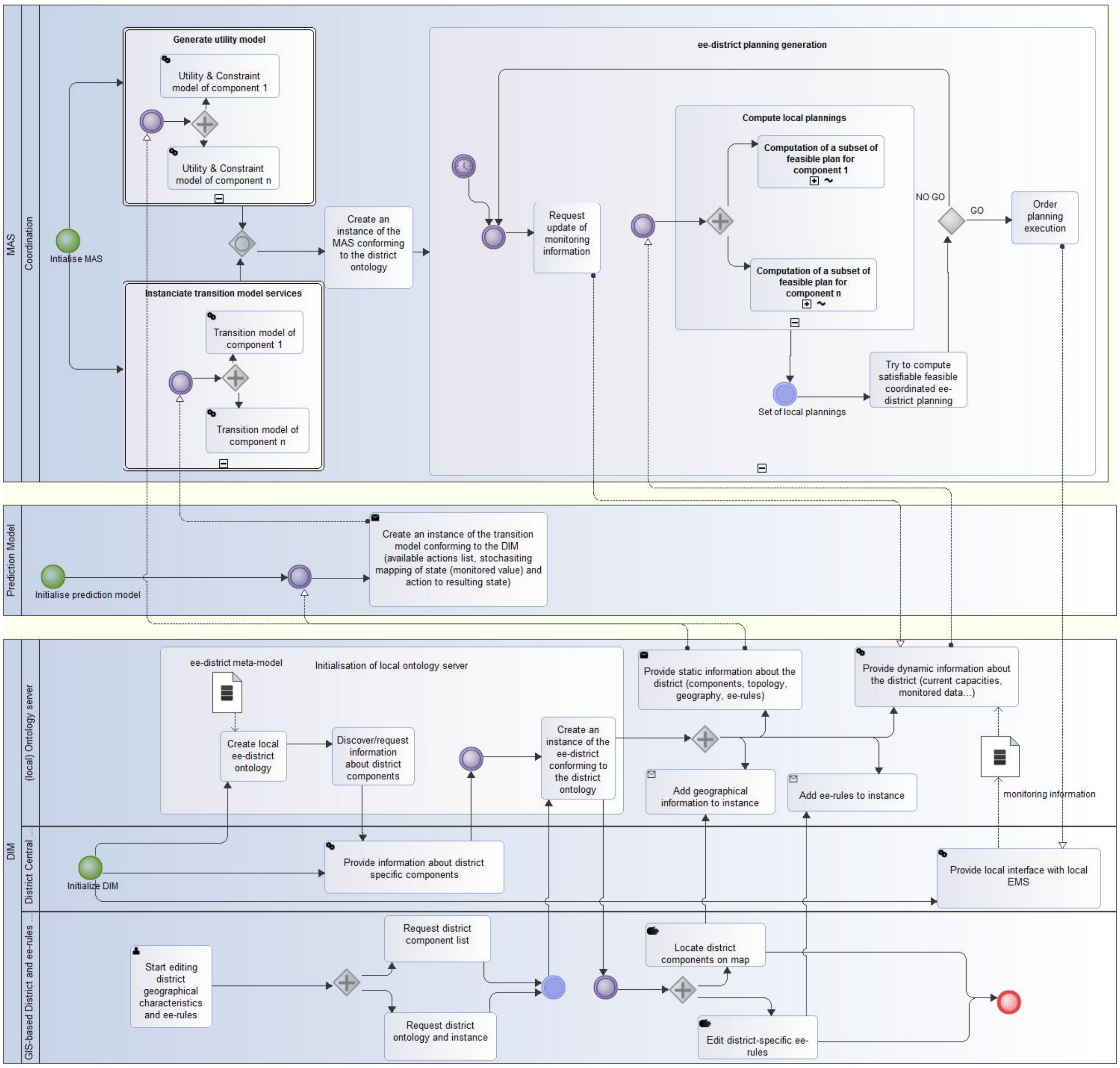


Figure 41 : ee-DIM and multi-agent based real-time optimizer collaboration diagram

6. Conclusions

This paper has presented the on-going development of an ee-district information model aiming to support an intelligent coordination between energy generation units, energy storage systems and energy loads at a district level. Although, the ontology itself is not complete yet, an iterative methodology has been defined to achieve comprehensiveness in representation, interoperability and operational requirements.

The methodology is composed of six stages: general understanding, case study, taxonomy definition, relationships and rules definition, validation against simulation and validation against real-time energy management system.

During the concept identification process, the multiplicity of knowledge sources and the interdisciplinary nature of the targeted domain have revealed needs for a multi-layered modular ontological structure.

The adoption of an ee-district ontology meta-model should help achieving more flexibility for the integration of various standards and protocols well as providing the formalism foundations to support the representation of the optimisation concepts required by RESILIENT's district-level coordination system.

All components of the RESILIENT framework, in particular an agent-based real-time coordination system, will rely on the ee-DIM.

Such a framework needs to be managed not only for energy efficiency or sustainability but also for resilience (the ability to recover from perturbation). A well designed structure such as the ee-DIM will help building such a versatile ICT infrastructure.

Acknowledgments

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References

1. AmI-MoSES Concept Public Report, Deliverable D7.4 , 2011, Available from http://www.ami-moses.eu/
2. Bonino, D.; Castellina, E. & Corno, F. (2008). DOG: an Ontology-Powered OSGi Domotic Gateway, In: Proceeding 20th IEEE International Conference on Tools with Artificial Intelligence, Vol. 1, pp. 157-160, IEEE Computer Society Washington, DC, USA
3. Brodies LLP (2007), 'Making ESCOs Work: Guidance and Advice on Setting Up & Delivering an ESCO', Report published by the London Energy Partnership.
4. Böhms, M.; Bonsma, P.; Willems, P.; Zarli, A.; Bourdeau, M.; Pascual, E.; Storer, G.; Kazi, S.; Hannus, M.; Sedano, J. A. G.; Triguero, L.; Tsahalis, H.; Eckstein, H.; Josefiak, F. & Schevers, H. (2008), 'D23 The SWOP Semantic Product Modelling Approach With PMO – The SWOP Product Modelling Ontology', Technical report, SWOP consortium.
5. Chowdhury, S.; Chowdhury, S. & Crossley, P. (2009), Microgrids and Active Distribution Networks, The Institution of Engineering and Technology.

6. Cricchio, F.; Mastrodonato, C. & Reccardo, D. (2012), 'D2.2.1: Report on state-of-the-art (International) ICT-based innovation projects', Technical report, IREEN Consortium.

7. van Dam, K. H. (2009), 'Capturing socio-technical systems with agent-based modelling', PhD thesis, Delft University of Technology.

8. d'Aquin, M.; Haase, P.; Rudolph, S.; Euzenat, J.; Zimmermann, A.; Dzbor, M.; Iglesias, M.; Jacques, Y.; Caracciolo, C.; Aranda, C. B. & Gomez, J. M. (2008), 'D1.1.3 NeOn Formalisms for Modularization: Syntax, Semantics, Algebra', Technical report, NeOn consortium.

9. IEC 61970-301:2011, 'Energy management system application program interface (EMS-API) Part 301: Common information model (CIM) base', BS/EN/ISO/IEC Standard, British Standard Institution.

10. Liente-Rocha, P.A. & Lozano-Tello, A. (2010). Ontology-Based Expert System for Home Automation Controlling, In: Proceeding IEA/AIE'10 Proceedings of the 23rd international conference on Industrial engineering and other applications of applied intelligent systems, Volume Part I, pp. 661-670, Springer-Verlag Berlin, Heidelberg

11. IntUBE Integration Platform Specification, In: IntUBE Executive Summary of Deliverable 6.2, 2011, Available from http://www.intube.eu/

12. ISO 16484-5:2012, 'Building automation and control systems. Data communication protocol', BS/EN/ISO Standard, British Standard Institution.

13. Morbach, J.; Wiesner, A. & Marquardt, W. (2007), 'A Meta Model for the Design of Domain Ontologies'(LPT-2008-24), Technical report, RWTH Aachen University.

14. Suárez-Figueroa, M. C.; de Cea, G. A.; Buil, C.; Dellschaft, K.; Fernández-López, M.; García, A.; Gómez-Pérez, A.; Herrero, G.; Montiel-Ponsoda, E.; Sabou, M.; Villazon-Terrazas, B. & Yufei, Z. (2008), 'D5.4.1. NeOn Methodology for Building Contextualized Ontology Networks', Technical report, NeON consortium.

15. Madrazo L., Sicilia A., Gamboa G. (2012), 'SEMANCO: Semantic Tools for Carbon Reduction in Urban Planning', in Proceedings of the 3rd Workshop fo the EEB Data Models Community, European Conference of Product and Process Modeling (ECPPM 2012)

16. Rezgui, Y. (2007), 'Text-based domain ontology building using Tf-Idf and metric clusters techniques', The Knowledge Engineering Review 22, 379--403.

17. BOS, Bristol Online Surveys, http://www.survey.bris.ac.uk/

4.3. Towards an integrated information system for energy management in buildings

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Abstract

For the purpose of automated holistic building energy management within the knoholEM FP7 project, a technique for the explicit and consistent integration of system 'perspectives' that include a number of knowledge, data and run time models is proposed. The technique employing a metamodel allows the systems development process to exploit native and mature domain specific modelling and shifts the developer away from implementation of data format transformations, focussing on conformance to modelling syntax and implied semantics. The integration of model 'perspectives' is realised with the definition of a metamodel using OMG's meta object facility (MOF). The metamodel defines the perspectives and establishes relevant relationships between the high level (abstract) entities that manifest in the various domain models, incorporating relevant theories and patterns. Further system wide theories and specifications (aspects) cross the perspectives in the metamodel are used to render consistency and uniformity. The metamodel is easily extendible to facilitate the integration of further perspectives such as those that interface to numerical simulation and optimisation tools.

Key phrases: multi perspective, meta model, uniform integration.

Introduction

In the knoholEM project [1], a number of established and mature domain modelling techniques are used in the *system* development which have varying properties and characteristics. The modelling of buildings from a (static) product perspective utilises primarily the emerging STEP/EXPRESS based Industry Foundation Classes (IFC) [2] standard while further perspectives, including the modelled descriptions of dynamic behaviours and whole building lifecycle related activities are captured using UML activity models. Additionally a further system perspective utilises data mining to realise core system functionality. Realisation of the 'non (native) executable' models (all those outside of the ontology / reasoner and data mining) are manifested by algorithmic and software code which are considered to embody further perspectives. Those system perspectives, capturing the knoholEM system development methodology, specialise the various development lifecycle stages in terms of their modelling, delivery of ICT support and integration of related activity including software implementation and system interaction (other tools, sensor hardware and humans). Thus a technique is required to describe the abstract formulation of the perspectives so as to attempt to provide consistent integration of the system and to persist common theories holistically, both in a *longitudinal* direction within the development lifecycle and in a *lateral* direction across a development phase. The use of a metamodel provides that specification and can be used to identify mappings to core theories which clarifies rationale and renders consistency, or to explicate any overlap and associated mappings where design considerations justify that.

