SEVENTH FRAMEWORK PROGRAMME OF THE EUROPEAN COMMUNITY
(EC GRANT AGREEMENT N° 26088)

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

Deliverable D2.2:
The HESMOS Architecture

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Due date : 30.06.2011
Issue date : 30.07.2011
Nature: Other

Start date of project: 01.09.2010 **Duration: 36 months**

Organisation name of lead contractor for this deliverable:
Technische Universität Dresden, Institut für Bauinformatik (TUD-CIB)

History:

Version	Description	Lead Author	Date
1.1	First Version (Sections 1, 2, part. 3)	Ken Baumgärtel (TUD-CIB)	09/06/11
1.2	Second Version (complete)	All involved partners	22/06/11
1.3	Third Version (consolidated)	Ken Baumgärtel (TUD-CIB)	20/07/11
1.4	Pre-final	Peter Katranuschkov (TUD-CIB)	28/07/11
1.5	**Checked and approved Final Version**	TUD-CIB	30/07/11

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Citation

Katranuschkov P., Baumgärtel K., Guruz R., Scherer R. J., Kaiser J., Grunewald J., Hensel B., Steinmann R., Zellner R., Laine T., Hänninnen R. (2011): HESMOS Deliverable D2.2: The HESMOS Architecture, © HESMOS Consortium, Brussels.

Acknowledgements

The work presented in this document has been conducted in the context of the seventh framework programme of the European community project HESMOS (n° 26088). HESMOS is a 36 month project that started in September 2010 and is funded by the European Commission as well as by the industrial partners. Their support is gratefully appreciated.
The partners in the project are Technische Universität Dresden (Germany), NEMETSCHEK Slovensko, S.R.O. (Slovakia), Insinooritoimisto Olof Granlund OY (Finland), Royal BAM Group NV (The Netherlands), Obermeyer Planen + Beraten (Germany) and AEC3 LTD. This report owes to a collaborative effort of the above organizations.

Project of SEVENTH FRAMEWORK PROGRAMME OF THE EUROPEAN COMMUNITY		
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PU	Public	**X**
PP	Restricted to other programme participants (including the Commission Services)	
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Executive Summary

The **objectives** of WP2 are the development of the software architecture for the **Integrated Virtual Energy Laboratory (IVEL)**, the identification of required components to enable various energy simulations and lifecycle studies where a great part of the functionality will be provided via outsourced web services and remote access to third-party tools and, last but not least, the development of an energy-enhanced BIM framework (eeBIM).

The IVEL is the overall HESMOS platform, which is developed using the service-oriented architecture (SOA) approach. It will include (1) services for energy and emission simulation that would typically precede decisions for design and retrofitting tasks initiated in result of detected under-performances in the facilities' management, (2) services for operative energy-related analyses regarding facilities control, operation and lifecycle management as well as (3) local background CAD and FM applications. The kernel of the platform will be provided by advanced BIM-based CAD and FM tools extended to support preliminary and final architectural design (including cost calculation and bills of quantities) but also capable of interacting with the energy analysis and simulation services.

This Deliverable covers two tasks of the overall work performed in WP2, namely:

- T2.1 Components Specification
- T2.3 Architecture of the platform and principal service orchestration

whereas Deliverable D2.1 is dedicated to task T2.2 BIM enhancement specification.

The deliverable report is structured into four parts:

In the **first part**, we present the overall concept of the IVEL and the technical scenarios for using it. This involves three principal ways to integrate the product of HESMOS in practice.

In the **second part**, the software architecture and its component modules are outlined. We define seven modules to cover the functionality of the user scenarios and the requirements identified in Deliverable D1.1. Three of these modules (Design, Facility Management, Public Access) are dedicated to the interaction of the end users with the IVEL, three others (Monitoring, Energy Computing and Reporting) are responsible for the specific energy-related functionality of the IVEL, and one module (IVEL Core) provides the necessary basic and advanced integration and coordination components.

In the **third part**, the identified components are specified in detail using a harmonised template. These components include third-party off-the-shelve applications, local and batch applications that will be extended for HESMOS, as well as web applications and web services that will be developed from scratch.

Finally, in the **fourth part**, the technical processes taking place on the IVEL in the identified user scenarios are defined, to provide the basis for adequate information exchange, service orchestration and technically grounded workflows.

Three partners were involved in the RTD work and each partner has contributed from their expert viewpoint as follows:

- **TUD**: IT components specification, IVEL Core and overall software architecture;
- **NEM**: Arch. design view, IVEL-Connector, external clients/services;
- **OG**: Facility management, client and operator view, external clients/services.

1. Concept of the IVEL

1.1 Introduction

Many advanced ICT applications for the design of energy efficient buildings already exist. However, while it is generally understood that decisions on energy efficient building design and operation have to be taken in all life cycle phases, current applications are mostly developed for the use by energy experts in detailed design, where most building parameters affecting energy performance are already determined and optimisation capabilities are limited. There is little energy-related ICT support both for early design, where vital strategic decisions have to be met, and for the later operational phase, where improvement decisions have to be taken. As a result, ICT integration is poor and the provided decision support is on limited level. With projects, however, where public-private contracts of 25-30 years of building operation are usual, there are excellent chances to develop a more efficient, holistic approach for the realisation of innovative services and tools for energy efficient and low carbon buildings, enabling better consideration of a large number of life cycle issues. A central enabling aspect in that regard is the achievement of a consistent integrated platform that can handle energy-related tasks while being at the same time aligned with design, facilities management, cost estimation and other life-cycle activities. Such a platform can be realized by an Integrated Virtual Energy Laboratory (IVEL) providing a set of value-add and supporting ICT components and a coherent approach how such components can be further extended, adapted or, if necessary, replaced by others.

