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ICT PLATFORM FOR HOLISTIC ENERGY EFFICIENCY SIMULATION AND LIFECYCLE MANAGEMENT OF PUBLIC USE FACILITIES

Deliverable D4.1:

Ontology specification for model-based ICT system integration

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PU	Public	**x**
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RE	Restricted to a group specified by the consortium (including the Commission Services)	
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TABLE OF CONTENTS:

1. Executive Summary

The **objective** of WP4 "Model-based ICT system integration and intelligent access services" is to close the gap between building information models and building automation systems. As a bridge between these two worlds, an ontology is used which is the core of this deliverable. Other goals of WP4 are (1) development of intelligent access services for easy energy-relevant evaluation of monitored data, (2) development of an engineering query language which allows user-friendly formulation of energy-related tasks and (3) definition of usage scenarios for the engineering query language.

This deliverable is based on the following **tasks**:

- T4.1 Principal concepts for information synthesis and interoperability with eeBIM
- T4.2 Ontology for integrated ICT system management

The tasks T4.3 and T4.4 are not content of this deliverable, but they will base on the results of tasks T4.1 and T4.2:

- T4.3 Intelligent access services to sensing data and other ICT-based sub-systems
- T4.4 Engineering query language and usage scenarios

The deliverable report is structured into three parts:

In the **first part,** the motivation for the ontology is explained. The state of the art is analyzed and the goals of the new ontology are given. A short description of the software to be implemented which uses the ontology helps to understand the meaning of the ontology.

In the **second part**, details about the ontology are described. Beginning with an overview about the whole ontology, the components of the ontology are explained.

The **third part** deals with the mapping from the abstract ontology view to real-world BAS technologies like LON, BACnet or EnOcean.

The following **partners** are involved in WP4:

- TUD: Lead (TUD-TIS), building automation expertise
- NEM: eeBIM knowledge, link to WP3
- BAM: end user (Task 4.1 and 4.4)
- AEC: broad IFC/BIM expertise (Task 4.2)

2. Motivation

2.1 Overview

Architectural building models and models of building automation systems are generated by different companies nowadays and with incompatible software. Until now, architects have not been interested in details of building automations systems. Building automation systems are designed when the main work of the architects is already finished and the building starts to be constructed.
In HESMOS things change since not only the design phase is of interest but also the **operation phase** as well as **refurbishments**. The proposals for refurbishments are intended to be based on **comparisons** between the energy-efficiency of **different solutions**. The energy-efficiency of these solutions can only be found by simulations. But, simulation models are not very exact if there is no validation of the simulation parameters. In the refurbishment phase, the sensor data of the building (monitoring data) can be used to compare the simulations of the current building state with the reality. The results of this comparison are used to improve the simulation model to be as close as possible to the reality.

The missing link between building automation systems and the building model of the architects hampers the simple comparison of simulations and measurements. Because of this, the goal of HESMOS work package four is to **close the gap between the building model (the eeBIM) and the BAS model**. This will be realized with the help of an ontology which is the subject of this deliverable.

The second motivation for the ontology of this document is that architects and energy evaluators are often not familiar with building automation systems and their ICT-oriented structure. People who are familiar both with architecture tools and building automation systems tools are rare. It is the goal of the ontology to set the end users free of dealing with building automation systems. End users should only select rooms and physical quantities like temperature or room air quality which they want to evaluate. The ontology as the backbone allows selecting the appropriate BAS devices which deliver the desired values.

There is a fact which complicates the integration of eeBIM and BAS model: There are many different kinds of building automation systems. The most famous ones are the open systems LON, BACnet and KNX as well as the emerging wireless technologies ZigBee and EnOcean. Since these technologies differ in details, an integration approach should be applicable for **all common building automation systems** and also for **future developments**.

Besides, it is intended to create the mapping between both worlds (BIM and BAS) as far as possible **automatically** for avoiding unnecessary human effort.
In the HESMOS context, the ontology will be used as a part of the **intelligent access services**, which are to be developed in task T4.3. Figure 1 shows the position in the IVEL architecture (Katranuschkov, et al., 2011) where the ontology will be located: at the interface between the IVEL core and the external modules.

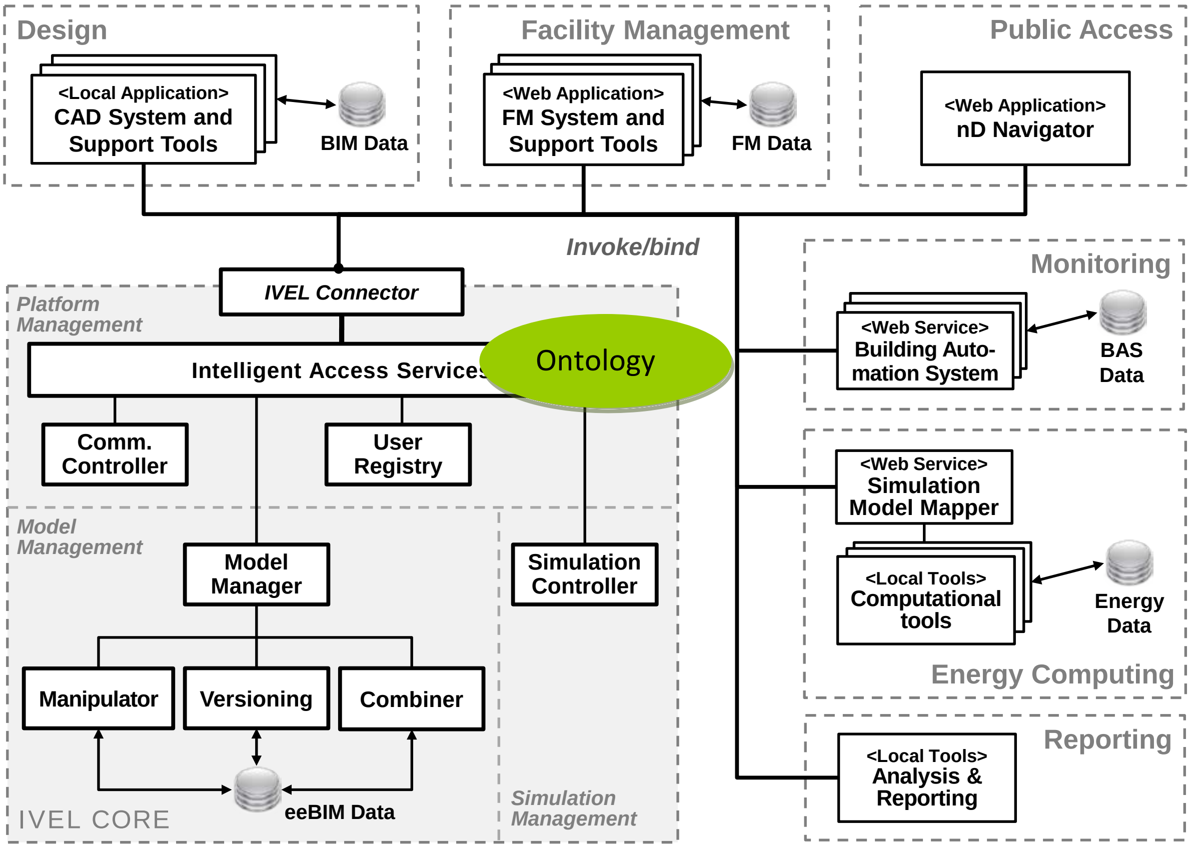

Figure 1: The ontology in the HESMOS software architecture.

2.2 State of the Art: Ontologies in Building Automation

It has never been tried to close the gap between building models and BAS models using an ontology, although such ideas have yet been published (Reinisch, et al., 2008). The existing ontologies can be divided in two groups:

- Ontologies for the **integration of different BAS types** like LON and BACnet. These ontologies are usually **technology-oriented** and not designed for end users of buildings.
- Ontologies for describing **smart homes** with components like washing mashines and televisions. These ontologies are usually less interested in technical details of building automation systems but in the **semantic meaning** of the devices for influencing their energy-efficiency by intelligent interoperation.

The nearest approach to the one described in this document comes from **TU Vienna** with their **ThinkHome** project (Reinisch, et al., 2008), (Reinisch, et al., 2010). The project contains an ontology development which is close to the objectives of HESMOS, because the goal is to create an abstract view on building automation systems which is independent from concrete technologies and supports energy-efficient building operation. Also the idea to bring it together with building automation models like IFC has been stated (Reinisch, et al., 2008), but this has not been realized until now.