Common general definitions of the term *metamodel* in the context of information technology refer to the specification of the constructs and rules used for the definition of (more abstract) models. Definitions reaching beyond the specification of modelling languages e.g. for UML (and OCL) and OWL, include that presented by Malavazos et al. [3]. They state the modelling scopes as "domain, design and integration" and identify the metamodel within the design scope as "macro-level design (generates concrete metamodels .... that act as templates or reference structure) and micro-level (concerned with the definition of the structure of data models or representation languages) design". Instantiated models conform to syntax described by the metamodel in terms of elements and rules (**Error! Reference source not found.**). Syntax in turn is mapped to semantic domain definitions which can be specified with an ontology, mathematical / logical expressions or plain text. Thus semantic foundations have varying formality e.g. the semantic definitions of the UML metamodel are presented as mainly informal textual descriptions.

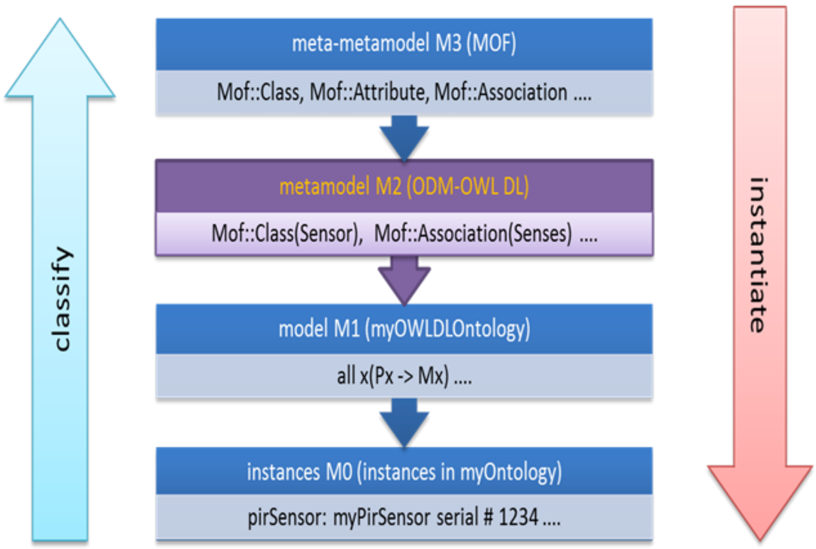

Figure 42 - metamodel in context with sample statements.

This paper presents the case to develop a *logical* metamodel to describe the knoholEM system perspectives and to facilitate the integration of those perspectives for the development and run time realisation of an automated holistic building energy management system. To illustrate the principles the manifestation of mereology in the metamodel and implementations in some model and run time perspectives is briefly mentioned. Semantics are typically derived from the donor formulation used.

1. Related areas

The work presented utilises fundamental principles defined by Model Driven Architecture (MDA) [4] incorporating conventional software artefacts such as models and their implementation and additional 'machinery' including knowledge bases, data mining (algorithms) and hardware. MDA supports the definition, transformation and interconnection of models (views) that depends on a metamodel, to define those models, their relationships and interconnections, across the same and between different levels of abstraction. Specifically, 'marks' for example describe the mappings for 'longitudinal' transformations in the platform independent model (PIM) to the platform specific model (PSM). Illustrative of MDA and metamodel utilisation is Executable UML (xUML) that executes platform independent models (PIM) for the purpose of for example to demonstrate compliance with appropriately represented requirements.

For authoring metamodels a number of notations exist including the above mentioned MOF (an object oriented, UML 'class like' notation). MOF was chosen here for its simplicity together with the availability of existing metamodels captured using that representation. Alternative frameworks include OMV, an ontology meta description language described as "a metadata standard reflecting the most relevant properties of ontologies for supporting their reuse" [5]. Other specific metamodeling facilities include MEMO [6] and MetaGen [7] among others. Additionally modelling layers can be structured as an RDFramework 'stack'. Well known model realisations of specifically MOF include UML, CORBA IDL, and XML.

Alternatives to metamodeling include of course the complete omission of any metamodel. Conversely while only targeting knowledge bases cf. system wide the NEON [8] framework's support for 'contextualised networked ontologies' object oriented 'like' support for integrating ontologies. A further alternative, definition of view correspondences at the meta level, in the scope of building form a significant part of the formulation of knoholEM) is the definition of ad-hoc partially localised exchange interfaces that could be defined with for example the Information Delivery Manual (IDM) [9]. A summary of the features of alternative

approaches are shown in

	Advantages	Disadvantages
Metamodel	Potential for consistency throughout diverse perspectives. Supports integration of perspectives and facilitates collaboration among developers and teams. Given a well design metamodel sounds engineering theories, application of patterns can be applied without detailed familiarity by the developer. Can be utilised formally or informally.	May require extensive effort to develop, might be ignored without tool support.
No 'upper' / meta formalism	No overhead and no constraints on the developer. Software engineering best practices can still be applied, relying on the application of modelling syntax with mapped / implied semantics	Rationale can be difficult to identify, not uniformly applied leading to duplication and possible inconsistency.
Information Delivery Manual	Well documented and some reported utilisation. Construction industry process focussed providing a ".... detailed functional breakdown of processes and the IFC capabilities needing to be supported" [10].	Related to specific product model namely IFC.
NEON	Existing formulation.	Restricted to knowledge base.

Table ***6*****.**

	Advantages	Disadvantages
Metamodel	Potential for consistency throughout diverse perspectives. Supports integration of perspectives and facilitates collaboration among developers and teams. Given a well design metamodel sounds engineering theories, application of patterns can be applied without detailed familiarity by the developer. Can be utilised formally or informally.	May require extensive effort to develop, might be ignored without tool support.
No 'upper' / meta formalism	No overhead and no constraints on the developer. Software engineering best practices can still be applied, relying on the application of modelling syntax with mapped / implied semantics	Rationale can be difficult to identify, not uniformly applied leading to duplication and possible inconsistency.
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NEON	Existing formulation.	Restricted to knowledge base.

Table 6 – summary comparison of the primary impact of alternative approaches to system integration

2. Development overview of the metamodel

The purpose of the knoholEM metamodel at the top level is to define the perspectives (views) and aspects and their interconnections which manifest as roles between constructs in the (sub) metamodels. The perspectives focus on domains and core theories while the aspects are concerned with typically simpler system wide formulations. In turn the meta formulations are manifested in models and in the implementations. As well as theories, the application of design patterns from software engineering e.g. Gamma et al. ('GOF') [11] are incorporated together with the definition of further attributes for entities such as statefulness and types of programming primitives used etc. That has the added advantage of familiarity for domain modellers while insuring system consistency. Moreover, rationale within views can be stated which can lead to 'clearer' designs e.g. by using a meta classifier for ontology taxonomies and meta level properties. The workflow in tools such as Protégé [12] for authoring ontologies typically starts in the development of a class hierarchy, but it can be observed that often the rationale along branches become unclear or inconsistent. Additionally the metamodel allows validation such as conformity to a specification, and can be shown to uphold consistency e.g. check conformance to semantics such as disjoint properties.

Similarly in the reuse of existing resources, the scope of an imported resource such as an ontology, its rationale, and any overlap and redundancy can be defined with the use of the metamodel. A large number of resources exist that exhibit diverse and different levels of abstraction and which may overlap in scope, so with the support of an appropriate metamodel, it is then feasible without the overhead of extensive reworking to exploit those. Utilising that metamodel or an adaption of it, some frameworks such as the Eclipse Modelling Framework [13] can be used to build system support or development tools.

Finally a further benefit of the utilisation of a metamodel is the facilitation of runtime reflection, including the provision to inspect properties / behaviours at runtime and possibly change (program) behaviours. Program behaviours can be dynamically changed at run time for example by invoking a software code compiler such as the Java compiler *javac*. The provision of reflection in general could generate a light weight ontology for run time implementations, building on the provision of some run time information in some languages and in Java specifically the *Class* APIs. Reflection also has practical use in implementation scopes for generating interfaces.

Some sample statements to be captured by the system metamodel in knoholEM follow:

- Wall compositions and 'make ups' are described by a particular merotopology theory
- Zone relationships are described by a particular topology theory among several other descriptions
- Heat transfer described by a numerical simulation model, is self-contained, and uses concepts from a particular static model (probably IFC)
- Dynamic behaviour is described by particular *event* concepts and temporal concepts
- The data mining metamodel defines relationships to integrate / align specific common domain patterns and algorithms. Many of its parameters will map to static building model (IFC) constructs and dynamic model entities in UML sequence diagrams.
- BuildingSmart's information delivery manual (IDM) constructs can be aligned within some views to facilitate information exchange to external tools

In the scope of the metamodel for the knoholEM system, the illustration in *Figure **43*** captures an excerpt. Vertically some of the system perspectives are presented while aspects that are not part of the primary logical implementation of the system are shown vertically. Where formulations of aspects are relevant to the perspectives shown, a suitable theory of formulation is shown as a horizontal bar. Some aspect formulations can exploit existing metamodels such as the Open Platform Communication Unified Architecture (OPCUA) metamodel [14]. Other aspect formulations employ theories or an ontology, or in some cases are very simple constructs such as that for time stamping or identification. The selection of resources process take into account the practical ease of reuse, richness in terms of theories captured and simplicity of the representation, among others.