There can be various points of view as to what such a virtual energy laboratory must cover. While a design team has to model and optimize a building in the *design and tendering phase*, the verification of building systems against the client requirements is done in the *commissioning phase*. Actual data is checked continually during the *operation phase* with the support of sensors from the Building Automation System (BAS). This involves the visualization of the current state and expected trends. If there is an increase in energy consumption, it should be possible to easily detect where it comes from and decide appropriate measures. Thus, the IVEL should provide an environment, which encapsulates functions to calculate the energy performance of the building by using suitable energy solvers. It has to be internet-based to allow easy access by various types of users and it must provide core functionalities for data mapping and communication issues like security checking, user management and access rights. Furthermore, it should have no direct interaction with the end users but be bound from various GUIs to enable different point of views. This principal concept has already been successfully applied in an earlier EU project, ISTforCE (Katranuschkov et al. 2001), albeit in another area of construction.

In this report, we describe possible scenarios for the use of the IVEL, define its overall architecture and the platform components, their linkage and the technical workflows required for realization of the envisaged TO-BE process.

1.2 Technical Scenarios

The HESMOS Deliverable D1.1 (Bort et al., 2011) defines four principal Use Case Scenarios for the envisaged improved PPP process named (1) *Design Phase*, (2) *Commissioning Phase*, (3) *Operational Phase,* and (4) R*efurbishment and Retrofitting Phase*. It shows also the differences between the current 'AS-IS' situation and the envisaged 'TO-BE' process in the form of detailed BPMN diagrams. On Figure 1 below, the main identified differences are synthesized.

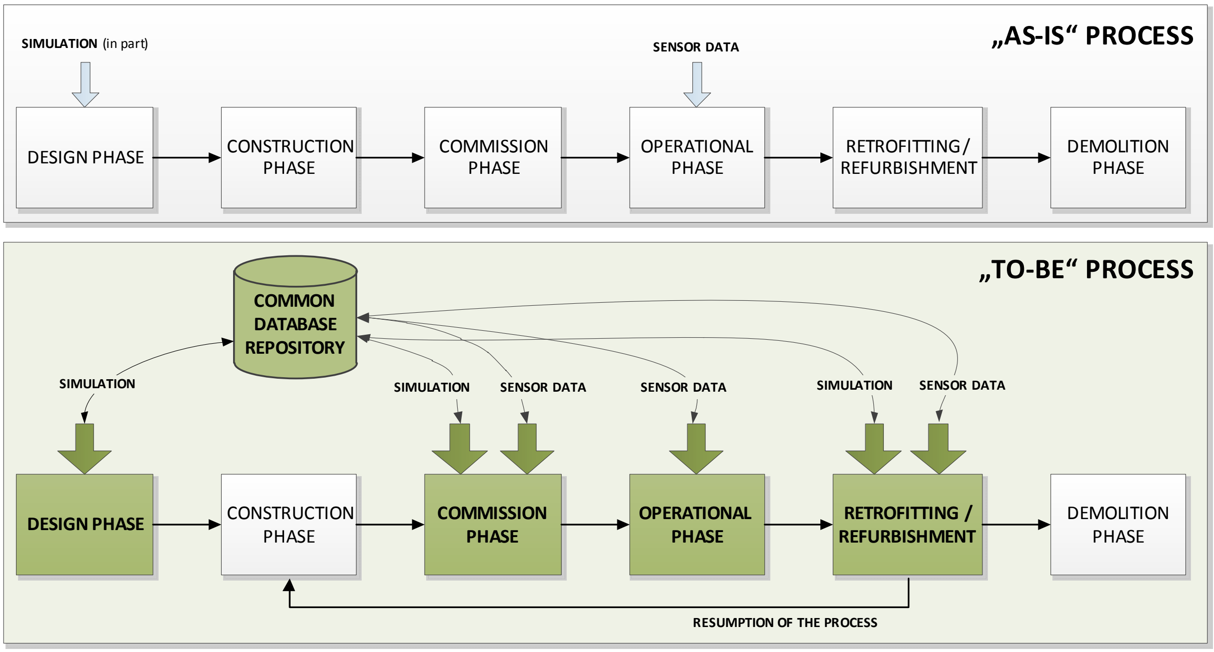

Figure 1: Comparison of the current "AS-IS" process and the envisaged HESMOS "TO-BE" Process in PPP projects

By examining these user scenarios, different technical scenarios for the IVEL realisation were derived. Firstly, we created for the design phase the technical schema that would allow users like architects and building services engineers to predict energy and emissions behaviour properly. Secondly, we developed the principal approach to integrate actual device data from BAS with facility management tools for the operational phase. Thirdly, we developed a general stand-alone scenario that would enable public access to the IVEL by owners, tenants or building authorities. The outcome is presented schematically in Figure 2. Even though on the high-level these scenarios look similar, there are significant differences in the detailed components and the way they should be orchestrated and used.