A commercial approach comes from **BrightCore** which is a division of **Elma Kurtalj Ltd.**, Zagreb (Kurtalj, 2010). Also this is an ontology-based approach for an abstract view on different building automation system types. The focus lies on the gateway, not on energy-efficiency. Also there the connection to BIM is stated as an idea but not yet realized.

TUD-TIS deals with ontology descriptions for building automations since 2007, first in the project **AUTEG** (Aut11) and now in the follow-up projects **AUDRAGA** (Aut111) and **ZESSY** (Res11). TUD-TIS is work package leader of HESMOS WP4 and also of the HESMOS ontology development. TUD-TIS has already experience in merging BAS and IFC (Karavan, et al., 2005), (Karavan, et al., 2005), but did not use an ontology for this purpose.

Also the chair for Industrial Communications at TUD (**TUD-IC**) has been active in the use of ontologies for describing intelligent devices (Gössling, et al., 2008), (Hegler, et al., 2007), but their focus lies on Industrial Applications, not on Building Automation and therefore there is also no BIM integration.

Another approach for an abstract view on building automation systems with an ontology is **DogOnt** (Dog11) (Bonino, et al., 2008), without an integration to any BIM.

Other comparable ontologies come from the **University of Patras** (Charatsis, et al., 2007) and from the **IntelliDomo** Project of the **Universidad de Extremadura** (**Junta de Extremandura Project**) (Valiente-Rocha, et al., 2010).

There are many ontology developments which are specialized on describing **Smart Homes** in a more broad sense and without the focus on building automation systems. Examples are DomoML / the NICHE project (Furfari, et al., 2004), (Sommaruga, et al., 2005), the RWTH Aachen (Fisch, et al., 2010), the Soongsil University in Korea (Kim, et al., 2006), the National University of Singapore (Gu, et al., 2004), the University of Toronto, Canada, together with the Centre Scientifique et Technique du Bâtiment (CSTB), France (Dirably, et al., 2003), as well as DEHEMS / Coventry University, UK (Shah, et al.).

2.3 Goals of the new ontology

The goal of the HESMOS ontology is beyond the ontologies described in the section before. It is neither the objective to only combine several building automation systems nor to describe smart homes with all possible components. However, both can be done with the HESMOS ontology by extending it.

The main intention of the new ontology is to **close the gap between building information model (BIM) and building automation systems (BAS)** to simplify energy evaluations. None of the ontologies above has this feature or intention. Reinisch remarked in 2008 his intention to possibly extend the ThinkHome ontology by a link to a BIM (Reinisch, et al., 2008), but until now there have been no results on that.

Besides, the ontology should allow both an easy integration by simple building operators as well as partial automatic generation by electronic device descriptions.

For better understanding of the aim of the ontology, the concept of the final application software is described in the next section.

2.4 Concept of the ontology application

The **distributed architecture** of the software application which will use the ontology is shown in Figure 2.

The architecture is composed by three separated components.

1. In the **building** to be evaluated there is the building automation system with the sensors, actuators and controllers. The building automation system is connected to a computer which is able to collect the desired information from the network and store it in a **local data base**.
2. In the **HESMOS IVEL** there is another database for caching **frequently used** measurement data as well as **topology information**.
3. The third part is the **components repository**. This is a specialized database which is able to find building automation devices which offer a desired functionality (e.g. temperature measuring).

The ontology is used to interpret the queries of the user, to translate rooms into device lists and to evaluate the contribution of the components repository. The result is **the IDs of the BAS devices which are able to fulfil the functionality requested by the user**.

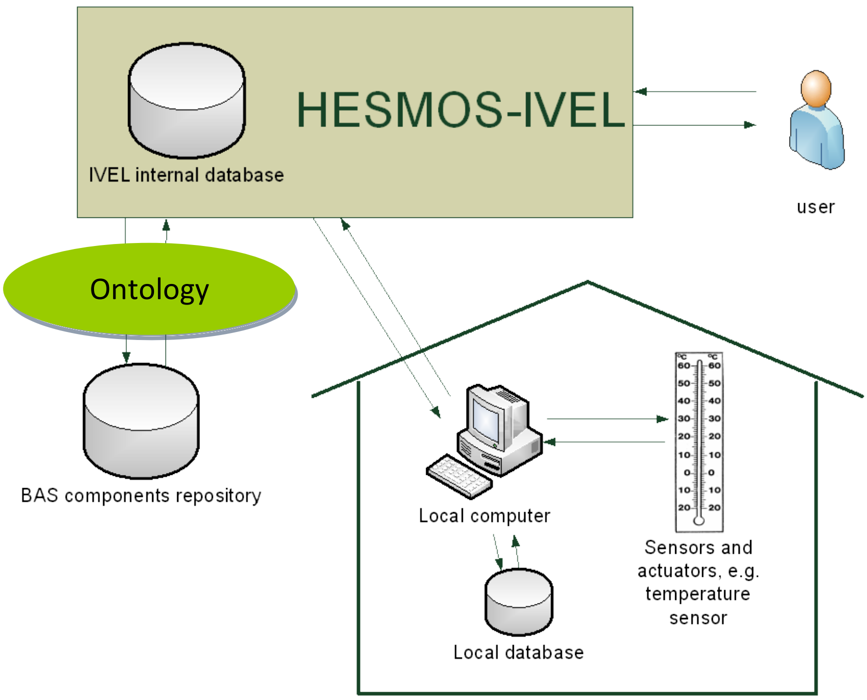

Figure 2: Architecture of the distributed software which uses the ontology

3. Ontology

This section will look into the details of the developed ontology. Section 3.1 presents the basic structure. The following sections describe the parts.

3.1 Ontology Structure

An Ontology which is used to bring together two worlds should contain as the two first parts the ontologies which represent each world. Besides, an ontology in the middle is needed for bringing both knowledge together.

There are different realizations (technologies) of building automation systems, e.g. LonWorks, EnOcean, KNX, BACnet, ZigBee etc. Furthermore, Building automation systems are a developing field and it should be expected that new technologies will evolve, especially for giving the user higher performance or lower energy consumption. One such example is EnOcean which allows energy harvesting, therefore renunciation of batteries and because of that lower costs for energy and maintenance. EnOcean is available since 2001, i.e. a very young technology. The goal of HESMOS is to be **independent** of these technologies, or to allow the usage of all of them. For reaching this, there is an **abstract layer** which allows describing **main concepts** of BAS which are equal in all building automation systems since they result from their functionality from the perspective of the user and not from technology details. Examples are abstract terms like controller, actuator, sensor, input and output. There are new standards (e.g. the German VDI 3813) which help to ensure that these concepts will also be attended in future. Hence, the HESMOS ontology is based on these standards. Additional parts of the ontology go into detail for each technology. This concept can be expanded to any new evolving BAS technology.

Figure 3 shows the ontology architecture. The parts are described in the following sections. Issues about the concrete BAS technologies are discussed in section 4.

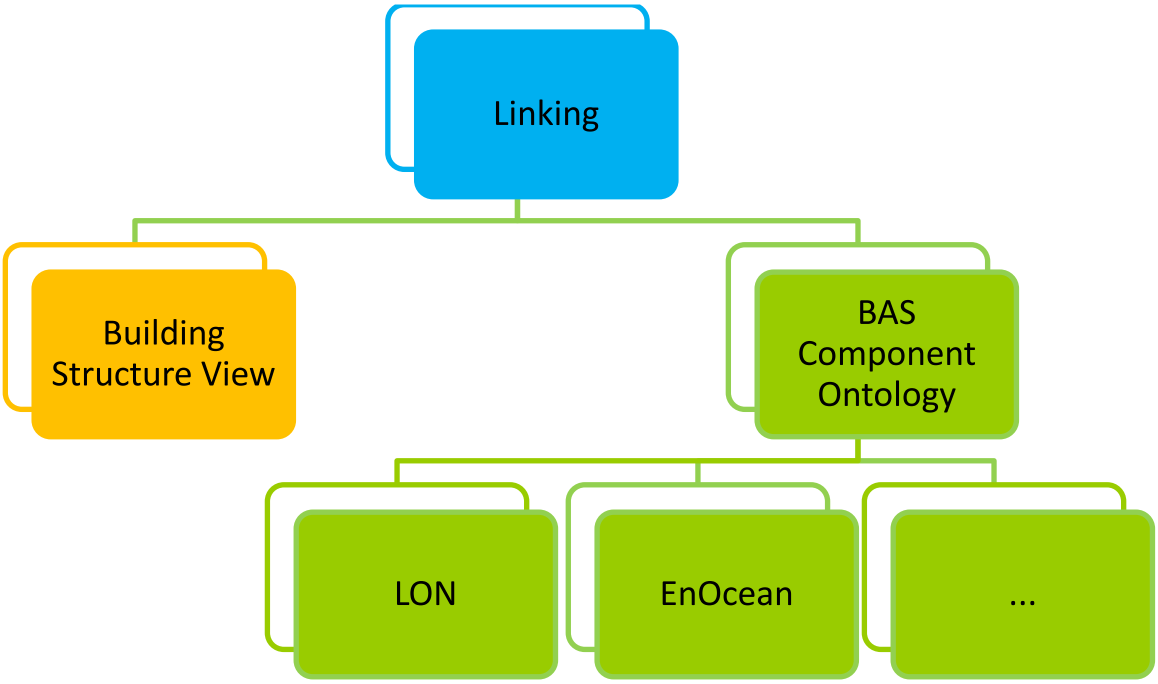

Figure 3: Architecture of the Ontology

3.2 BAS Component Ontology

The BAS Component Ontology describes in an abstract form devices of the BAS and their functionality. This is based on the work of Dibowski (Dibowski, et al., 2011).