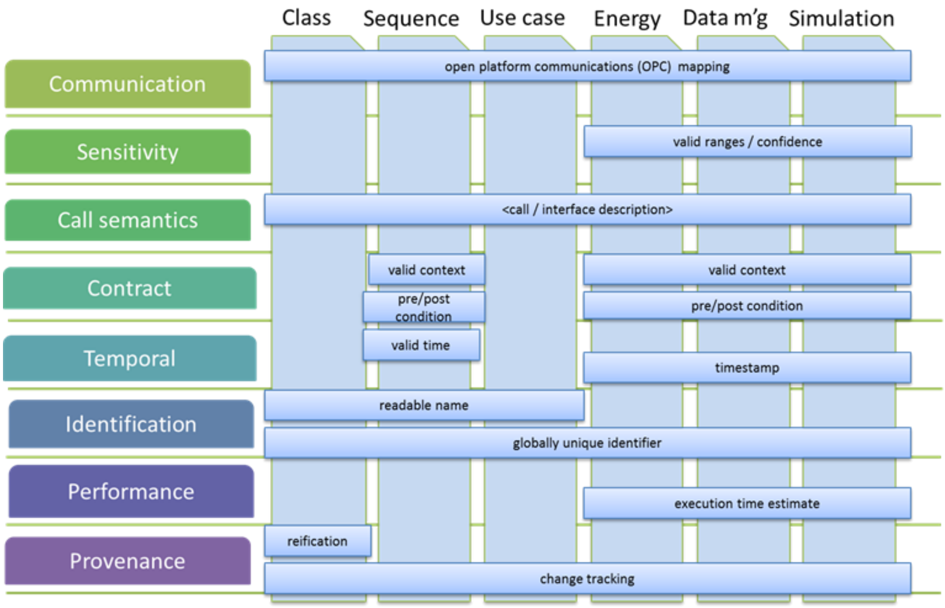

Figure 43 - integration of selected metamodel perspectives and aspects.

As a brief illustrative example of the development and application of an aspect of the metamodel spanning the object oriented (class, sequence etc) and knowledge base perspectives, an overview of a formulation of mereology theory for application in the knoholEM system is briefly outlined below (mereology is one of six immediate sub classes of ontology described in Yudelson's metamodel [15]).

The requirement to nominate particular properties arises due to the existence and valid usage of several different axiomatic definitions. While there are some simple definitions in UML (aggregation, composition), mereology has no defined constructs in OWL, so the provision of an appropriate metamodel can render alignment between those views. Constructs for the knowledge base and fully elaborated ones for the object oriented perspectives should be specified to which the metamodel specifications can be mapped. Implementation dependency in the 'late' lifecycle stage specification will typically utilise patterns within the metamodel.

Thus taking a common axiomisation for `part_of` as transitive, reflexive, antisymmetric (hence a partial order) from typical knowledge based system use, the formulation can be propagated into the metamodel and subsequently mapped into views based on object oriented principles.

Although the presentation of the metamodel for knoholEM is beyond the scope of this positioning paper, an initial draft of a (top level) candidate metamodel is presented in *Figure* ***44***, shown using UML class notation. The metamodel is a first iteration and would be expected to significantly evolve during development. The figure shows a preliminary and partial elaboration of the informal presentation in *Figure* ***43***. Some existing metamodels are linked and their roles will be refined during the development of the metamodel.

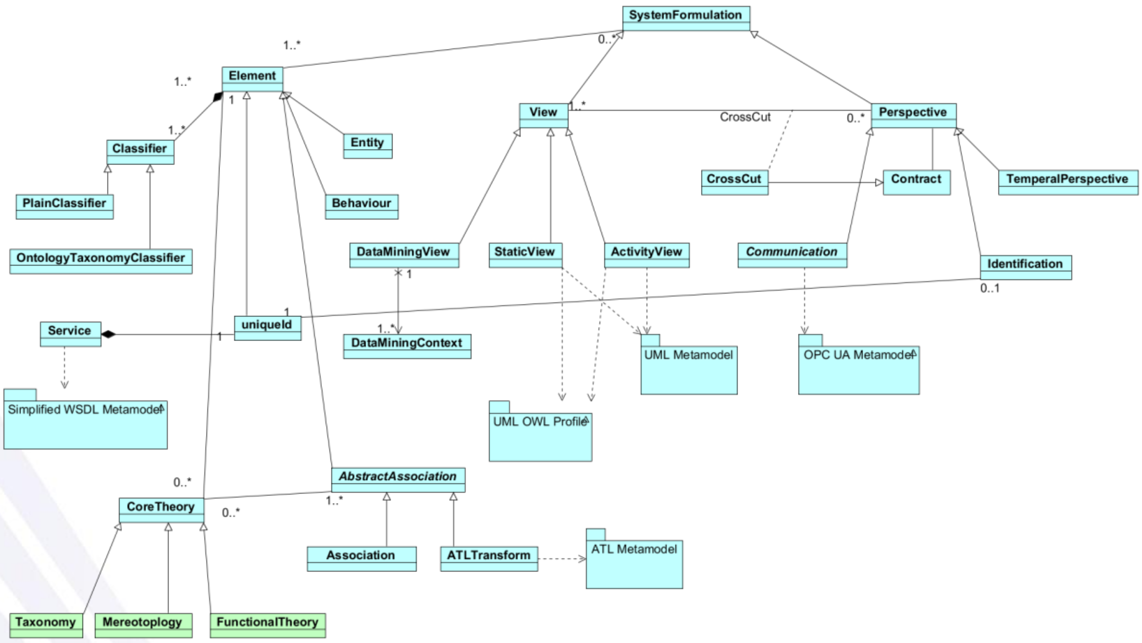

Figure 44 - excerpt from initial draft of knoholEM metamodel in UML class notation.

3. Discussion

While the advantages of the use of a metamodel has been identified, in the context of knoholEM there is a risk that the metamodeling effort, without the support of tools such as a customised Eclipse user interface, could only achieve limited impact and practical value. Additionally without automatic compliance checking or 'enforcement' via tool support and appropriate interfaces, there is reliance on manual adherence to the metamodel. The specification of workflows to facilitate and assist the metamodel application is an important area of further research. Similar (implicit) model utilisations in s/w development, which are traditionally and primarily manual, are helped by requirement traceability and model dependency relationships as well as best practice guidance documents. Those procedures embody the metamodel without the developer needing explicit knowledge of it.

The work is at a preliminary stage and further work to complete immediately is the elaboration of the metamodel using the MOF or close variant. A top down approach elicits potentially system wide useful theories, while simultaneously a bottom up approach of model development elicits practical domain knowledge which can be aligned with relevant constructs in the meta layer. The simultaneous development eliminates unnecessary details, replication and refactoring while encouraging the emergence of relevant abstract formalisms. Iterative development will add missing details and remove unused ones. Additional relevant aspects of MDA should be identified so that existing tools could potentially be utilised. Further research will address the task of formalising the testing and validation processes.

The structure of the metamodel is such that it is very extensible and an additional possible further useful application is the creation of supplementary formalised views having simplified (and consistent) semantics that would allow some reasoning to be carried out on the integrated model without the overhead of authoring and maintaining a complex ontology associated with a fully described semantic system (even if it were possible regarding performance constraints). Instead the proposed ontology support remains relatively simple and compact with low reasoning overhead, focussing semantic modelling in selected areas. Further, the use of alternative semantic knowledge representation to the core OWL perspectives is a further potentially useful addition that could be realised with extra integrated views. Those knowledge models would be comprised of an alternative set of constructs that are more suited to particular domains e.g. probabilistic, reduced expressivity or having different ontological commitments. Also, lightweight refinement of model perspectives with the addition of constraints, similar to the use of UML model profiles, may find useful application within the system modelling. Furthermore the mapping of relevant sub metamodels to elements of the ontology definition metamodel (ODM) [16] e.g. UML would simplify modelling in those domains.

Similarly, another attractive further 'perspective' is one that includes a rule layer (extending rules beyond those captured in knowledge bases in the form of SWRL). That new perspective would capture system wide rules via an interface to a rule engine such as JESS. Finally, the integration of further perspectives such as interfaces to numerical simulation tools is also feasible.

Summary and Conclusions

The case for the utilisation of a metamodel for the support of the knoholEM system design, development and run time implementation has been presented. The key claims and benefits of the metamodel utilisation are the complementary (symmetric) integration of views to promote consistency, the leveraging of sound engineering theories, the rendering of more explicit rationale, and the avoidance of ad-hoc linking and communication protocol use. Additionally the consistent application of design patterns can be ensured. The architecture allows the exploitation of native and mature domain specific modelling and shifts the developer away from implementation transformations, focussing on conformance to domain modelling syntax and implied semantics. Some risks are present and those have been identified. Further work will endeavour to address the application of a defined metamodel and later demonstrate the benefits its metamodel utilisation. Those findings will be reported in a later paper.

Acknowledgments

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References

1. knoholEM consortium, "knowledge based energy management for public buildings through holistic information modelling and 3d visualisation," 10 2012. [Online]. Available: http://www.knoholem.eu/page.jsp?id=14. [Accessed 05 12 2012].

2. buildingSMART, "Model - Industry Foundation Classes (IFC)," 2010. [Online]. Available: http://www.buildingsmart.com/bim. [Accessed 09 06 2010].

3. C. Malavazos, D. Ioannidis, D. Kehagias and D. Tzovaras, "Energy and behavioural modelling and simulation for ee-buildings design," in *Proceedings of the CIB W78-W102*, Sophia Antipolis, France, 2011.

4. Object Management Group, "MDA - The Architecture of Choice for a Changing World," Object Management Group, 04 April 2008. [Online]. Available: http://www.omg.org/mda/. [Accessed 29 July 2008].

5. J. Hartmann, R. Palma and Y. Sure, "OMV– Ontology Metadata Vocabulary," in *ISWC 2005 Workshop on Ontology Patterns for the Semantic Web*, Galway, Ireland, 2005.

6. U. Frank, "Multi-Perspective Enterprise Modeling (MEMO) - Conceptual Framework and Modeling Languages," in *Proceedings of the 35th Hawaii International Conference on System Sciences*, Hawaii, 2002.

7. G. Blain, N. Revault, H. A. Sahraoui and J.-F. Perrot, "A Meta Modeling Technique," in *OOPSLA'94 : Workshop on AI for OO Software Engineering*, Portland, USA, 1994.

8. Integrated Project (IST-2005-027595), "D5.4.1. NeOn Methodology for Building Contextualized Ontology Networks," NeOn-project, 2008.

9. IDMC, "Information Delivery Manual - Guide to Componenets and Delivery Methods Ver.1.2," IUG, 2010 .

10. AEC3 UK Ltd, "Information Delivery Manual," 2012. [Online]. Available: http://www.aec3.com/en/5/5_009_IDM.htm. [Accessed 10 05 2013].

11. E. Gamma, R. Helm, R. Johnson and J. Vlissides, Design Patterns: Elements of Reusable Object-Oriented Software, Reading, MA: Addison-Wesley, 1995.

12. Stanford Center for Biomedical Informatics Research, "The Protégé Ontology Editor and Knowledge Acquisition System," Stanford Center for Biomedical Informatics Research, 2008. [Online]. Available: http://protege.stanford.edu/. [Accessed 29 July 2008].

13. The Eclipse Foundation, "Eclipse Modeling Framework Project," 2013. [Online]. Available: http://eclipse.org/modeling/emf/?project=emf#emf. [Accessed 25 04 2013].