In the *CAD integration scenario,* a BIM-CAD system shall be integrated in the IVEL. The user can export IFC files from CAD and s/he is offered a comfortable overview of the energy efficiency calculated by energy solvers in an adequate web application. Changes will be submitted directly to the BIM-CAD model. This will extend BIM-CAD with energy views and analyses, which are not directly included at present. The interface of the CAD system will launch the nD Navigator (a Web application for the configuration and execution of energy simulations), register the user automatically and allow the upload of the BIM files that need to be analysed. After initializing the core of the IVEL, the nD Navigator will be opened and shown in the web browser of the client. The users can then configure the IVEL, start the desired simulation and visualize the obtained results from different perspectives.

In the *Facility Management integration scenario,* the linkage of FM tools to the IVEL will be realised. The users (building operators and managers) can control sensor and other device data from the building automation system and setup the technical parameters. The consequences of intended or made changes of these parameters can be then quickly calculated and evaluated with the help of the energy solvers in the IVEL.

The *stand-alone scenario* will view the IVEL as a web service, which can be called from registered users to analyse the energy-enhanced building information model (eeBIM) of the facility. Thus, the core of the IVEL can be accessed from any application by using a general-purpose web interface. This interface component can be plugged into any application for the simulation of energy performance.

Additionally, the user can open the nD Navigator in her/his web browser and can use it as graphical user interface in the IVEL. The scenario does not involve FM tools or CAD, neither direct access to BAS. It only integrates some of the energy solvers. The purpose is to provide lightweight easy-to-handle access to owners, tenants and public bodies to the energy performance of the facility during its lifecycle and to allow for examination of variants with regard to energy use, but without any design changes (e.g. experimenting with different materials, glazing, façade elements, different climatic conditions etc.).

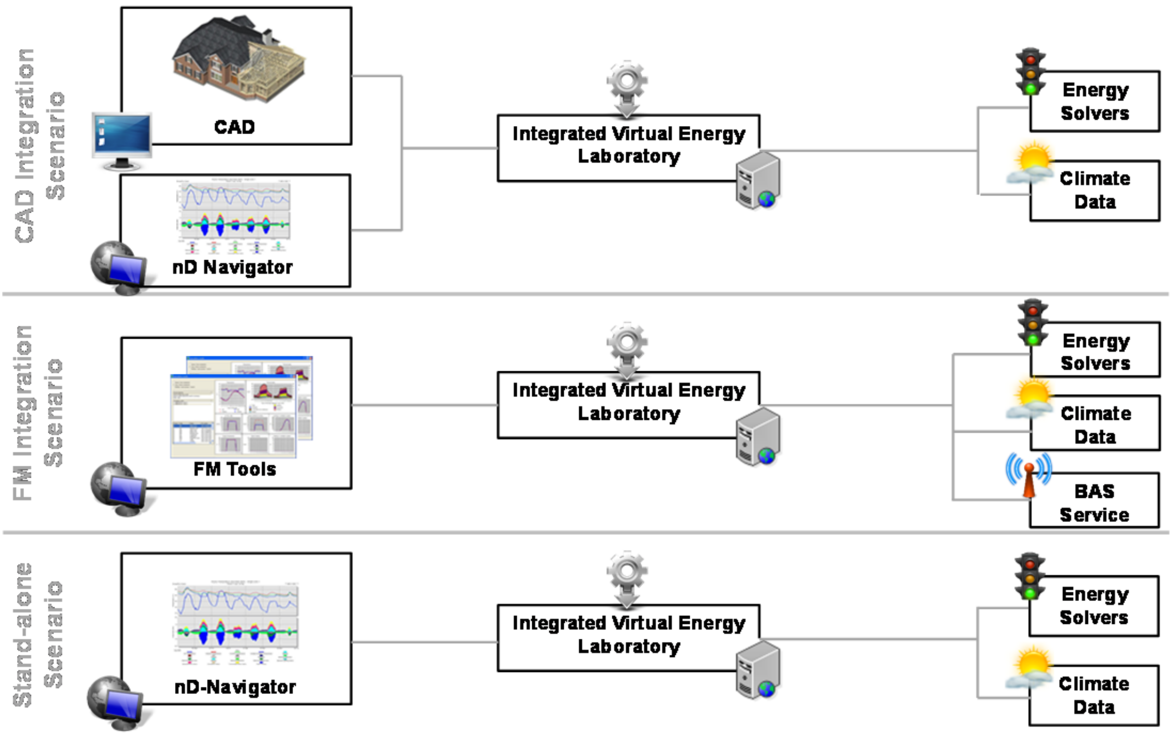

Figure 2: Technical Scenarios

1.3 Major Challenges and Design Decisions

There are several *ICT challenges* with regard to the envisaged IVEL platform that can be deduced from the shown overall "TO-BE" process and the derived technical scenarios. This includes:

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

These challenges all play direct or indirect role in the development of the software architecture of the IVEL. To tackle them efficiently, a SOA concept is applied (Papazoglou 2003) following a standard UML-based modular approach. Accordingly, the overall platform comprises several types of services and applications, bound together by an *IVEL Core Module* that acts as middleware providing for the required data and functional interoperability. Modularisation of the platform components is consistent with the identified actor roles and respective business cases. Consequently, the following modules are identified:

- *Design module* – comprising a CAD system and related design and cost estimation tools. The primary use of this module is by the building designers – architects, building services engineers etc.
- *Facility Management module* – comprising a FM system and related FM and cost calculation tools. The main users are the facility managers.
- *Public Access module* – providing a general-purpose interface to the IVEL via the newly developed nD Navigator, thereby enabling lightweight easy-to-do studies of the building performance with regard to energy, emissions and life cycle costs. The main users are the building owners and the PPP contractors, but can be also any involved public bodies and tenants of the facility. Thus, while a CAD system is responsible for the development of the building model, the nD Navigator can be used to examine energy-enhanced building model data for different performance alternatives.
- *Monitoring module* – providing services for operative monitoring of building performance and control of the Building Automation Systems. The main users are the building operators and the facility managers.
- *Energy Computing Module* – providing the energy related computational services and tools. Here, unlike traditional approaches that presume as main users of such tools highly specialized energy consultants, a service-oriented approach shifting the preparation of simulation models partially to the other modules and the related actors on the basis of well-defined data models, data exchange specifications and respective workflow facilities is suggested.
- Reporting Module, providing analysis and reporting services for generating comprehensive studies about the energy and emissions over the whole building life cycle.

Each of these modules is principally exchangeable due to the standardised data models in the eeBIM framework and the harmonized information exchange specifications and APIs. With the exception of the *IVEL Core Module* and the *Energy Computing Module* (which are strictly service-oriented and accessed via WSDL-based interfaces) (see Christensen et al., 2001) all other modules provide their own GUIs, tailored to the specific needs and views of the respective actors. The IVEL Core controls the binding to all other services and provides the required workflows and model transformations. The interoperability is provided by a so-called *IVEL Connector* defining a homogeneous interface via SOAP technology.

Within this modular approach, four types of software tools have to be considered:

- *Local applications*: Typically, these are legacy stand-alone systems providing user access via their own GUIs. They have to be upgraded for use on the IVEL platform with the help of IVEL Connector based service descriptions. In the current implementation of the IVEL these include a CAD system and some FM tools for the various FM aspects

- *Web applications*: Similar to the above, these are legacy application with their own GUIs. However, the GUI is Web Browser based or at least web-enabled, which provides for direct connection to the IVEL Core. In the current implementation of the IVEL these include an FM system and a newly developed nD Navigator for general purpose access to the platform
- *Batch applications or Local tools*: Such applications are most sophisticated energy solvers, such as EnergyPlus or Delphin (Nicolai et al, 2007). They may have an own GUI or may use an external one, like Design Builder for EnergyPlus. However, the actual input is file-oriented and allows for easy application of plug-in technology via the IVEL Connector or other, more dedicated web services
- Web Services: These are software services defined via WSDL. In IVEL, all components of the Core Module, the IVEL-Connector and a specialized Energy Solver front-end are in this category.

2. Overall Software Architecture

2.1 Overview

Using the IDM methodology (ISO 29481) and the defined "TO-BE" process shown in Figure 1, the software architecture of the IVEL platform together with the related information exchange and interoperability requirements and the software components with their major features, APIs and GUIs were conceptually developed.

Figure 3 shows a generalised view of the architecture of the IVEL with its principal modules, services and applications. The shown modules, framed in the dashed boxes, are briefly examined in the following sections. The specification of their components on technical level is provided in Chapter 3. This marks the starting point of the actual software development in the WPs 3-7. UML component diagrams are omitted so that the presentation does not become overly verbose.