3.2.1 Main idea

The main idea of the BAS Component Ontology is shown in Figure 4. There are the following parts:

- *Device*: Devices are physical entities which can combine several functions.
- *FunctionalProfile*: Functional profiles are sets of associated inputs and outputs. Many typical functional profiles are standardized, e.g. Light Switch, Temperature Sensor, Heating actuator, occupancy sensor etc. One device can implement more than one functional profile.
- *Input*: Inputs are a kind of software interface which allow influencing the function of a functional profile. E.g. a lamp profile has as its input a binary value whether the lamp should be on or off. A controller has as its input the measured variable and the reference variable.
- *Output*: Outputs are software interfaces which allow giving results of the functional profile to another profile. E.g. a light switch has as its output the state *On* or *Off*. A controller has as its output the manipulated variable.
- *OperationMode*: Some functional profiles use operation modes which specify different semantic meanings of a profile. E.g. a temperature controller could run as PID or as two-point control. Depending on the profile the used inputs and outputs may change. A PID

controller will give a continuous output while a two-point controller gives only a binary output.

- *Function*: A function is the standardized semantic meaning of an operation mode according to VDI 3813.
- *Configuration Parameter*: A configuration parameter is something similar to an input with the difference that it cannot be altered by the application (i.e. by other functional profiles), but only by the administrator of the BAS. This could be for example a timer setting or the tuning parameters of a PID controller.
- *Parameterization*: A parameterization is the set of configuration parameters which is used by a specific operation mode. This is useful since the configuration parameters of different operation modes of the same functional profile can differ.

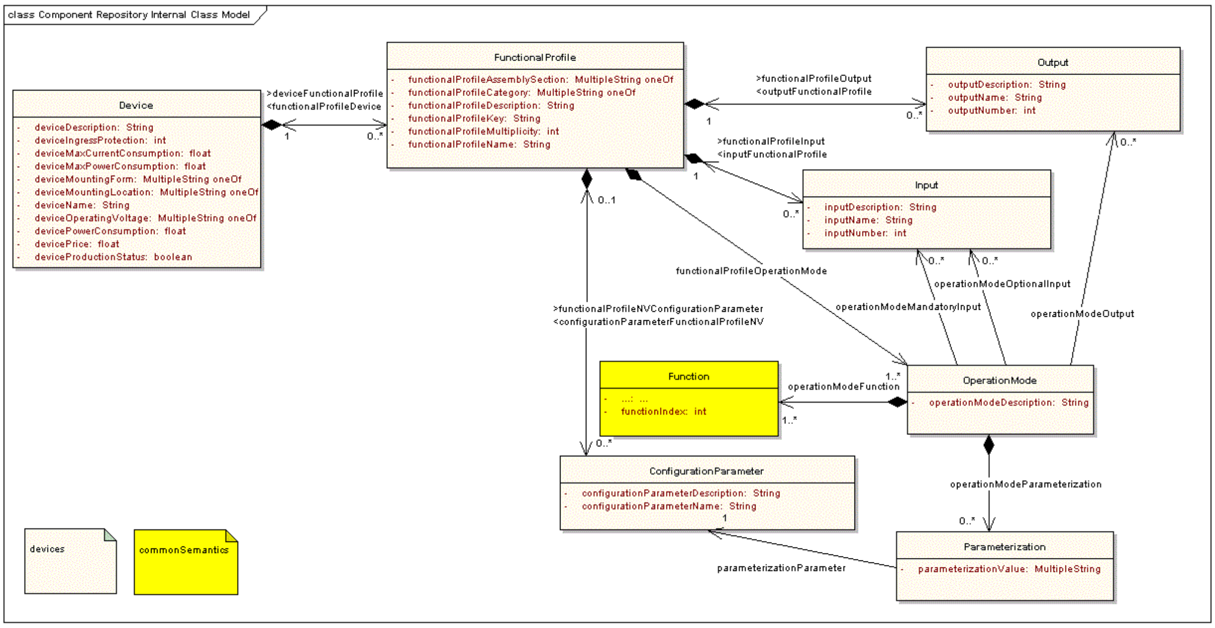

Figure 4: BAS Component Ontology

3.2.2 Instances

It is important to distinguish between component **types** and their **instances**. Information about component **types** can be stored in a central database (**Component Repository**) which is used for all projects together. Information about component **instances** (i.e. real devices in a specific building) will usually be handled in a separate database for each project.

Each device instance may work in its own operation mode and therefore has its own parameterization. This must be found in the ontology.

Figure 5 shows the BAS Ontology with device types and device interfaces together with its details.

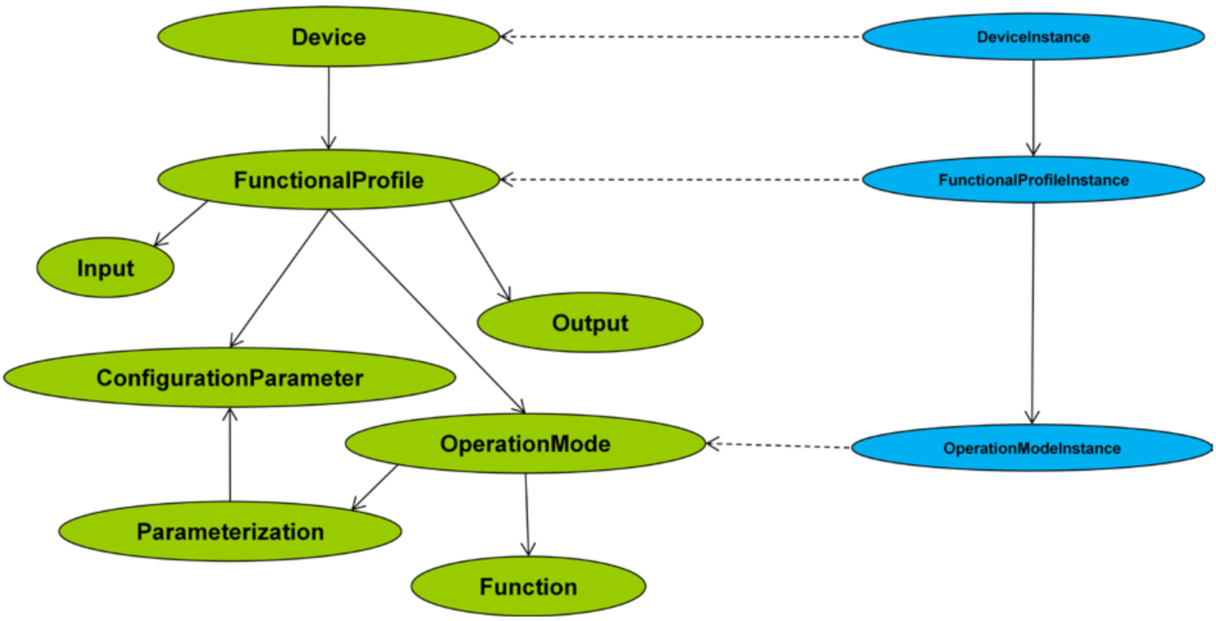

Figure 5: Instances

3.3 Building Structure View Ontology

The second "world" which is described in the HESMOS Ontology is the necessary subset of the building information model (BIM). As the basis of the BIM, IFC (Industry Foundation Classes) has been chosen which is an international standard (ISO-16739). Because of that, this part of the ontology is based on the structure of IFC. Only a small part of IFC is needed for linking the BIM to the BAS components. This part is shown in Figure 6. A wider approach to model IFC as ontology can be found in (El-Mekawy, et al., 2010). Ontology and IFC are also brought together in (Beetz, et al., 2005) and (Schevers, et al., 2005).