14. OPC Foundation, "Specifications : OPC UA," OPC Foundation, 2013. [Online]. Available: http://opcfoundation.org/Downloads.aspx?CM=1&CN=KEY&CI=283. [Accessed 30 04 2013].

15. M. Yudelson, T. Gavrilova and a. P. Brusilovsky, "Towards User Modeling Meta-Ontology," in *User Modeling 2005*, Edinburgh, 2005.

16. OMG, "Ontology Definition Metamodel," OMG, 2008.

4.4. Shared Vocabularies to Support the Creation of Energy Urban Systems Models

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Abstract

The problem of carbon emission reduction in urban areas cannot be constrained to a particular geographical area or scale, nor is it the concern of a particular discipline or expert: it is a systemic problem which involves multiple scales and domains and the collaboration of experts from various fields. The aim of models of urban energy systems is to identify the processes that determine the energy intensity in a specific urban area. Such models can help experts to understand the systems' behaviour and take measures to improve its performance. The application of semantic technologies can help to create urban energy models which integrate the knowledge from experts in various domains. The goal of the SEMANCO research project is to create a comprehensive framework –i.e. methods and tools– using semantic technologies which enable experts from different domains to devise and deploy urban energy models that help various stakeholders –planners, consultants, policy makers– to understand the complexity underlying carbon reduction in urban areas. A key component of the project is the Semantic Energy Information Framework (SEIF) which facilitates the link between the tools which are intrinsic to an energy model and the required data. This paper describes the process and results obtained in the development of this semantic framework. In particular, the paper discusses the creation of its underlying ontology, that is, the vocabulary shared by different domain experts which is necessary to access the contents of the different data sources required by an energy model. The configuration of the urban energy models and the access to the semantic data and the tools that characterise them take place through the SEMANCO integrated platform. Therefore, the current state of the development of this platform is also presented in the paper.

Key words

Semantic technologies, ontologies, urban energy systems, urban energy models

1. Urban energy systems and energy models

Urban energy systems have been defined as "the combined process of acquiring and using energy to satisfy the demands of a given urban area" (Keirstead and Shah, 2013, p.273), whereas an energy system model is "a formal system that represents the combined processes of acquiring and using energy to satisfy the energy service demands of a given urban area" (Keirstead et al., 2012, p.6). A model of an urban energy system fulfils two main purposes: to understand the current state of the system and to help to take decisions to influence its future evolution (Shah, 2013). An urban energy model is expected to provide answers to questions formulated by actors involved in the improvement of the urban energy system's efficiency. For example, it should enable those actors to address questions such as how much energy is consumed in an urban area, what is that energy used for, how can that consumption be reduced and what are the connections between urban density and energy demand.

A model, according to the definition of Echenique (1972, p.164) is "a representation of a reality, in which the representation is made by the expression of certain relevant characteristics of the observed reality and where reality consists of the objects or systems that exist, have existed or may exist". Such 'representation' is built with a set of abstractions that is, with the methods, data and tools that make the theoretical framework of the model. These capture the internal structure and the dynamics of a system as perceived by the observers. In the case of urban energy models, a multiplicity of these abstractions comes into play, in so far as there are multiple experts and knowledge domains involved in understanding how an urban energy system works. These include experts in energy supply and demand, in transportation networks, in building stock evaluation, in socioeconomic analysis and in environmental policy-making. The multiple models built from the particular point of view of the different observers need to be integrated to create urban energy models which span across various disciplines (Shah, 2013).

One inherent difficulty with urban energy models is the delimitation of the boundaries of the energy systems they represent. As Steinberg and Weisz (2013) have contended, the limits of an energy system can be established in two ways: adopting a 'production' perspective, by considering fixed geographical limits based on physical or administrative territorial divisions or, from a 'consumption' perspective, by establishing unfixed limits which take into account economic exchanges linked to energy use. As these authors argue, the answers to questions which can be informed by a model –for instance, how much energy a type of building consumes in a city –depend on the limits of the system. Urban energy assessments, therefore, need to include an explicit definition of the systems' boundary since "arbitrary, or ill-defined, system boundaries defy the very purpose of urban energy assessments: to guide public and private sector policies and decisions and to allow comparability and credibility of the entire process" (Steinberg and Weisz, 2013, p.54).

Ultimately, the value of a model relies on the availability and reliability of the data with which the model operates. Energy related information is dispersed in numerous databases and open data sources and it might have different levels of quality. It is also continuously changing, since urban energy systems are dynamic entities in continuous transformation. Moreover, the information which is required by integrated urban energy models is heterogeneous since it is generated by different applications in various domains. The effectiveness of an energy model depends on having access to the data required for a particular purpose (for example, to compare alternative solutions to reduce energy consumption in an urban area) and on assuring the reliability of the data which is handled by the model, the input data as well as the output data.

2. Semantic technologies and urban energy models

The application of semantic technologies can help to overcome some of the difficulties which are intrinsic to the development of urban energy systems models, in particular those concerning the integration of multiple domains and the accessibility to the data. Ontologies can be used to create shared vocabularies which help experts from different fields to establish relationships between certain objects of an urban energy system according to their knowledge and experience. An ontology, as formulated by Gruber (1992), stands for "a description (like a formal specification of a program) of the concepts and relationships that can exist for an agent or a community of agents". Considering this definition, an ontology can be thought of as collectively constructed knowledge that various experts have about an urban energy system. In fact, building a common vocabulary is itself, a knowledge construction process by which the knowledge that the different domain experts have on the issue at stake is made explicit and formal. At this point, there is a fundamental distinction to be made with previous concepts of urban energy models. An urban energy model supported by ontologies built by a group of experts is not just an abstraction of a complex system (e.g. an isomorphism of the system's structure) but it stands for a way of thinking from multiple perspectives about a complex problem which is embodied in the ontology. In other words, a model is not a representation of a simplified reality, but a representation of a complex reality as conceptualised by experts and formalised in the ontology.

Ontologies can serve to foster communication between the semantically modelled data and the various software applications used by experts. The connections between tools and the data they handle can be captured by the ontologies. This way, when a tool is used within a particular energy model, the data which the tool needs as input can be retrieved via ontologies (in the case of SEMANCO, this function is fulfilled by the Semantic Energy Information Framework). This makes it possible to create multiple urban energy models of an urban energy system, each one with its own set of tools and associated data. This way, semantic technologies can facilitate the interoperability between the semantically modelled data and the variety of tools with which an urban energy model operates.

In the SEMANCO project, semantic technologies are used to create a comprehensive framework which supports the creation –collaboratively and over time– of urban energy systems models. These models represent the combined knowledge of the different experts involved in the evaluation and planning of the system. This framework includes procedures to build an ontology model (i.e. shared vocabularies) and a multiuser platform. The latter enables different users (planners, consultants, policy makers) to create urban energy models and to develop and assess different scenarios to improve the performance of the urban energy system.

3. Using ontologies to model experts' knowledge

Ontology design is a process by which the knowledge that experts, from one or numerous domains, have is made explicit. In the case of energy urban systems, different experts –planners, consultants, policy makers– know about a particular part of the overall system. Their knowledge is determined by the tools and methods in their particular disciplines, by their experience, and by the information they have at any given moment.

Typically, the knowledge of experts arises as they are confronted with the solution to specific problems. To make this knowledge explicit so that it can be formalised as ontologies, a use case methodology has been applied in three cases studies: Manresa (Spain), Copenhagen (Denmark) and Newcastle (United Kingdom).

Within the SEMANCO project, a case study refers to the delimitation of research scope to a geographic location and to the factors that influence the problem of carbon reduction in a particular urban area. That is, to the stakeholders involved the planning issues at stake and the energy policy agenda (Madrazo, 2012). A use case, on the other hand, is a framework which encapsulates data, tools and users and the interactions between them in to fulfil a specific goal within an urban energy system (for instance, reducing carbon emissions at the district level). A use case, therefore, stands for a pre-conceptualization of a model which represents an urban energy system, as thought by experts within a particular context (Figure 1).

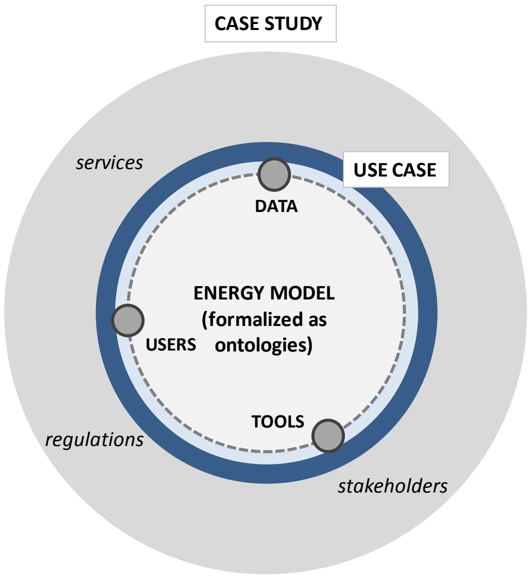

Figure 1. A use case as a pre-conceptualization of the energy model within the context of a case study.

To solve the complex problem described by a use case, a series of discrete actions –called *activities*, in the language of the project– need to be undertaken (Figure 2).

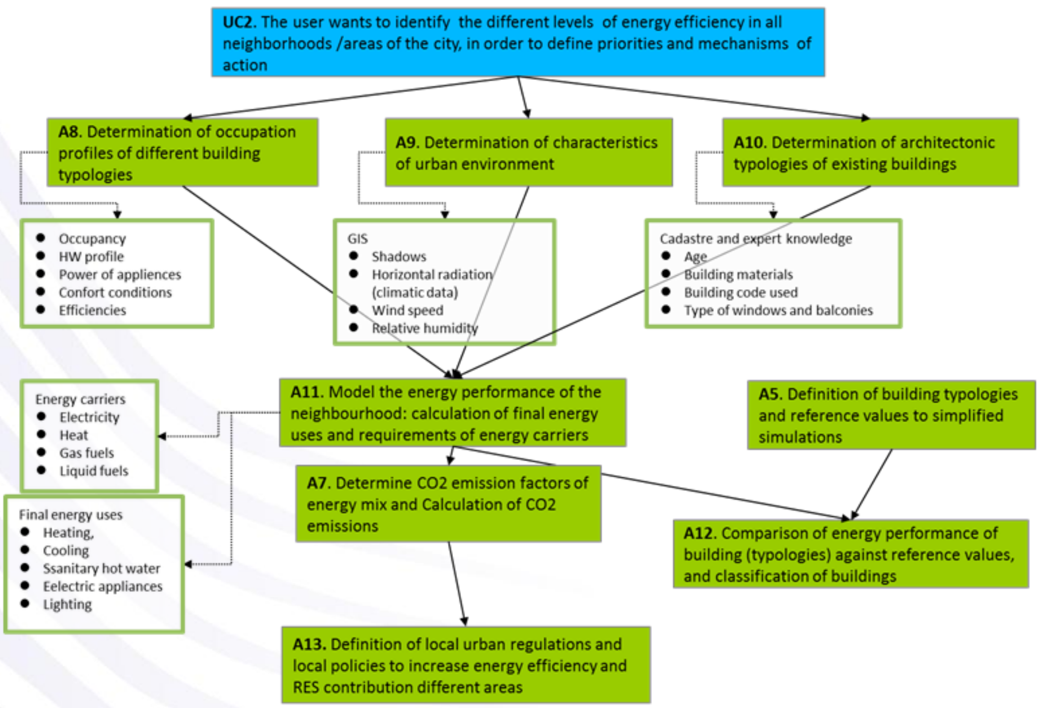

Figure 2. An example of a use case, its activities and the data associated to them.