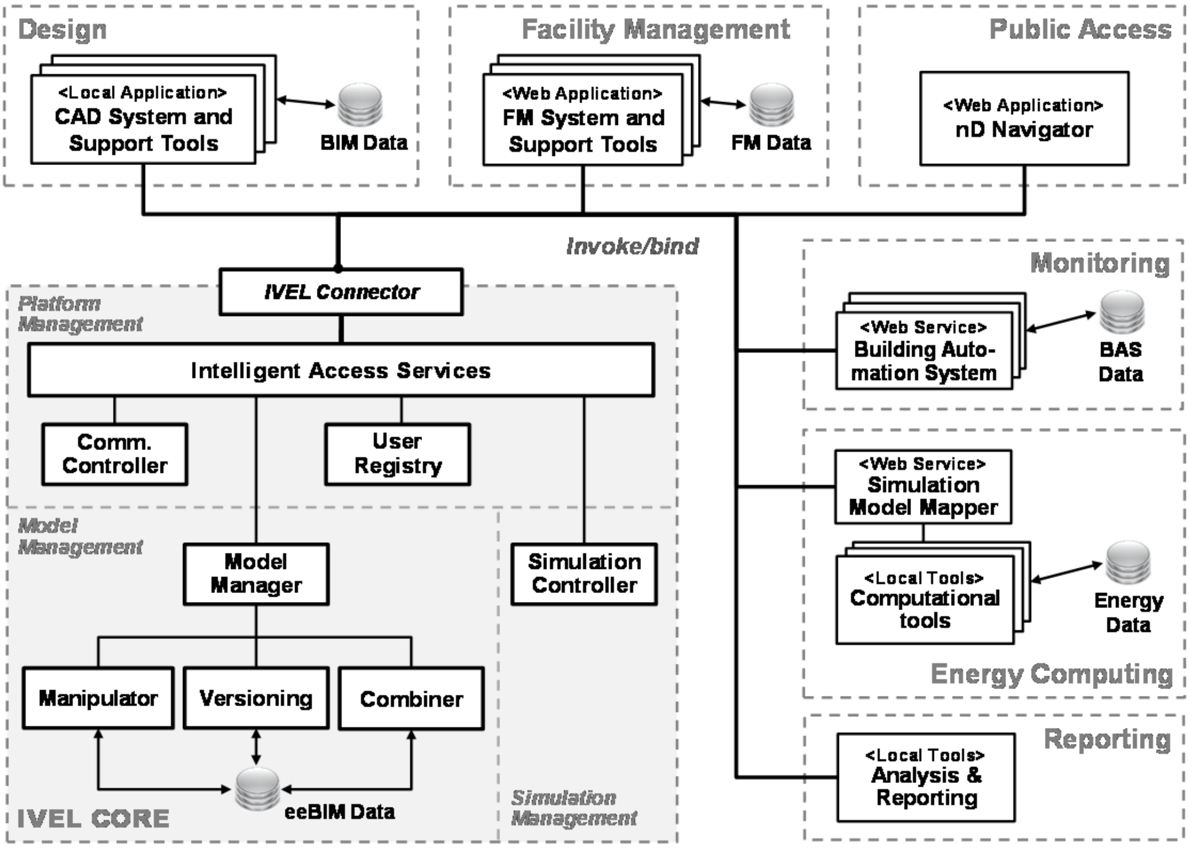

Figure 3: Software Architecture of the IVEL

2.2 IVEL Core

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

It comprises three sub-modules, namely *Platform Management*, *Model Management* and *Simulation Management*, thereby enabling separation of concepts, high level of modularity and parallel RTD work.

2.2.1 Platform Management

Platform Management involves the plugins for integrating the IVEL Core and for binding the components in the integrated virtual laboratory. It will be developed in a very general form to provide interfaces for any possible, present or future component in the virtual laboratory.

The interface to the IVEL Core is comprised by two services - the *IVEL Connector* and the *Intelligent Access Service (IAS)*. The *IVEL Connector* binds all external distributed services and can be bound from (web-) applications in a homogenous way. It is described in WSDL and its functions can be accessed via SOAP thereby providing the entry point for the IVEL Core. It is a service requester and service provider at the same time. It provides a GUI for the administration of the IVEL where the linkage of services and data is specified. The *IAS* is responsible for the interpretation of user queries to the underlying information models. It will interpret the *Engineering Query Language (EQL),* which is a user-friendly definition of requests to start a specific simulation, filter models or search model elements.

The *User Registry (UR)* stores and manages user data whereby each user is assigned a specific role and access rights. His/her profile influences the actual workflow and the user's views on the system. For example, an architect will never have the possibility to control the facility management of a building, while a facility manager would not be allowed to change the building model.

The Communication Controller (CoCo) is dedicated to the management of the communication between (web-) applications and web services. It will test the status of a requested web services and, if reachable, route the requests to it. It includes all declared data channels between each service and specifies the data in- and output to allow a homogeneous data flow. If a web service cannot be accessed, CoCo will interact with the user and provide him a list of alternative web services and can choose another one if possible. Therefore, it contains also a priority list with adequate web services and rules for choosing the appropriate one.

2.2.2 Model Management

Model Management constitutes the largest part of the IVEL Core. It consists of four components: *Model Manager*, *Model Manipulator*, *Model Combiner* and *Versioning*.

The *Model Manager (MM)* will provide the integrating interface of the other model management services. It will be used to request the manipulation of the eeBIM to prepare for the energy analyses. After the analyses are performed, it will control the preparation of results and the enrichment of eeBIM data.

The *Model Manipulator (MoMa)* will check if the eeBIM fulfils the minimal requirements of an energy simulation and enhance it as necessary. For example, it will convert 1st level to 2nd level space boundaries, which are physical or virtual delimiters of a space and are needed for proper energy simulations. A main part of the MoMa service is the appropriate filtering of the building model to provide the needed focus and improve the performance of the simulation. Consequently, it will be possible to simulate easily energy requirements or performances for one building storey or only some rooms.

The purpose of the *Model Combiner (MoCo)* is to generate, compile and bring together the involved multiple data models (BIM, climate, material, BAS) and link them on instance level as necessary. To achieve such combinations we use so-called *Information Containers* with references to the linked models, following the suggestion from (Fuchs et al, 2010). In accordance with that, MoCo will generate containers containing the model links for the required data exchange transactions, whereas the actual information will be only referenced and will be provided by the IAS.

Finally, the *Versioning* component will be responsible for storing all data connected to each user in a database to guarantee the comparison of former analysis results with current ones and to load and compare former versions of a changed building model.

2.2.3 Simulation Management

Simulation management is achieved by a single component, the *Simulation Controller (SiCo),* which will be responsible for the simulation workflows generated from simulation input data and their parallelization runs. It has to analyse the building model and the given user queries to create the right data format for the energy solver services. Furthermore, it will request the manipulation of the building model to enable the energy simulation. It may also create multiple tasks to be computed concurrently, thereby enabling parallel simulation of many possible variants.

2.3 End User Applications

The end user applications provide the productive environment and the GUIs for the users to the IVEL, where they can configure simulation parameters and control the overall simulation process and its results. The different users will have different access rights depending on their roles and each user can use her/his specific expertise to detail the workflow and refine the process. With regard to the identified user scenarios, we distinguish:

- Architectural design and Investment costs calculation
- Building performance, facility management and client requirements
- Varying simulation configurations and light-weight visualization for non-professionals.