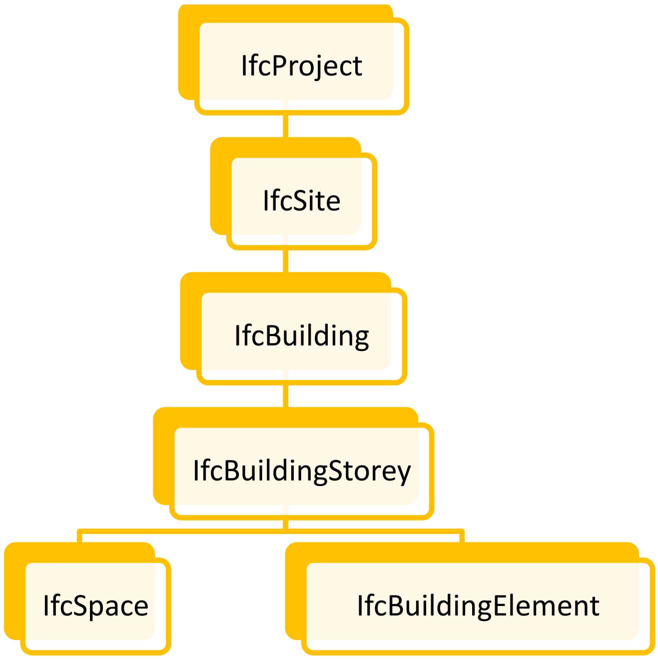

Figure 6: eeBIM Ontology Part

3.4 Linking Ontology

The linking ontology brings BIM and BAS ontology together. There are two versions – one optimized for BAS experts and one optimized for building operators.

3.4.1 Main version

The link between the BIM ontology and the BAS ontology is done by mapping a physical device to a room (**IfcSpace**) or to a building element like a wall (**IfcBuildingElement**), see Figure 7. The reason is that there are two types of sensors: Sensors measuring quantities of **spaces** like room temperature, room humidity, room air quality etc., and sensors measuring quantities of **walls** between spaces, e.g. heat flow sensors, heat transfer coefficient sensors etc.

Also **coordinate** information (location) can be added for sensors where this is important. E.g. it is important for exact energy evaluation whether the temperature is measured near a window or near a heat source.

This ontology can be partially created **automatically** with the help of **electronic device descriptions**. These descriptions document the functionalities of devices in a standardized form. The information of these descriptions will be stored in the component repository. If the device type of the used components in a BAS system is given by the BAS raisers in a table, database etc., also the mapping between the eeBIM ontology and the component repository can be supported by an automatic proposal.

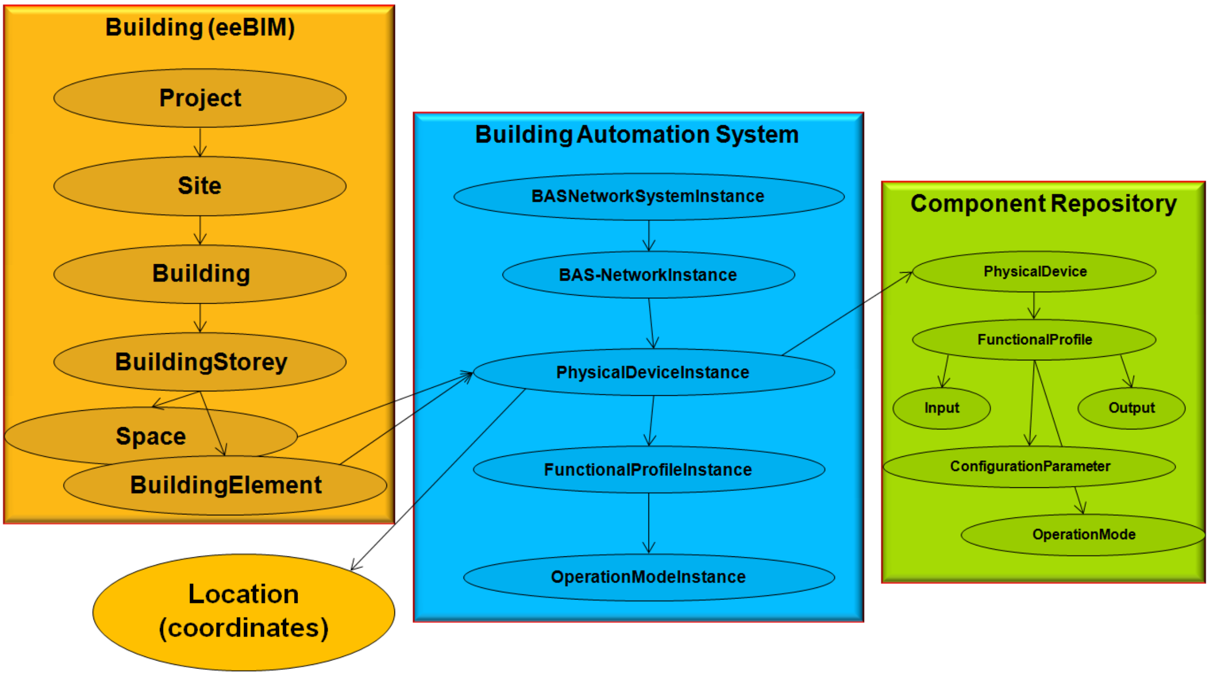

Figure 7: Ontology Mapping

3.4.2 Simple version

There is also a simple version of the mapping ontology which is intended to be used by building operators which are not familiar with BAS technologies, only with the "application layer" of their own BAS system. That means that these persons usually know an **ID** and the **location** of each measurement point but not details about the used technology. For the purposes of HESMOS this is enough in a first step. This simple ontology version is shown in Figure 8. The component repository and the eeBIM part are not altered.

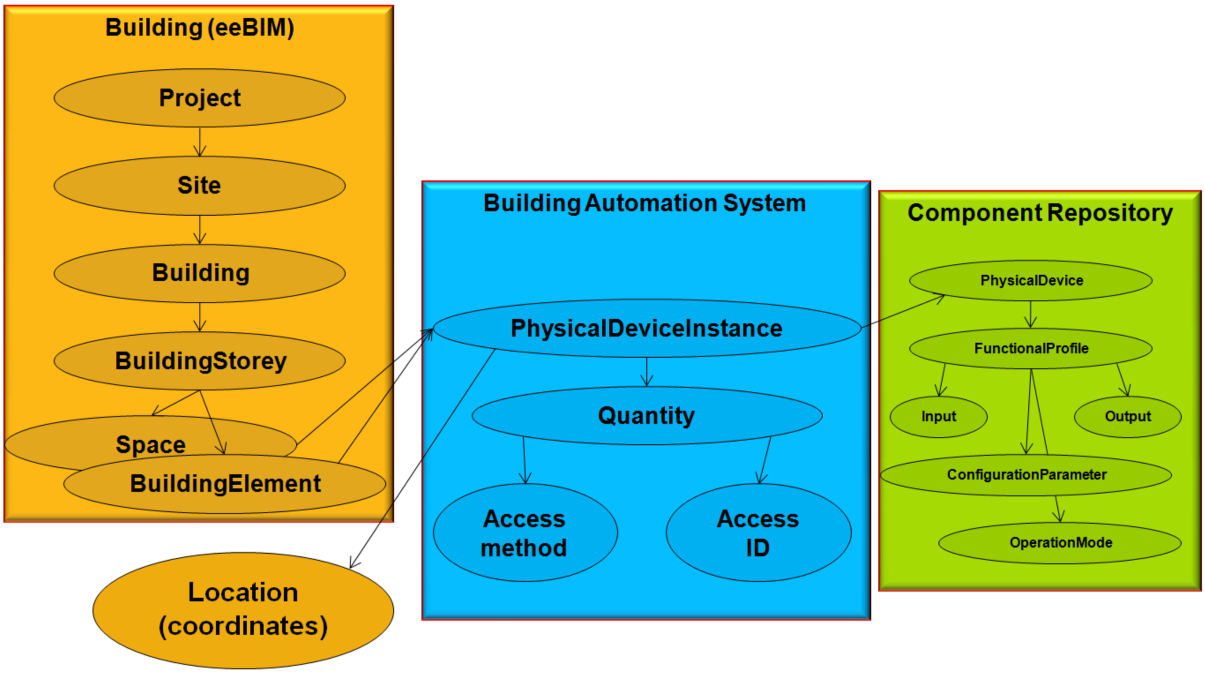

Figure 8: Simple version

For better comprehension, a (simplified) part of an example building modelled using the simple ontology version is given in Figure 9.