Use cases and activities defined in this way give rise to a network by which the same activities can be shared by different use cases (Figure 3).

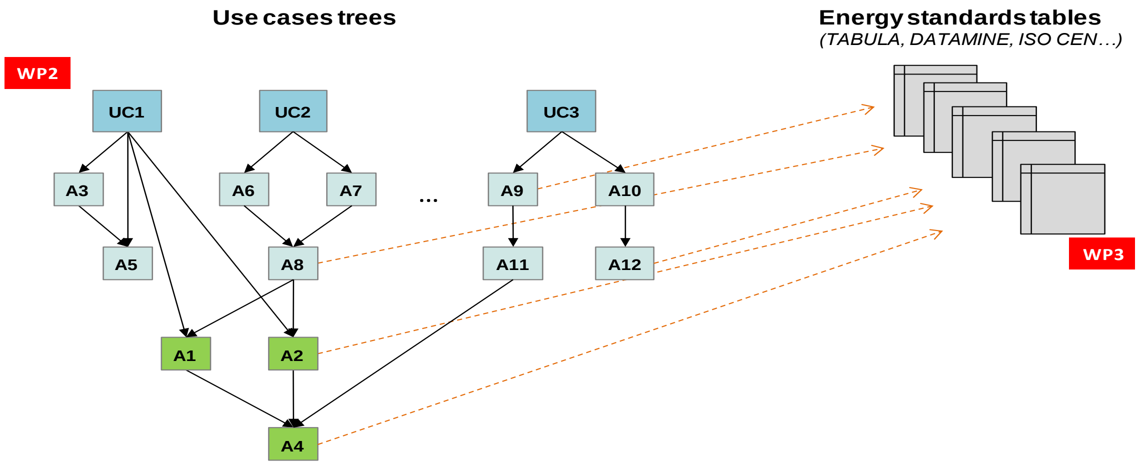

Figure 3. Network of activities connected to different use cases.

In SEMANCO, use cases and activities are defined by means of templates (Figures 4 and 5) which were specifically created for this purpose. The terms and units of measurement used in the templates are derived from international standards and/or established by the research community. The templates provide enough detail for experts to define a specific issue, while the use of terms based on standards assures that the contents can be transformed into the ontology. Therefore, use cases and activities defined by means of templates are the first step in the construction of a shared vocabulary which can then be formalised as an ontology.

Activities templates include references to the data sources required to perform the activities, as well as specifications of the tools and the data required. Altogether, the information collected through the use case and activities templates, in each case study, provide the specifications required to develop the semantic energy framework and the tools associated to it (Figure 6).

Acronym	UC10
Goal	To calculate the energy consumption, CO2 emissions, costs and /or socio-economic benefits of an urban plan for a new or existing development.
Super-use case	None
Sub-use caseUC9	
Work process	Planning
Users	1. Municipal technical planners 2. Public companies providing social housing providers 3. Policy Makers
Actors	4. Neighbour's association or individual neighbours: this goal is important for them to know the environmental and socio-economic implications of the different possibilities in the district or environment, mainly in refurbishment projects. They use to ask these questions to the municipality 5. Mayor and municipal councillors: In order to evaluate CO2 emissions impact of different local regulations or taxes
Related national/local policy framework	6. Sustainable energy action plan (Covenant of Mayors) 7. Local urban regulations (PGOUM, PERI, PE in Spain) 8. Technical code of edification and national energy code (CTE, Calener in Spain)
Activities	9. A1.- Define different alternatives for urban planning and local regulations 10. A2.- Define systems and occupation (socio-economic) parameters for each alternative 11. A3. Determine the characteristics of the urban environment 12. A4. Determine the architectural characteristics of the buildings in the urban plans 13. A5. Model or measure the energy performance of the neighbourhood 14. A6. Calculate CO2 emissions and energy savings for each proposed intervention 15. A7. Calculate investment and maintenance costs for each proposed intervention

Figure 4. Template to define a use case.

Acronym	A1
Super-activity/use case	UC10
Sub-activities	A2, A3, A4
Goal	Define different alternatives for urban planning and local regulations
Urban Scale	Micro-Meso
Users	1. The municipality (councilors of urban planning, housing, environment and countryside, …) (stakeholder) 2. Urban planners 3. Public company of social housing 4. Owner/promoter of the building (stakeholder) 5. Neighbor's association (stakeholder) 6. Consultants and technicians from Engineering and consultancy companies 7. Supply companies (i.e. supply company of district heating)
Related national/local policy framework	▪ Sustainable energy action plan (SEP from Covenant of Mayors) ▪ Local regulations 8. National energy codes (Código Técnico and certificación energética in Spain, DECC 2012 and HECA in UK, and Heat Planning Act, and danish Planning regulation in Denmark)
Issues to be addressed	1. To define the comparison of different CO2 emissions scenarios of urban planning, according to local energy requirements acts and/or Plans, in order to select the most efficient urban planning alternative in next steps. 2. To select a set of technologies, and local regulation in order to evaluate their CO2 impact ▪ To select different scenarios to evaluate the socio-economic impact of different measures ▪ To define alternative building performance levels in order to calculate scenarios of improvement of energy efficiency

Input Data

Name	Description	Domain	Format
Local regulations and requirements	Local regulations related to Energy Efficiency, RES, and CO2 emissions, as well as Local Urban regulation that can affect to de different proposals to implement	Energy efficiency Urban planning	Maps, and technical requirements
List of objectives from different users	List of scenarios of energy performance, energy supply, and/or urban planning	Energy efficiency Urban planning	Documents

Figure 5. Template to define an activity within a use case.

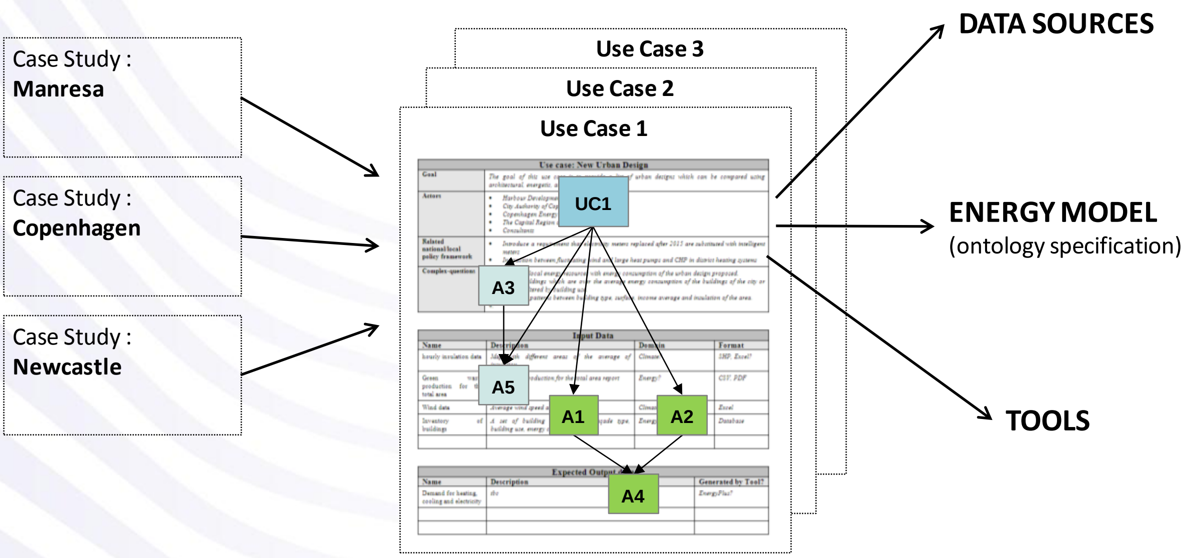

Figure 6. Use cases as links between case studies and the technological development of the project.

4. Semantic Energy Information Framework (SEIF)

The Semantic Energy Information Framework (SEIF), developed in SEMANCO, is the nexus between the distributed data sources and the tools using the semantically modelled data (Figure 7). The access to the tools takes place via an integrated platform, which provides services for different types of user.

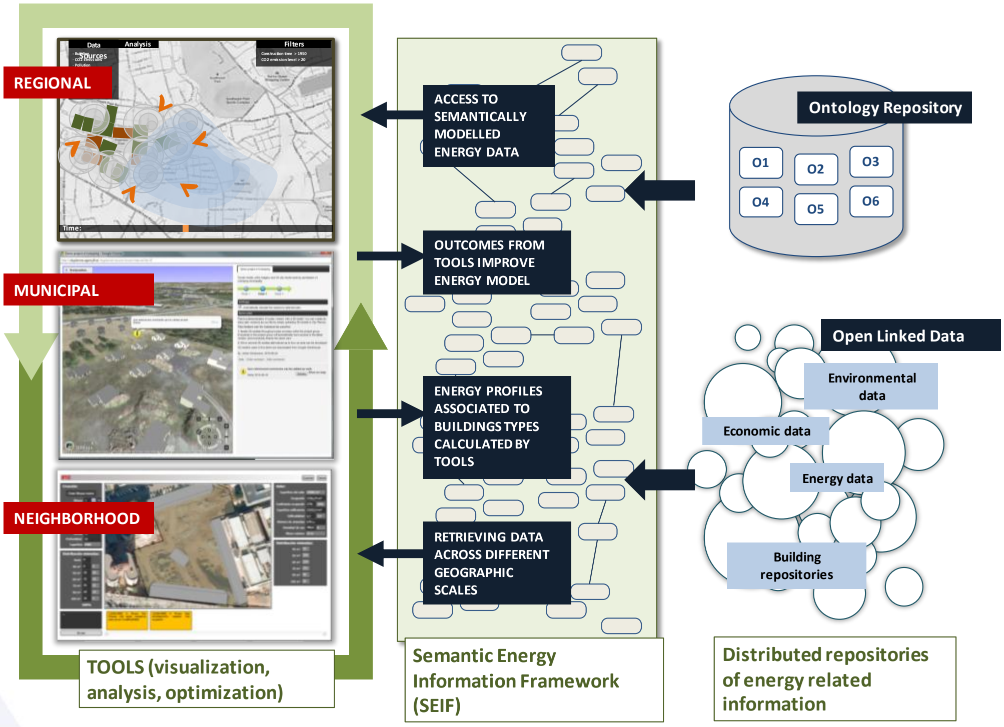

Figure 7. SEIF as a bridge between data and tools.