2.4 Monitoring

Monitoring is provided by the building automation system, which is connected with the observed building through sensors. For HESMOS we will use AutoSpy-Lon (Kabitzsch & Vasyutynskiy, 1999) and a component repository with an ontology for mapping spaces with sensors. The integration of such services in a service oriented architecture (SOA) warranting the efficient collaboration of the involved users and their applications is recognised as the most promising approach today (Stack et al, 2009).

2.5 Energy Computing

As energy solvers in HESMOS the batch applications COND (Häupl et al, 1997), DELPHIN (Niemz et al, 2003) and THERAKLES (Therakles 2009) as well as RIUSKA (Jokela et al, 1997) will be extended and used, along with the widely-known EnergyPlus (DOE 2002). The former three (from TUD-IBK) as well as EnergyPlus comprise the Energy Computing module, while RIUSKA (from OG) is embedded in the Facility Management module. The Simulation Controller in the IVEL Core will be responsible for integrating the right solvers depending on the building model, the user role and the particular task.

2.6 Reporting

The reporting module is foreseen as a service, which generates country-specific reports dependent on the guidelines and the simulation results. While this is an important task in business use cases, we defined it as an auxiliary service, which will be covered but is not in the main focus of HESMOS.

3. Software Components Specification

3.1 Overview

In this section, we describe the software components that will be integrated in the HESMOS virtual energy laboratory. These components are local (interactive or batch) application which will be upgraded to (web) service components, libraries which provide additional functionality, and real web services requesting and providing up-to-date, just-in-time information.

In addition to the general description of the components, a template for determining all relevant requirements was developed to assure comparability of all data input and output. Services to be developed are outlined from the viewpoint of current knowledge and are marked with black table headers, whereas existing/services tools that will be further extended but their core functionalities are already available are marked in green. Tools that will be used on as-is basis are briefly mentioned but are not further detailed since their own user documentation can be consulted at any time.

3.2 IVEL Core Module

As already explained, the IVEL Core, responsible for the specialized middleware functionality of the overall platform is subdivided into three independent sub-modules:

- the platform management, handling user/service registry and the overall platform connectivity;
- the model management, handling all multi-model related issues, such as model filtering, model linking and model transformations;
- the simulation management, responsible for the setting up, invocation and control of the simulation runs.

3.2.1 Platform Management

IVEL Connector

Type: Web Application, new development in HESMOS	**Main developer: NEM**
Synopsis: HESMOS is going to use the IVEL-Connector as the central data pool for downloads and uploads of projects and project variants as well as project content. The IVEL-Connector himself controls the user access to different BIM projects. There will be additional services available on the web platform that enables data analysis and different simulations (comparison of energy demands of project variants, collision control, etc.). It includes the communication between services and the user registry of the IVEL with the overall user management.	
Features: • Service binding • Service registration • User registration	**Users:** • IVEL Administrator (directly) • All Users (indirectly)

INPUT & OUTPUT	Major Data Items	Type
BUILDING DATA (BIM) INPUT:	1. IFC2x3 BIM data incl. space boundaries 2. Allplan CAD data incl. space boundaries 3. Allplan Assistances (= predefined objects which already includes Material-ID-Code and all other important parameters	1. BIM file or data stream 2. File or data stream 3. CAD Object
MATERIAL DATA INPUT:	1. Will be selected directly in Allplan, Material ID-Code will be stored in the respective BIM-Object 2. Custom Allplan BIM assistances which already include Material definition (= Allplan Library)	1. Text 2. CAD Object
CLIMATE DATA INPUT:	1. Latitude - will be selected directly in Allplan 2. Longitude - will be selected directly in Allplan 3. Direction - will be selected directly in Allplan	1. Number 2. Number 3. Text
BAS DATA INPUT:	Allplan sensor data assistances (= predefined objects which already include CAD relevant sensor parameters)	CAD Object
ENERGY DATA INPUT:	Energy specific Data will be imported to Allplan via IFC2x3 (room temperatures / space boundaries)	BIM file or data stream
BUILDING DATA (BIM) OUTPUT:	1. IFC2x3 BIM data incl. space boundaries 2. Native Allplan data incl. space boundaries 3. Allplan assistances (= predefined objects which already includes Material-ID-Code and all other important parameters	1. BIM file or data stream 2. File or data stream 3. CAD Objects
MATERIAL DATA OUTPUT:	1. The Material ID-Code will be stored in the BIM-Object 2. Custom Allplan BIM assistances which already include Material definition (= Allplan Library)	1. BIM file 2. CAD Object
CLIMATE DATA OUTPUT:	Climate specific data will be exported from Allplan via IFC2x3 (latitude, longitude, direction)	BIM file or data stream
BAS DATA OUTPUT:	Allplan Sensor data assistances (= predefined objects which already include CAD relevant sensor parameters)	CAD Object
ENERGY DATA OUTPUT:	Energy specific Data will be exported from Allplan via IFC2x3 (room temperatures/space boundaries)	BIM file or data stream
PROGRAMMING LANGUAGE/ FRAMEWORK:	Web service (XML/Java)	