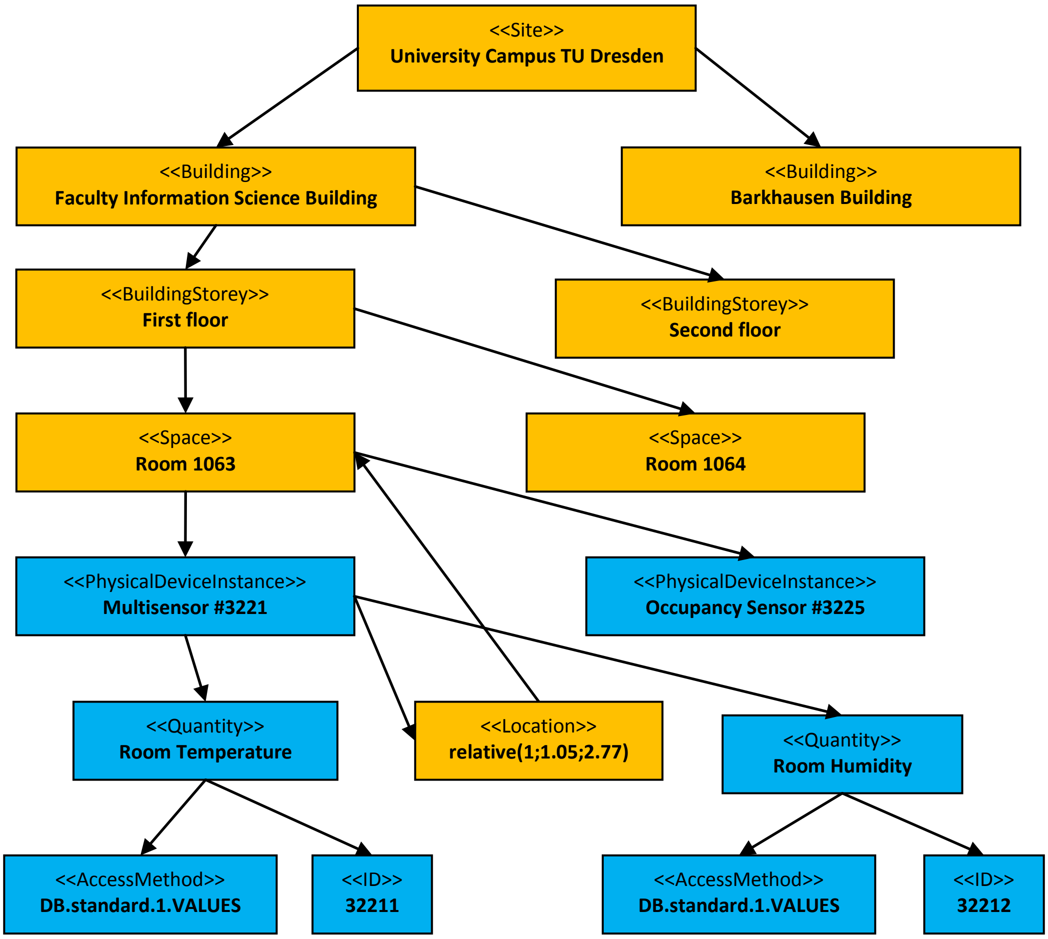

Figure 9: Example building modelled using the simple version of the ontology

3.4.3 Constraints

A strength of ontologies is the use of constraints for checking an ontology. In addition to conventional **OWL constraints** which can be defined with OWL, **integrity constraints (ICs)** based on SPARQL can be applied, analogue to (Rieckhof, et al., 2011). Using that it is possible to describe formally, how the mapping between of devices to rooms has to be made to get a consistent specification and on which condition the definition is correct and complete. For example, a room has to be attached to each device instance (existence constraint). At the same time, the device instance must not be attached to more than one room (maximum cardinality). The validity of the constraints for a given building ontology can be checked with a combination of an OWL reasoned and an IC engine.

4. Mapping to existing BAS technologies

In this section the mapping between the HESMOS ontology and the most common building automation systems is presented.

For the purposes of energy evaluation technology details like cabling, topology and bandwidth are not of interest, but the information model is important. The information models of the different technologies are different but it will be shown how they work together with the HESMOS ontology.

4.1 LON mapping

Local operating network (LON) is a fieldbus technology which has been developed since about 1990. It is standardized in EN 14908 (European Committee for Standardization, 2005).

An example for a LonWorks Application Layer object is shown in Figure 10. In LonWorks, there are **input network variables (nvis)**, **output network variables (nvos)** and **configuration parameters (cps)**. These match to inputs, outputs and configuration parameters of the HESMOS ontology. Objects are usually standardized to profiles. There are no operation modes in the formal specification of LonWorks, but the concept of operation modes is implicitly used via configuration parameters.

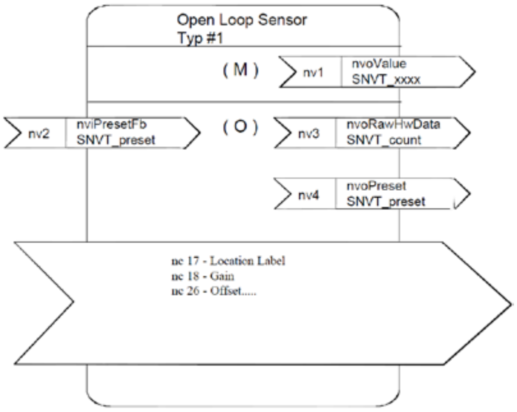

Figure 10: LON object (example), taken from (eTg-unitro Computersystem GmbH, 1999)

The mapping between LON and the HESMOS ontology is shown in Figure 11.

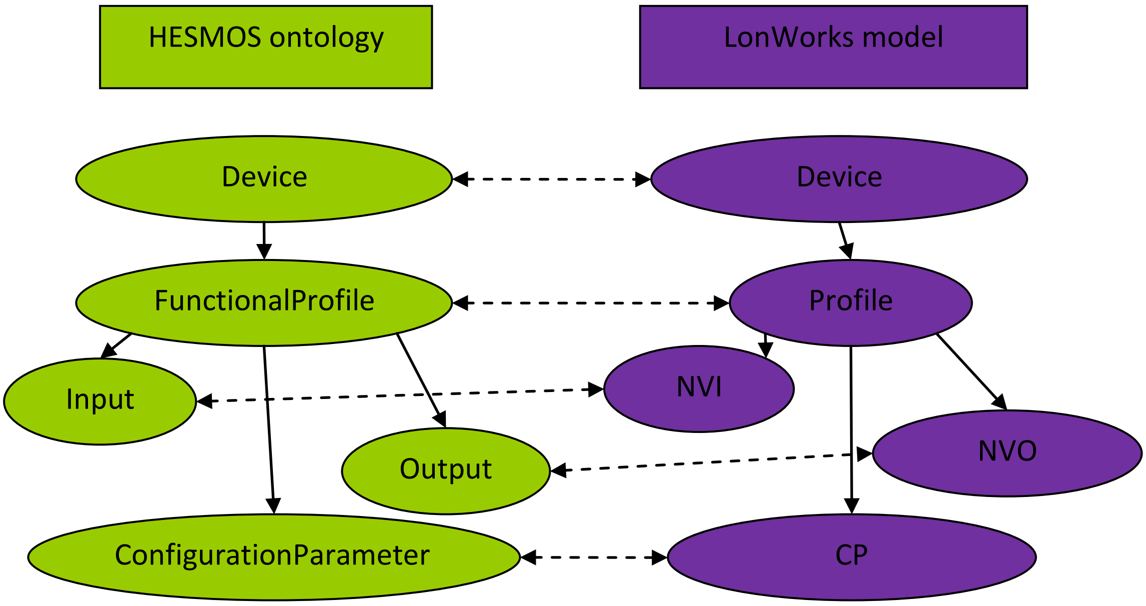

Figure 11: Mapping between LON and the HEMOS ontology

4.2 EnOcean Mapping

EnOcean is a young wireless network technology which is optimized for energy efficiency to allow energy harvesting and avoid batteries. The EnOcean GmbH was founded in 2001.

Differing from the other network technologies presented in this document, EnOcean does not contain any information model. In contrast, only different **EnOcean radio protocol (ERP) radio telegram types** are distinguished (EnOcean Alliance, 2009). These message types are used for different application purposes and are thus equivalent to the functional profiles in the HESMOS ontology. The radio telegram types are standardized as **EnOcean equipment profiles**.

The inputs and outputs are not described in an object orient fashion but in **bit ranges or offsets** of the message which is sent by this device.