The SEIF has three main goals:

- Integrating proprietary data which is presently off-line or/and heterogeneously structured into a consistent knowledge base, making the data accessible for information discovery and retrieval purposes.
- Providing a bridge between different domains (city planning and energy provision) and contents (consumption data, pollution sources, simulated energy profiles and benchmarks).
- Gathering outputs generated by the tools developed in the project –tools for design evaluation and energy simulation, visualisation and modelling at urban scale, and analysis and optimisation processes– in order to create a distributed knowledge base.

4.1 The ontology building process: creating a semantic energy model

The process of creating an ontology requires a methodological approach to avoid redundant work, to reduce design errors, and to be replicable in other contexts. Generic processes are described by Gruber (1995) and Uschold and King (1995) assuming that ontology design will follow the same process as software development: identification of the requirements, development, evaluation and documentation. This approach is further elaborated by Fernandes, Guizzardi and Guizzardi (2011). A survey of methodologies for ontological design can be found in Fernández-López (1999). However, these methodologies mostly focus on modelling the conceptualisation of a specific domain, rather than on the integration of data sources in ways that support querying using federated access. Besides, it can be argued that a methodology per se is not enough. Rather, it should be supported by design patterns, document templates, tools or platforms which guide developers along the process. Since no methodological approach takes into account the integration of data sources and their querying using federated access, it has been necessary to develop an ontology design process (Nemirovski, Nolle, Sicilia, Ballarini and Corrado, 2013).

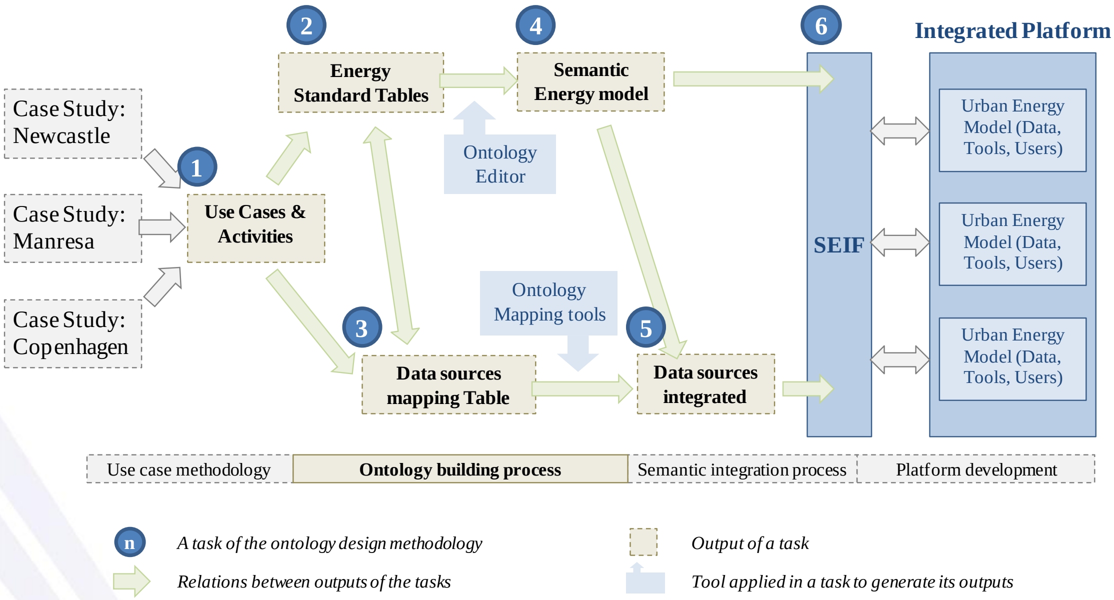

Figure 8. The processes and methods employed to build the SEIF.

The methods and processes followed to create the SEIF are summarised in Figure 8. It starts with a description of use cases and activities –according to the use case methodology– from which energy standard tables containing the terms and definitions of the vocabulary which are then transformed into an ontology. In parallel, the data sources are identified and the contents mapped to the terms of the energy standard tables. Finally, the ontology is mapped to the data sources to transform them into Resource Description Framework (RDF) data. Both the semantic energy model (a model of the urban energy system represented as global ontology) and the RDF data sources make the SEIF.

The goal of the process outlined above is twofold: to design a semantic energy model as a formal ontology and to integrate data sources by reorganising them according to the ontology structure. The resulting semantic energy model is a formal global ontology embracing the terminology and relations needed to integrate the data sources and query them in a unified way. This way, the semantic integration process converts the data sources to RDF in accordance with the global ontology.

In the following sections the six main tasks involved in the ontology building process are explained and the outcomes achieved are described.

4.1.1 Vocabulary capture

The first task of the ontology design process is to capture the base terminology for the ontology, that is to say, to make the knowledge that domain experts have about the issues related to a use case explicit. By means of use cases, experts describe how actors, tools, and data relate to each other in order to fulfil a specific goal under a specific policy framework. The activities encompassed by a use case are described in form of requirements and competency questions following current approaches, such as the Neon methodology (Suárez-Figueroa et al., 2012). This way, the data sources required to carry out the activities are identified and briefly described.

The output of the process of vocabulary capture is 14 use cases and 44 activities defined through templates. The actors considered in the use cases encompass social housing providers, city councils, building owners and energy consultants. The policy frameworks considered are local urban regulations, Covenant of Mayors, national building codes, UK Fuel Poverty Strategy among others. The activities deal with a wide range of issues examples include the identification of areas with high instances of fuel poverty the calculation of the potential of local solar gains, and the calculation of the CO_2 emissions of buildings and urban areas.

4.1.2 Building an initial vocabulary

In the second task, the use cases and activity specifications are analysed with the goal of defining an initial vocabulary. This is a categorised set of terms connected by simple relations such as subsumption (is) and aggregation (has). To build the initially vocabulary it is necessary to identify the data categories, to scrutinise the existing international standards for energy modelling and to create energy standard tables, which are a set of semantically structured terms, including objects, attributes and standard definitions.

The data categories are divided in two major groups: 1. those which concern data on energy systems, energy quantities and boundary conditions, and 2. those concerning contextual data. The first group contains the categories of energy data (e.g. CO_2 emission coefficient, CO_2 emissions, delivered energy, energy demand, energy supply etc.), climatic data (e.g. air temperature, solar irradiance, wind speed, relative humidity etc.), and building technical data (e.g. space heating systems, energy generator, mechanical ventilations, type of walls etc.). Contextual data includes energy costs (e.g. running costs and refurbishment costs), environmental data (e.g. air pollutants and air quality), legislative constrains such as energy performance requirements, geographical and land registry data (e.g. land lots, land value, land classification, etc.), socio-economic and demographic data (e.g. gender, level of education, tenure, income etc.).

The resulting vocabulary requires a common and shared terminology. With this purpose, international technical standards, research projects, and European directives were consulted to obtain the definitions of the terms, the relations between concepts and the symbols and units of the quantities.

The initial vocabulary is specified in the form of an energy standard table. Each category in this table contains numerous terms identified by the various activities. The initial vocabulary contains the description of the terms, and the relations between terms and, in this regard, it can be equated with a formal ontology specification.

Building an initial vocabulary is an important intermediate step towards the design of a semantic energy model. It simplifies formal ontology coding significantly by using a formal language, such as OWL. This task was carried out following the methodology for structuring and semantically modelling energy and contextual data developed in the SEMANCO project (Corrado and Ballarini, 2012, 2013).

The initial vocabulary is composed of 24 categories including building use, climate and building geometry. Around 1000 terms were collected including; descriptions, references, units, and type of data. 18 standards (e.g. ISO/IEC CD 13273-1[15], ISO/IEC CD 13273-2[16], EN 15603[17] and the EN ISO 15927-1[18]) and 16 references (e.g. research project, public recommendations, European directives) were used to create the energy standard tables.

4.1.3 Mapping data sources to vocabularies

The goal of the third task is to map the data entities of the data sources –identified in the activities of the use cases– to the initial vocabulary. If a target data source is a relational

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[15]ISO/IEC CD 13273-1:2012. Energy efficiency and renewable energy sources. Common international terminology. Part 1: Energy Efficiency.

[16]ISO/IEC CD 13273-2:2012. Energy efficiency and renewable energy sources. Common international terminology. Part 2: Renewable Energy Sources.

[17]EN 15603:2008. Energy performance of buildings - Overall energy use and definition of energy ratings..

[18]EN ISO 15927-1:2002. Hygrothermal performance of buildings. Calculation and presentation of climatic data. Part 1: Monthly and annual means of single meteorological elements.

database, then the fields of their tables are mapped to the terms of the initial vocabulary. The mappings are specified by data owners and domain experts using a table template. For example, Table 1 shows the mappings of the Manresa census data source.

Data source	Data name (in the Data source)	Data name (in the vocabulary)	Data category (in the vocabulary)
Manresa census	ID	Building	Building
Manresa census	NUMCOD	Address	Building
Manresa census	DOMCOD	Address	Building
Manresa census	ADRDESC	Address	Building
Manresa census	TITULACIO	Education_Level	Housing
Manresa census	SEXE	Household_Type	Housing

Table 1. An activity description.

As illustrated in Table 1, the term 'Address' contains in the initial vocabulary it is mapped to the terms NUMCOD, DOMCOD and ADRDESC from the targeted data source. This information is used as an input for the fifth task -Mapping data sources- explained later. Unfortunately, not all of the terms contained in the data sources can be univocally mapped to the initial vocabulary, so it is necessary that an ontology expert deals with some of the less evident mappings. In these cases, ontology experts have three alternatives: to modify/extend the initial vocabulary (which is the most often selected choice); to implement non-trivial mapping preferences; or to specify complex queries.

Nine different data sources have been mapped to the initial vocabulary including census and cadastre records, building typologies, neighbourhoods, energy coefficients among others. In total, more than 60 mappings are established between the data entities of the data sources and the initial vocabulary.