Intelligent Access Service

Type: Web Service, new development in HESMOS		**Main developer: TUD-CIB**
Synopsis: The Intelligent Access Service interprets requests semantically such as EQL queries from services and converts it into execution routines depending on the context.		
Features: • Interpreting EQL queries • Managing and dispatching of service requests		**Users:** • All platform users (indirectly)
INPUT & OUTPUT	**Major Data Items**	**Type**
BUILDING DATA (BIM) INPUT:	Changes of building elements	Structured query
MATERIAL DATA INPUT:	Changes of material parameter	Structured query
CLIMATE DATA INPUT:	Changes of climate parameter	Structured query
BAS DATA INPUT:	Changes of BAS parameter	Structured query
ENERGY DATA INPUT:	Changes of energy parameter	Structured query
DATA OUTPUT:	Depending on the input	eeBIM File, BIM File or Text
PROGRAMMING LANGUAGE/ FRAMEWORK:	Web service (XML/Java)	

3.2.2 Model Management

Model Manipulator

Type: Web Service, new development in HESMOS		**Main developer: TUD-CIB**
Synopsis: The model manipulator service is responsible for appropriate filtering of models e.g. IFC and conversion / transformation of elementary models to eeBIM.		
Features: • Model filter • Model conversion • Model enhancement		**Users:** • All users (indirectly)
INPUT & OUTPUT	**Major Data Items**	**Type**
BUILDING DATA (BIM) INPUT:	1. IFC2x3 BIM Data incl. space boundaries 2^{nd} level 2. IFC2x3 BIM Data excl. space boundaries 2^{nd} level	1. BIM file or data stream 2. BIM file or data stream
MATERIAL DATA INPUT:	Material defined in IFC2x3 BIM data, linked to material DB or file	BIM File or data stream

CLIMATE DATA INPUT:	1. Climate data defined in IFC2x3 BIM data through Property Sets, linked to climate DB or file 2. Climate data from climate service	1. BIM File or data stream 2. XML File or data stream
BAS DATA INPUT:	BAS data from BAS service, linked to BIM	File or data stream
ENERGY DATA INPUT:	N/A	N/A
DATA OUTPUT:	Depending on the input	eeBIM File, BIM File or Text
PROGRAMMING LANGUAGE/ FRAMEWORK:	Web service (XML/Java)	

Model Combiner

Type: Web Service, new development in HESMOS		**Main developer: TUD-CIB**
Synopsis: The Model Combiner offers a framework for working with multi-models. It shall allow inspection and creation of multi-models comprised of elementary (domain) models and links between their elements. Hence, it provides a plug-in mechanism for the generation of multi-model domain views (such as e.g. filtered, interconnected BIM-BAS data for a set of room, corresponding to some pre-defined criteria such as temperature or humidity threshold). The service can be accessed via EQL from CAD, FM or the nD Navigator, as well as directly, from a dedicated desktop application.		
Features: • Model linkage • Multi-Model management • Multi-Model filtering		**Users:** • All Users (indirectly)
INPUT & OUTPUT	**Major Data Items**	**Type**
BUILDING DATA (BIM) INPUT:	1. Full BIM model 2. BIM model view, e.g. a group of adjacent rooms to be analysed and the associated building elements	1. BIM file or data stream 2. BIM file or data stream
MATERIAL DATA INPUT:	Related material definitions for energy computations, including all material of all relevant building elements	Link File or data stream
CLIMATE DATA INPUT:	Related climate definitions for energy computations	Link File or data stream
BAS DATA INPUT:	Related BAS definitions	Link File or data stream
ENERGY DATA INPUT:	Related energy definitions for energy computations	Link File or data stream

DATA OUTPUT:	Linked data in eeBIM dependent on the input	eeBIM objects, or alternatively, Information Container file or data stream
PROGRAMMING LANGUAGE/ FRAMEWORK:	Web service (XML/Java)	

Model Versioning

Type: Web Service, new development in HESMOS		**Main developer: TUD-CIB**
Synopsis: The model versioning stores models in a repository and enables comparisons of different versions.		
Features: • Model repository • Model version management		**Users:** • IVEL admin (directly) • All users (indirectly)
INPUT & OUTPUT	**Major Data Items**	**Type**
BUILDING DATA (BIM) INPUT:	IFC2x3 BIM Data	BIM File
MATERIAL DATA INPUT:	1. Material defined in IFC2x3 BIM Data through Property Sets 2. Material defined in eeBIM Data	1. BIM File 2. eeBIM File
CLIMATE DATA INPUT:	1. Climate data defined in IFC2x3 BIM Data through Property Sets 2. Climate data defined in eeBIM Data	1. BIM File 2. eeBIM File
BAS DATA INPUT:	1. BAS data defined in IFC2x3 BIM Data 2. BAS data defined in eeBIM	1. BIM File 1. eeBIM File
ENERGY DATA INPUT:	1. Energy data defined in IFC2x3 BIM Data 2. Energy data defined in eeBIM Data	1. BIM File 2. eeBIM File
DATA OUTPUT:	Depending on the input	Versioned eeBIM File or BIM File
PROGRAMMING LANGUAGE/ FRAMEWORK:	Web service (XML/Java)	