The mapping of EnOcean to the HESMOS ontology is shown in Figure 12.

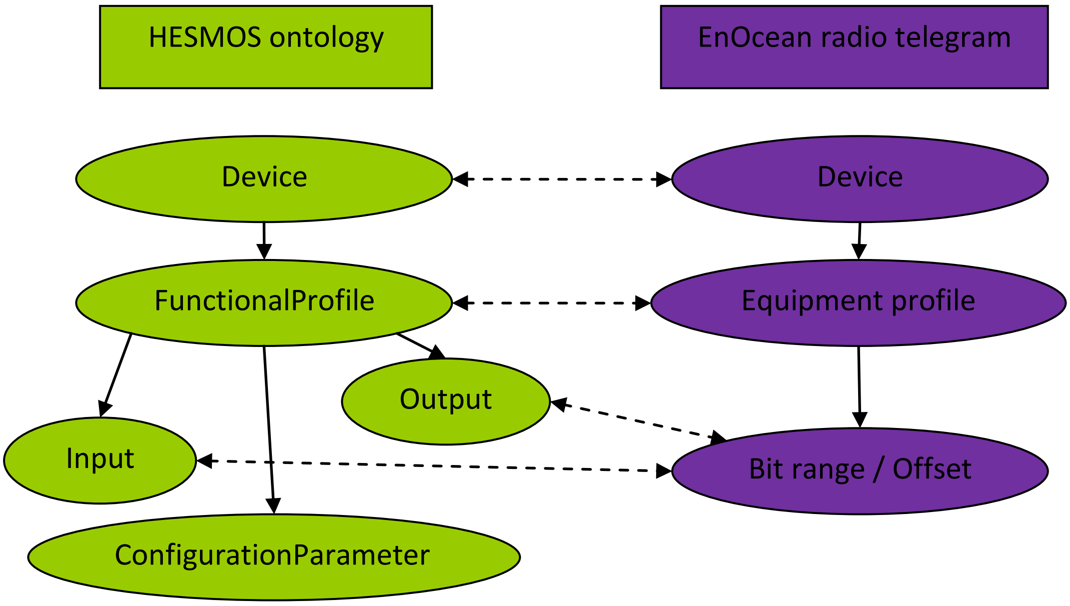

Figure 12: Mapping between EnOcean and the HESMOS ontology

4.3 BACnet Mapping

The history of BACnet goes back to 1987. BACnet has been standardized in the meantime (ASHRAE/ANSI Standard 135, ISO 16484-5). BACnet allows many types of physical layers. It even can run on top of a LonWorks network. The communication in the BACnet protocol is more complicated than the other ones presented in this document. However, the mapping between BACnet and the HESMOS ontology need not address these complex functionalities.

In BACnet, devices contain **objects** with **properties** (European Committee for Standardization, 2008). Properties are datapoints in the meaning of inputs, outputs and configuration parameters in the HESMOS ontology. There are readable (R) properties and read- and writable (W) properties. Many objects are standardized and represent the semantic of functional profiles in the HESMOS ontology.

Figure 13 shows the mapping.

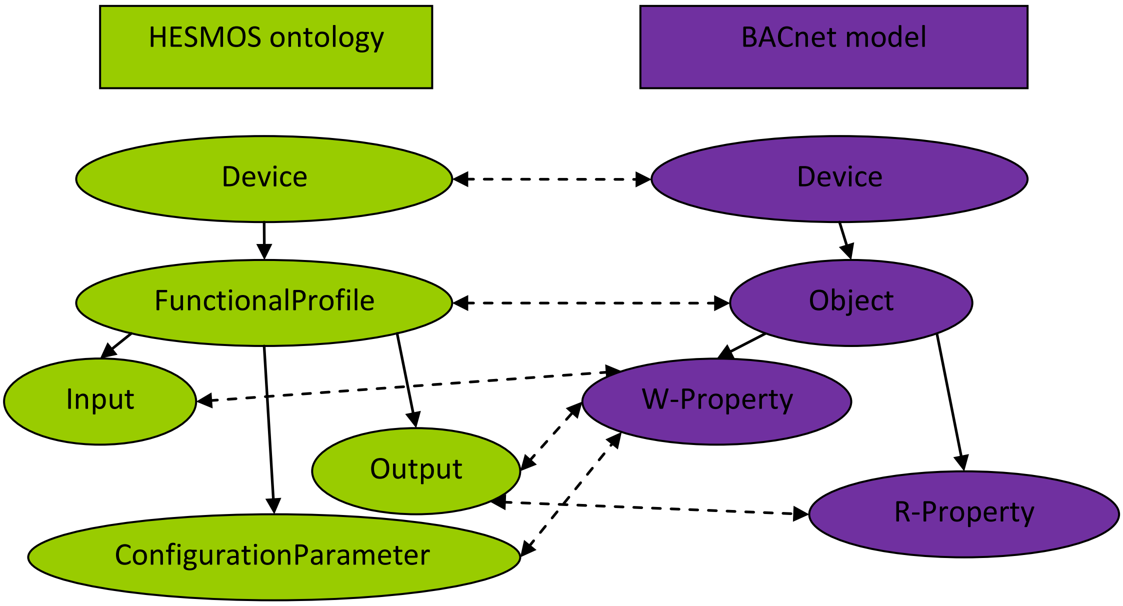

Figure 13: Mapping between BACnet and the HESMOS ontology

4.4 KNX Mapping

KNX is a very common network communications protocol in building automation, which is standardized in EN 50090 and ISO/IEC 14543. The history of KNX goes back to 1996 when three older network types were integrated into one new BAS technology.

The **KNX model** (KNX Association, 2009) is shown in Figure 14. In KNX, an application is a collection of **datapoints** which can send and receive data. Datapoints are grouped to **interface objects**. There is also the term “profile” in KNX but this means characteristics of devices which are not semantically the same like the HESMOS ontology **Functional Profiles**. Figure 15 shows the mapping between KNX and the HESMOS ontology.

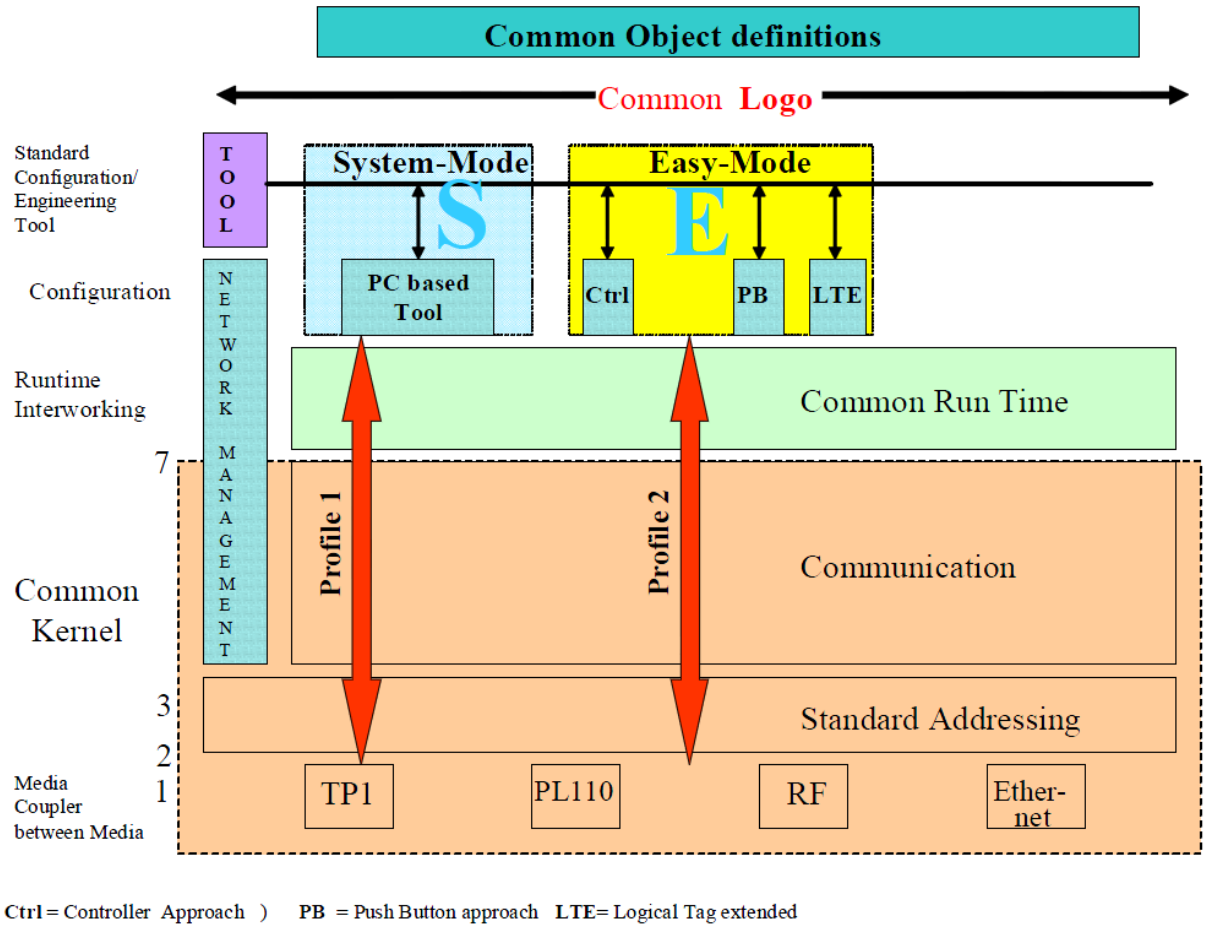

Figure 14: KNX model (taken from (KNX Association, 2009))