4.1.4 Ontology coding

The fourth task is focused on the codification of the semantic energy model, as a formal ontology based on the *DL-Lite$_A$* formalism which outperforms most other description logic formalisms when managing data distributed in heterogeneously structured sources (Poggi et al., 2008). The coding of the semantic energy model is carried out by SEMANCO's ontology editor (Figure 9) described by Wolters, Nemirovski and Nolle (2013). This editor provides a user-friendly interface which facilitates the participation of domain experts in the ontology building process. Besides, the editor supports the coding of *DL-Lite$_A$* axioms to represent domains and ranges of object properties which require the processing of reasoning. These two features are the main reasons for the development of a bespoke editor instead of using an existing one such as Protégé[19] or TopBraid Composer[20]. The SEMANCO ontology editor offers the user two simultaneous views of an ontology: one for editing the taxonomy of concepts, and another one for editing the graph of non-subsumption relations.

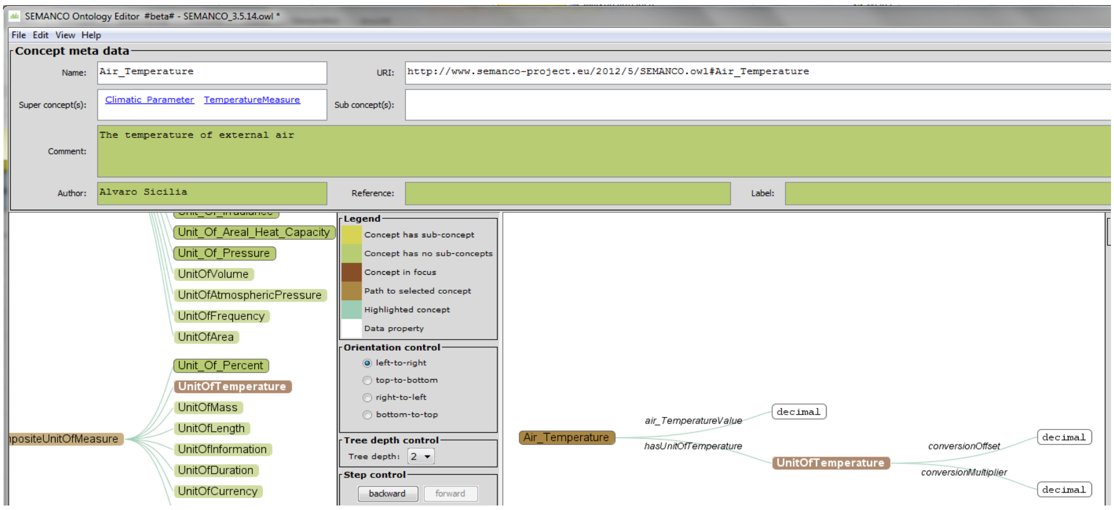

Figure 9. SEMANCO's ontology editor (© Albstadt-Sigmaringen University).

Annotations are key components of an ontology, which enable users to understand its structure and the criteria adopted in their conceptualisation. The ontology editor enables users to define four types of annotation properties for each concept; label, comment, reference and author. The values of the annotation properties are taken directly from the energy standard tables; such as the name, the description and the reference.

Following a modular approach to ontology design, the semantic energy model is built with modules of the Suggested Upper Merged Ontology (SUMO). In this way, each concept of the semantic energy model is subsumed at least by one concept of SUMO. SUMO was selected, rather than DOLCE, PROTON, General Formal Ontology (GFO), and Basic Formal Ontology (BFO) because of its simplicity of understanding, applicability for reasoning and inference purposes, the ability to apply units of measurement to data, and the number of concepts it contains related to the urban planning domain.

The outcome of this task is the creation of a global ontology based on the SUMO upper-ontology encompassing 592 concepts and 468 relations implemented with 3459 axioms in *DL-Lite*$_A$ style.

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[19] http://protege.stanford.edu

[20] http://www.topquadrant.com/products/TB_Composer.html

4.1.5 Mapping data sources

The aim of this task is to apply the informal mappings produced in the previous task to transform the contents of the data sources into RDF resources. After coding the mappings, using a formal language of a dedicated middleware, the data stored in relational databases becomes available for SPARQL querying in terms of the target global ontology.

These mappings are implemented with declarative mapping languages, which offer rich expressive features helping to adjust rigid relational schemas to real cases. In SEMANCO for D2RQ (Bizer and Cyganiak, 2007) was selected. It is supported by the D2R server, a mature and stable lightweight middleware. Nevertheless, other software products, such as Quest (Rodriguez-Muro and Calvanese, 2012) using standard mapping language R2RML are also being tested.

The creation of such mappings is a complex process, which involves experts from different domains with different skills. The process requires them to understand both the structure of the ontology and the data sources. To support their work, two environments were developed using D2RQ and R2RML language. The OWL mapping extractor to extract an OWL ontology file and a D2RQ mapping file from the structure of a relational database, and the ontology mapping collaborative web environment that provides a graphical interface to assist non- ontology experts to implement the mappings (Figure 10).

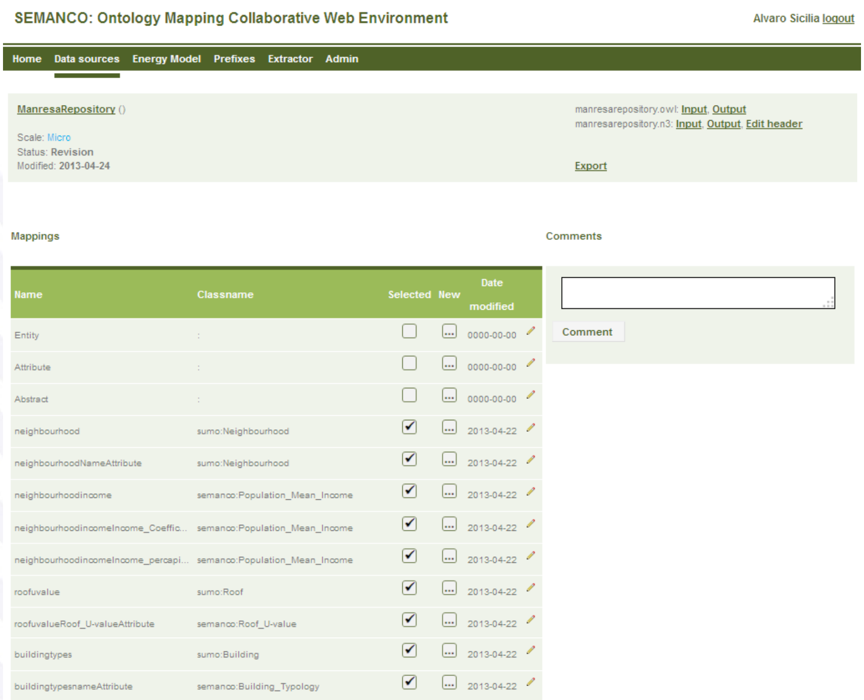

Figure 10. Ontology mapping environment with the mappings created for the Manresa database (© ARC Engineering and Architecture La Salle).

Typically, 90% of these mappings are automatically generated by the ontology mapping environment, while the remaining 10% are coded manually because they are too different to the general cases.

As a result of this task, 9 data sources have been semantically integrated using more than 400 mappings automatically generated by the ontology mapping tool. More than 3 million RDF triples have been generated.

4.1.6 Evaluation

In this task the quality of the ontology created in the previous stages of the process is evaluated. In particular, three properties have been evaluated: intelligibility that is the ability of experts that use the ontology to understand the ontology structure; mapping compliance ensuring the complete correspondence of the mapping with the ontology; and computational efficiency regarding the ability of the ontology to support conjunctive querying on high efficiency level, for example, with a comparatively short response time.

The intelligibility test was carried out at the early stages of the ontology development, with two independent groups of users: a group of computer science students and another made up of experts in the field of building energy. The positive scores obtained in the test were 97.30% for computer science students and 91.20% for domain experts.

5. Integrated Platform

The SEMANCO integrated platform is the front-end for users, with different profiles, to interact with the semantic data using the tools associated to a model of an urban energy system. The open structure of the platform enables an urban energy model to be enhanced when new tools and data –either from existing data sources or from the data generated by the different applications– become available.

In the integrated platform, both the experts' knowledge, captured through the use case methodology (use case and activities templates), as well as the links to the external data sources are available through the SEIF (Figure 11). This combination of knowledge and information constitutes the base for creating energy models for a particular urban area.

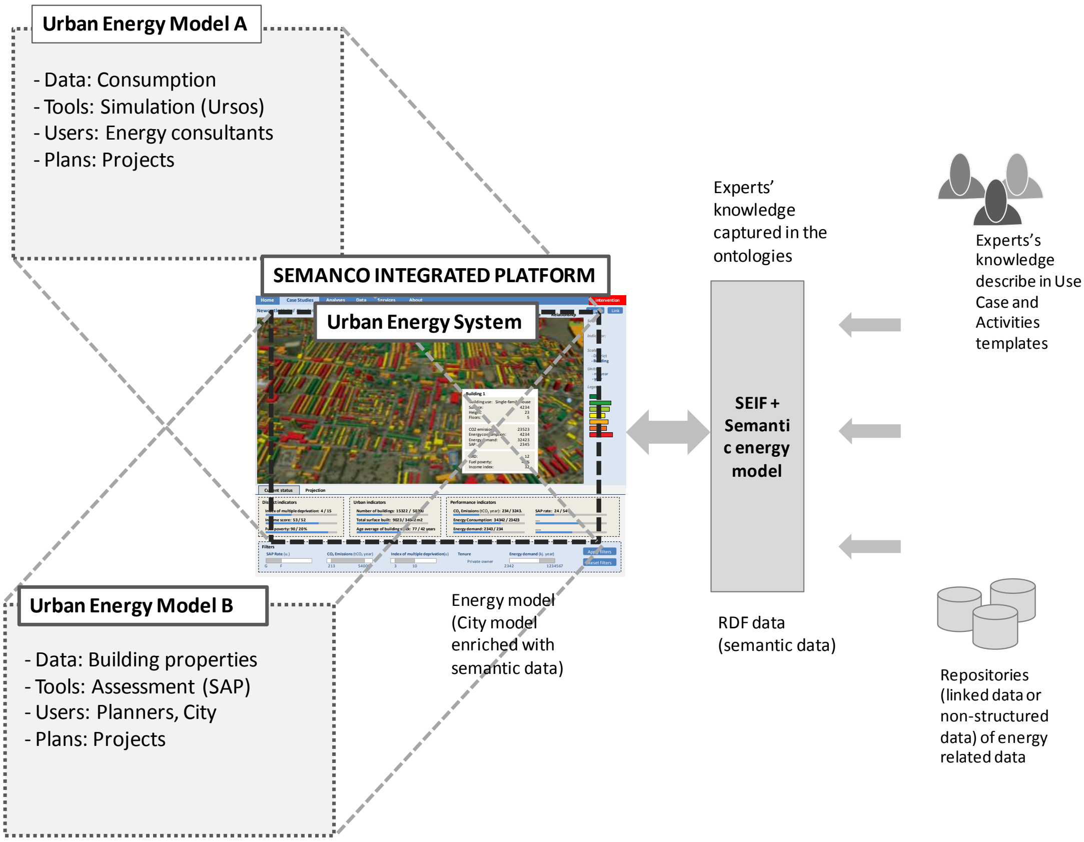

Figure 11. Different models providing partial views of the overall urban energy system.

Urban energy models are constructed in an asynchronous manner by adding energy related information to a geometric model created with the 3dMaps software of Agency9 (a project partner). For this purpose, the platform provides different kinds of tools:

- Embedded; tools which are part of the platform and developed specifically for it.
- Interfaced; existing tools (e.g. simulation, assessment) which can interact with other tools and services in the platform.
- External; existing tools that can use data exported from the platform and generate data that can be imported to it.

Within a particular energy model domain experts can represent the existing conditions of the urban system (descriptive model), analyse the future evolution of the system (predictive model), explore different scenarios for future development (exploratory model) and propose improvement plans and evaluate projects to improve the performance of the urban energy system (planning model)[21] using multicriteria decision analyses tools[22].

[21] These four types of models are identified in Echenique (1972).

[22] Yamaguchi and Shimoda (2010) provide an example of the application of a set of tools to analyse alternatives to improve energy performance in a district within a given energy model.

Figure 12. Integrated platform (© SEMANCO).

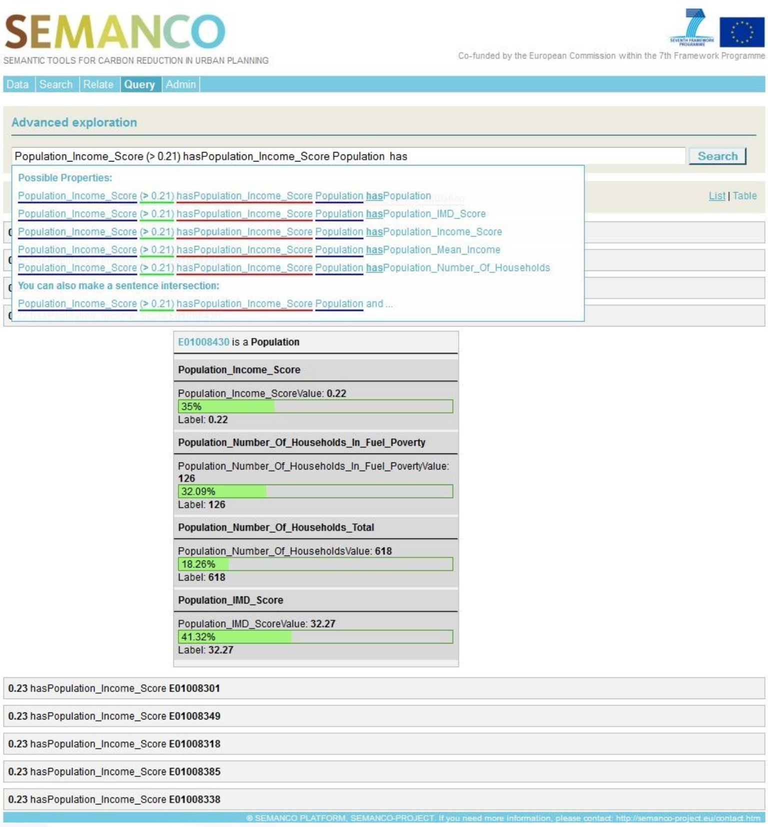

Figure 13. Semantic data explorer (© ARC Engineering and Architecture La Salle).

The platform has been designed to support services for four user groups:

- Domain experts. They collaborate in the construction of an energy model (e.g. describing use cases and activities, defining terms of the ontology), and/or they interact with the model (e.g. extracting reports, enriching the energy model with new data). They produce and evaluate alternative plans to improve the performance of the urban energy system, and they provide advanced data analyses services to other experts.
- Ontology engineers. They collaborate with domain experts in the maintenance and enhancement of the system's ontology. With this purpose, they use the tools developed for the project to create the energy model as a global ontology (Ontology Editor), to carry out the semantic integration process (Ontology mapping environments), and to verify the outputs of the process (Semantic data explorer).
- Platform developers. They assist experts in the integration of new tools and data in the platform.
- Non-experts. They interact with the platform –either by themselves or assisted by a domain expert– to visualize the energy data using different tools provided by the platform (3D models, tables and diagrams), to extract the information they need and derive conclusions from it.

Once the project is completed, the integrated platform will provide a generic structure to support the development of services based on the exploitation of the semantic data and the tools interacting with them. Most important, it will be possible to incorporate into the platform additional energy systems from urban areas other than the three case study areas included in the SEMANCO project.

6. Conclusions

In the first two years of the SEMANCO project partners have devised and implemented a methodology to capture experts' knowledge –that is, the implicit knowledge, which experts possess that emerges as they are confronted with a particular problem concerning the performance of an urban energy system– with the purpose of creating a semantic framework to support decision making in energy efficient urban planning. This knowledge has been formalised as a global ontology created with the participation of domain experts and ontology engineers. As a result, a Semantic Energy Information Framework (SEIF) has been created, which provides access both to the experts' knowledge, captured by the terms and relations that form the ontology, and to information required by different energy models based on the ontology. A prototype of the integrated platform, which is currently being finalised, will facilitate access to the energy models for different types of users. Overtime, the use of the platform's services will support the addition of more energy related data, as well as enhancing the system's ontology with new terms and relations. SEMANCO's platform will provide a generic, flexible and open, structure that facilitates the continuous development of complex models of urban energy systems carried out with the participation of the different users and stakeholders.

The results of the SEMANCO project are therefore contributing to the development of integrated urban energy models which can help agents involved to improve the efficiency of urban energy systems by enabling a better understanding of the complexity of the issues involved. In this regard, the most relevant outputs of the project are not its end-products (e.g. the integrated platform and the various tools devised to build the ontologies) but rather, the comprehensive semantic framework which integrates energy accounting methods, energy related data, and energy assessment tools.

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8. References

1. Bizer, C. and Cyganiak, R. 2007. D2RQ – Lessons learned. Position paper at the W3C Workshop on RDF Access to Relational Databases, Cambridge, United Kingdom.
2. Corrado, V., and Ballarini, I. 2012. SEMANCO Deliverable 3.2: Guidelines for Structuring Energy Data. Accessed July 31, 2013 at website: http://semanco-project.eu/index_htm_files/SEMANCO_D3.2_20130121.pdf
3. Corrado, V., and Ballarini, I. 2013. SEMANCO Deliverable 3.3: Guidelines for Structuring Contextual Data. Accessed July 31, 2013 at website http://semanco-project.eu/index_htm_files/SEMANCO_D3.3_20130321.pdf
4. Echenique, M. H. 1972. Models: A discussion. In L. Martin and L. March (editors) Urban space and structures. London: Cambridge University Press.
5. Fernandes, B.C.B., Guizzardi, R.S.S. and Guizzardi, G. 2011. Using Goal Modelling to Capture Competency Questions in Ontology-based Systems. Journal of Information and Data Management, Vol. 2, No 3, pp. 527-540.

6. Fernández-López M. 1999. Overview of methodologies for building ontologies. In Proceedings of the IJCAI-99 workshop on ontologies and problem-solving methods: lessons learned and future trend, Stockholm, Sweden.

7. Gruber, T. R. 1992. A Translation Approach to Portable Ontology Specifications. Accessed July 31, 2013 at website http://www-ksl.stanford.edu/kst/what-is-an-ontology.html

8. Gruber, T. 1995. Towards principles for the design of ontologies used for knowledge sharing. In International Journal of Human Computer Studies, Vol. 43 (5-6), pp. 907-928.

9. Keirstead, J., Jennings, M., and Sivakumar, A. 2012. A review of urban energy system models: approaches, challenges and opportunities. Renewable and Sustainable Energy Reviews, 16(6), pp. 3847–3866. Accessed July 31, 2013 at website https://spiral.imperial.ac.uk/bitstream/10044/1/10206/4/review.pdf

10. Keirstead, J., and Shah, N. (editors). 2013. Urban Energy Systems: An Integrated Approach. Urban energy systems : an integrated approach. London: Routledge.

11. Madrazo, L. (editor) 2012. SEMANCO Deliverable 1.8: Project Methodology. Accessed July 31, 2013 at website http://semanco-project.eu/index_htm_files/SEMANCO_D1.8_20120921.pdf

12. Nemirovski G., Nolle A., Sicilia Á., Ballarini I., and Corrado V.2013. Data Integration Driven Ontology Design, Case Study Smart City. The Semantic Smart City Workshop (SemCity-13), Madrid, Spain.

13. Poggi, A., Lembo, D., Calvanese, D, De Giacomo, G. Lenzerini, M and Rosati, R. 2008. Linking data to ontologies. Journal on Data Semantics, pp. 133–173.

14. Rodríguez-Muro, M. and Calvanese, D. 2012. High Performance Query Answering over DL-Lite Ontologies. In Proceedings of 13th International Conference on Principles of Knowledge Representation and Reasoning (KR 2012), pp. 308-318.

15. Shah, N. 2013. Modelling urban energy systems. In J. Keirstead and N. Shah (eds.) Urban Energy Systems. An Integrated Approach. London and New York: Routledge.

16. Steinberger, J. and Weisz, N. 2013. City walls and urban hinterlands: the importance of system boundaries. In A. Grubler and D. Fisk (editors) Energizing Sustainable Cities. Assessing Urban Energy. London: Routledge.

17. Suárez-Figueroa, M.C., Gómez-Pérez, A., Motta, E. and Gangemi., A. 2012. Ontology Engineering in a Networked World. Berlin: Springer.

18. Uschold, M. and King, M. 1995. Towards methodology for building ontologies. Workshop on Basic Ontological Issues in Knowledge Sharing, held in conjunction with IJCAI-95, Cambridge, United Kingdom.

19. Wolters, M. Nemirovski G, and Nolle, A. 2013. ClickOnA: An Editor for DL-LiteA based Ontology Design. 26th International Workshop on Description Logics. Ulm, Germany.

20. Yamaguchi, Y. and Shimoda, Y. 2010. District-scale simulation for multi-purpose evaluation of urban energy systems. Journal of Building Performance Simulation, Vol. 3, Issue 4.

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