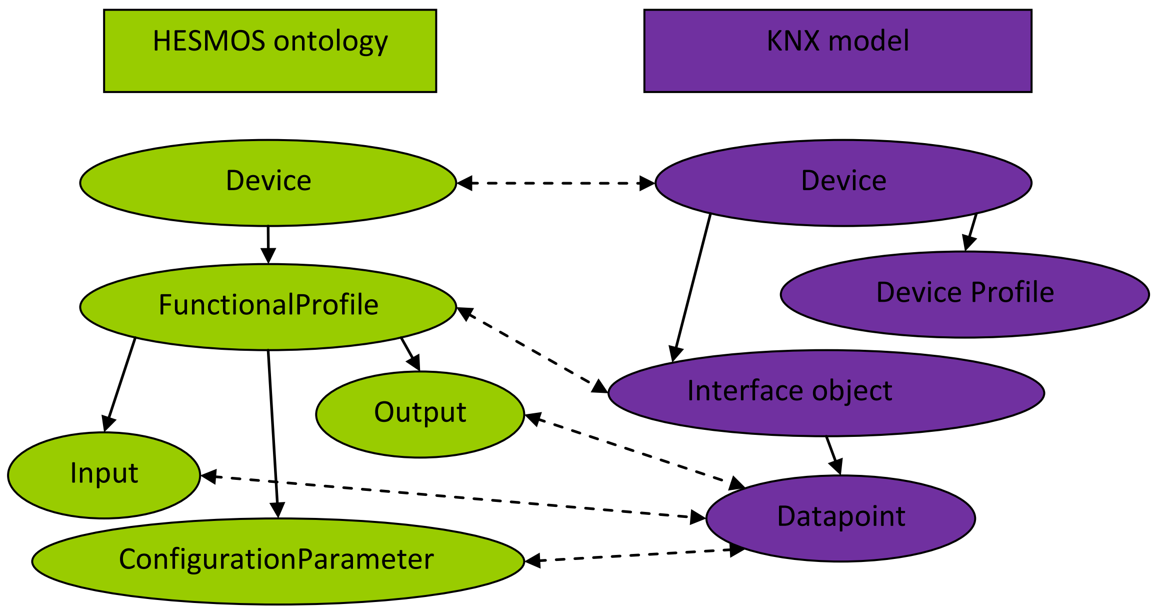

Figure 15: Mapping between KNX and the HESMOS ontology

4.5 ZigBee Mapping

ZigBee is a high level wireless communication protocol which is based on IEEE 802.15.4. The ZigBee Alliance has been founded in 2002 and the first stack release was published in 2004. There are different types of ZigBee standards. The currently most common one is **ZigBee PRO** which was released in 2007. Other standards are **ZigBee RF4CE** which is more suited for consumer electronics (e.g. intelligent remote controls) and **ZigBee IP** (currently in progress).

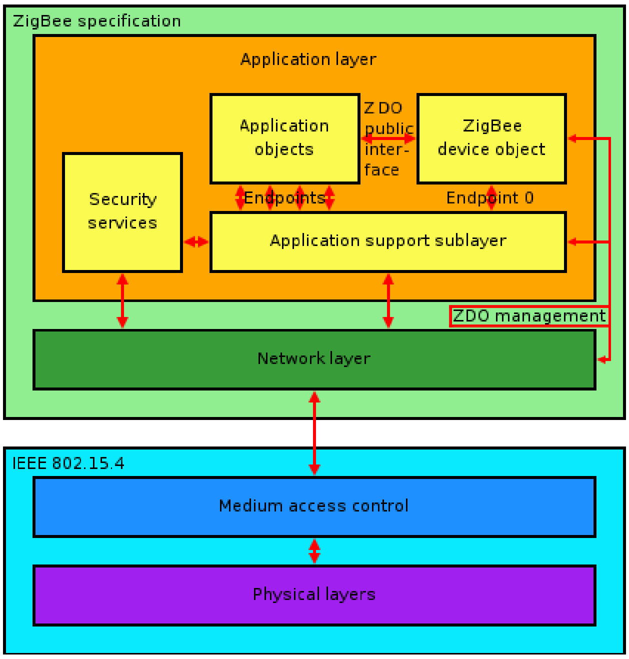

Figure 16: ZigBee Protocol Stack (taken from (2011))

The ZigBee Application layer consists of **application objects**, the **ZigBee Device Object**, the **application support layer** and **security services**, see Figure 16. For the end user only the **application objects** are of interest. Each ZigBee node can have up to 240 application objects which can be accessed via **endpoints**. Each application object is equal to exactly one application profile. Application profiles have **clusters** which are objects with commands and attributes. These clusters are the concepts of ZigBee which are equal to **inputs and outputs** in the HESMOS ontology.

An example for a ZigBee application profile would be a light switch, there called “Home Automation On/Off Light Switch”. This application profile has several clusters, e.g. “Commissioning”, “Identify” and “On/Off”. For the application, the cluster “On/Off” is important. This cluster has the methods “On”, “Off”, and “Toggle” and as an attribute the binary state (on or off).

The mapping between the HESMOS ontology and the ZigBee information model is shown in Figure 17.

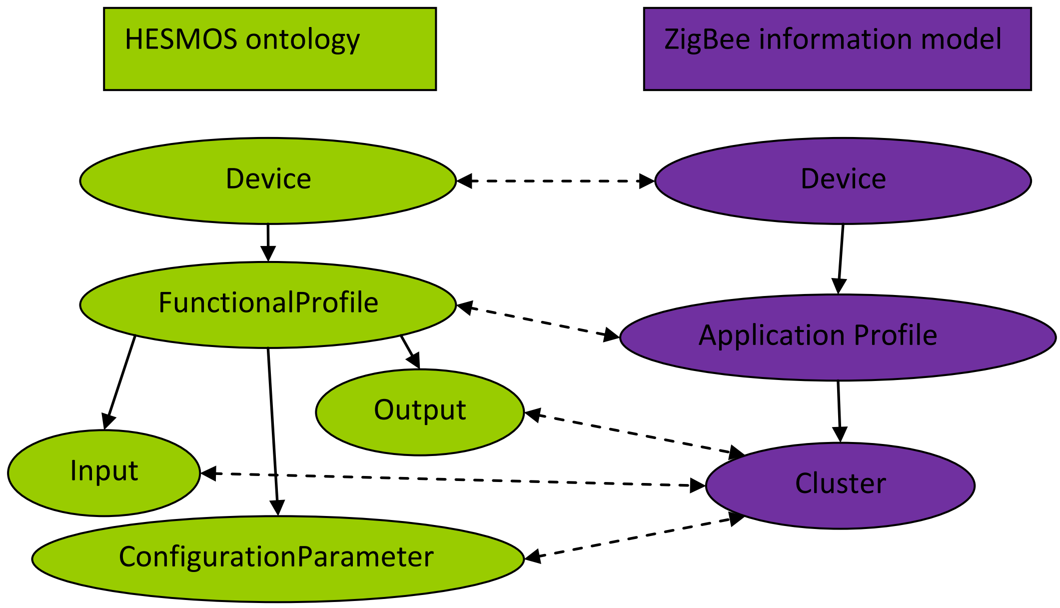

Figure 17: Mapping between HESMOS ontology and the ZigBee information model

5. Conclusions and Outlook

HESMOS closes the gap between building information models and building automation systems. The ontology described in this document is used to allow a link between the information available in the BIM and the measurement data from the building automation systems via a location-based link. Two versions of this link can be used, a more technology-oriented one which can be partially automated with the help of device descriptions, and a more end user oriented view which allows the easy editing by building operators.

To be prepared for future developments, an abstract view on building automation systems has been used. The mapping between the currently most important BAS network technologies and the ontology has been shown.

HESMOS will use the ontology in upcoming tasks. The main task dealing with the ontology is task T4.3 which will use the ontology for **intelligent access services**. The software prototype will be ready after month 24 in the deliverable D4.2. Further use of the ontology will be indirect via the intelligent access services. So, WP7 will result in an nD Navigator which will show the monitoring data that is accessed using the ontology. In WP5, the measurement information will be used to improve simulation models. Evaluation of monitored data is also part of WP9 and WP6. Thus, the ontology will be one of the main backbone components of the HESMOS IVEL.

Literature Sources

Automatische Installation drahtloser Systeme der Gebäudeautomation [Online]. - 4. November 2011. - http://iis807.inf.tu-dresden.de/~auteg/de/index.html.

Automatisierter Entwurf für die Gebäudeautomation [Online]. - 4. November 2011. - http://iis807.inf.tu-dresden.de/~auteg/de/index.html.

Beetz J., Leeuwen J.P. van und Vries B. de An Ontology Web Language Notation of the Industry Foundation Classes [Konferenz] // Proceedings of the 22nd CIB W78 Conference on Information Technology in Construction. - Dresden, Germany : [s.n.], 2005.

Bonino Dario und Corno Fulvio DogOnt - Ontology Modeling for Intelligent Domotic Environments [Konferenz] // Proceedings of the 7th International Semantic Web Conference. - Karlsruhe, Germany : [s.n.], 2008. - S. 790-803.

Charatsis Konstantinos J. [et al.] Integration of Semantic Web Services and Ontologies into the Industrial and Building Automation Layer [Konferenz] // EUROCON 2007 The International Conference on “Computer as a Tool”. - Warsaw, Poland : [s.n.], 2007.

Dibowski Henrik und Kabitzsch Klaus Ontology-Based Device Descriptions and Device Repository for Building Automation Devices [Artikel] // EURASIP Journal on Embedded Systems. - 2011.

Dirably T. El, Fies B. und Lima C. An Ontology for Construction Knowledge Management [Konferenz] // Proceedings of the Annual Conference of the Canadian Society for Civil Engineering. - Moncton, Canada : [s.n.], 2003.

DogOnt [Online]. - 7. November 2011. - http://elite.polito.it/dogont-tools-80.

El-Mekawy Mohamed und Östman Anders Semantic Mapping: an Ontology Engineering Method for Integrating Building Models in IFC and CITYGML [Konferenz] // Proceedings of the 3rd ISDE Digital Earth Summit. - Nessebar, Bulgaria : [s.n.], 2010.

EnOcean Alliance EnOcean Equipment Profiles (EEP) V2.0 [Buch]. - San Ramon, USA : [s.n.], 2009.

eTg-unitro Computersystem GmbH Technische Grundlagen zur LonWorks-Technologie [Buch]. - Thun : LonTech Thun, 1999.

European Committee for Standardization EN 14908-x Open Data Communication in Building Automation, Controls and Building Management — Building Network Protocol — [Buch]. - Brussels : [s.n.], 2005.

European Committee for Standardization EN ISO 16484-5 Building automation and control systems — Part 5: Data communication protocol (ISO 16484-5:2007) [Book]. - Brussels : [s.n.], 2008.

Fisch N. M. [et al.] The Energy Navigator - A Web based Platform for functional Quality Mangement in Buildings [Konferenz] // Proceedings of the 10th International Conference for Enhanced Building Operations . - Kuwait City, Kuwait : [s.n.], 2010.

Furfari Francesco [et al.] DomoML: the definition of a standard markup for interoperability of Human Home Interactions [Konferenz] // EUSAI2004. - Eindhoven, the Netherlands : [s.n.], 2004.

Gössling Andreas und Wollschlaeger Martin On Working with the Concept of Integration Ontologies [Konferenz] // Proceedings of the IEEE International Conference on Emerging Technologies and Factory Automation. - Hamburg, Germany : [s.n.], 2008. - S. 709-712.

Gu Tao [et al.] An Ontology-based Context Model in Intelligent Environments [Konferenz] // Proceedings of Communication Networks and Distributed Systems Modeling and Simulation Conference. - 2004.

Hegler Sebastian und Wollschlaeger Martin The Semantic Web in action: semantically enabled Device Descriptions [Konferenz] // Proceedings of the 5th IEEE Conference on Industrial Informatics. - Wien, Austria : [s.n.], 2007.

Karavan A., Neugebauer M. und and Kabitzsch K. Integration of Building Automation Network Design and 3D Construction Tools by IFC2x Standard [Konferenz] // Proceedings of the 6th IFAC International Conference on Fieldbus Systems and their Applications. - Puebla, Mexico : [s.n.], 2005.

Karavan A., Neugebauer M. und and Kabitzsch K. Merging Building Automation Network Design and IFC 2x Construction Projects [Konferenz] // Proceedings of the 22nd Conference on Information Technology in Construction. - Dresden, Germany : [s.n.], 2005.

Katranuschkov Peter [et al.] HESMOS Deliverable 2.2: The HESMOS Architecture [Bericht]. - Brussels : HESMOS Consortium, 2011.

Kim Eunhoe und Choi Jaeyoung An Ontology-Based Context Model in a Smart Home [Konferenz] // ICCSA 2006. - 2006.

KNX Association KNX System Specification - Architecture [Buch]. - 2009.

Kurtalj Nino Connecting Building Automation to Everything [Online]. - November 2010. - 4. November 2011. - http://www.automatedbuildings.com/news/nov10/articles/brightcore/101029112404brightcore.html.

Reinisch Christian [et al.] Integration of heterogenous building automation systems [Konferenz] // Proceedings of the 34th Annual Conference of the IEEE Industrial Electronics Society. - Orlando, USA : [s.n.], 2008.

Reinisch Christian, Kofler Mario J. und Kastner Wolfgang ThinkHome: A Smart Home As Digital Ecosystem [Konferenz] // Proceedings of the 4th IEEE International Conference on Digital Ecosystems and Technologies. - Dubai, United Arab Emirates : [s.n.], 2010.

ResUbic Lab Dresden - EnergyDesign [Online]. - 4. November 2011. - http://resubic.inf.tu-dresden.de/?page_id=94.

Rieckhof F., Dibowski H. und Kabitzsch K. Formal Validation Techniques for Ontology-based Device Descriptions [Konferenz] // Proceedings of the 16th IEEE International Conference on Emerging Technologies and Factory Automation. - Toulouse, France : [s.n.], 2011.

Schevers Hans und Drogemuller Robin Converting the Industry Foundation Classes to the Web Ontology Language [Konferenz] // Proceedings of the First International Conference on Semantics, Knowledge, and Grid. - 2005.

Shah Nazaraf und Chao Kuo-Ming Ontology for Home Energy Management Domain [Konferenz].

Sommaruga Lorenzo, Perri Antonio und Furfari Francesco DomoML-env: an ontology for Human Home Interaction [Konferenz] // Proceedings of SWAP 2005 the 2nd Italian Semantic Web Workshop. - Trento, Italy : [s.n.], 2005.

Valiente-Rocha Pablo A. und Lozano-Tello Adolfo Ontology-based expert system for home automation controlling [Konferenz] // Proceedings of the 23rd international conference on Industrial engineering and other applications of applied intelligent systems - Volume Part I . - 2010.

ZigBee [Online]. - 26. September 2011. - 4. November 2011. - http://en.wikipedia.org/wiki/Zigbee.

Appendix I: Acronyms

BAS	**B**uilding **A**utomation **S**ystems
BIM	**B**uilding **I**nformation **M**odel
eeBIM	**E**nergy **e**nhanced **B**uilding **I**nformation **M**odel
HESMOS	Holistic Energy Efficiency Simulation and Life Cycle Management of Public Use Facilities
ICT	**I**nformation **C**ommunication **T**echnology
IFC	**I**ndustry **F**oundation **C**lasses
IVEL	**I**ntegrated **V**irtual **E**nergy **L**aboratory
LON	**L**ocal **O**perating **N**etwork
BACnet	Data Communication Protocol for **B**uilding **A**utomation and **C**ontrol **Net**works
OWL	**W**eb **O**ntology **L**anguage
SPARQL	**S**PARQL **P**rotocol **A**nd **R**DF **Q**uery **L**anguage
IC	**I**ntegrity **c**onstraint