3.2.3 Simulation Management

Simulation Controller

Type: Web Service, new development in HESMOS		Main developer: TUD-CIB
Synopsis: The simulation controller defines and configures the overall simulation process. It includes the pre- and post-processing and checking of data in- and outputs.		
Features: • Simulation management • Process validation		**Users:** • Energy planners (indirectly)
INPUT & OUTPUT	**Major Data Items**	**Type**
BUILDING DATA (BIM) INPUT:	Model view (energy view) of a building	BIM file or data stream
MATERIAL DATA INPUT:	Material data of walls, windows etc.	File or data stream
CLIMATE DATA INPUT:	Actual climate data and climate requirements	File or data stream
BAS DATA INPUT:	Sensor data input	CSV File or data stream
ENERGY DATA INPUT:	Energy requirements	File or data stream
BUILDING DATA (BIM) OUTPUT:	N/A	N/A
MATERIAL DATA OUTPUT:	N/A	N/A
CLIMATE DATA OUTPUT:	N/A	N/A
BAS DATA OUTPUT:	N/A	N/A
ENERGY DATA OUTPUT:	Energy results	File or data stream
PROGRAMMING LANGUAGE/ FRAMEWORK:	Web service (XML/Java)	

3.3 Design Module

In accordance with the identified user scenarios, for the architectural design relevant to the IVEL an advanced 3D BIM-CAD system will be used. In HESMOS, this will be Nemetschek's Allplan. However, other CAD systems complying with IFC could also be easily integrated, e.g. Autodesk's Revit.

<u>Allplan</u>

<table>
<tr><td colspan="2">Type: Local Application, extended in HESMOS</td><td>Main developer: NEM</td></tr>
<tr><td colspan="3">Synopsis:
The design module involves applications, which support the user in the design phase of building information modelling. Nemetschek's Allplan is an object oriented 3D-design software for architects and engineers, which covers all phases of a CAD system – from 2D design to 3D modelling through to the virtual building model. Allplan Architecture efficiently supports from the initial draft to application and construction cost planning right through to working and detailed drawings. Allplan compromises a full range of tools for design, layout and visualization. Allplan enables by creating an intelligent building model, which is a precondition in HESMOS.
In addition, Allplan BCM is used for the purpose of estimating quantities and calculating costs. It supports users when estimating quantities for technical specifications, which can then be transferred to a TAI system and used as the basis for tendering. Allplan BCM offers cost transparency by providing a range of different analyses.</td></tr>
<tr><td colspan="2">Features:
• Moisture proof (DIN 4108-3)
• Minimum heat protection (DIN 4108-2)
• Optimisation of the component's layered structure
• Assessment of mould growth criteria etc.
• Comprehensive GUI</td><td>Users:
• Designers (Architects, Building Services Engineers, Energy calculators)
• FM Managers</td></tr>
<tr><td>INPUT & OUTPUT</td><td>Major Data Items</td><td>Type</td></tr>
<tr><td>BUILDING DATA (BIM) INPUT:</td><td>Allplan native data or BIM / IFC2x3 interface to Allplan</td><td>BIM File</td></tr>
<tr><td>MATERIAL DATA INPUT:</td><td>1. Physical material properties of different materials will be identified in the Material Database via the material ID Code. The Material ID will be stored in the Allplan Object Parameter content
2. It is also possible to attach additional material parameters directly at Allplan objects</td><td>1. Text
2. Number (The data type depends on the material parameter definition)</td></tr>
<tr><td>CLIMATE DATA INPUT:</td><td>1. Latitude/Longitude
2. Direction</td><td>1. Number
2. Text</td></tr>
</table>

BAS DATA INPUT:	1. Sensor (X,Y,Z) Coordinates 2. Sensor type (CO_2, Temperature sensor, etc.) 3. Sensor Name and other Parameters (All sensor CAD relevant parameters will be stored in the Allplan Macro.)	1. Number 2. Text 3. Text
ENERGY DATA INPUT:	Rooms/space boundaries temperature	Number
BUILDING DATA (BIM) OUTPUT:	Allplan native BIM Data or IFC2x3 BIM Models	File
MATERIAL DATA OUTPUT:	1. The object Material-ID and other energy relevant parameters will be exported via IFC2x3 to external applications 2. Material-ID will be exported explicitly	1. File 2. Text
CLIMATE DATA OUTPUT:	1. Latitude/Longitude 2. North direction via IFC2x3	1. Number 2. Number
BAS DATA OUTPUT:	1. Sensor (X,Y,Z) Coordinates 2. Sensor type (CO_2, Temperature sensor, etc.) 3. Sensor Name and other Parameters 4. Room location via IFC2x3 format	1. Number 2. Text 3. Text 4. Text
ENERGY DATA OUTPUT:	BIM Model in IFC2x3 Data Format (with Rooms/space boundaries temperature)	BIM File
PROGRAMMING LANGUAGE/ FRAMEWORK:	C++, asp.net	

3.4 Facility Management Module

For the needs of facilities management, both specialised tools, dedicated to specific tasks, and complex FM systems are used. In HESMOS, software tools for FM tasks related to energy-efficient design are developed mainly by OG. However, other FM systems complying with the defined requirements could also be easily integrated. Optionally, this will be done for the FM system developed by GRAVIS, a German SME associated with TUD-IBK.

ROOMEX

Type: Web Application, extended in HESMOS		**Main developer: OG**
Synopsis: ROOMEX is a Web Application for thermal requirements management.		
Features: • Definition of thermal requirements for space types and spaces • Visualization of analyzed thermal performance • Comparison of analyzed performance between design alternatives and against requirements		**Users:** • Building Services Designers • Building Owners • FM Managers and Architects
INPUT & OUTPUT	**Major Data Items**	**Type**
BUILDING DATA (BIM) INPUT:	1. Site, building, floors, spaces 2. Space footprint geometry	1. Object 2. File
MATERIAL DATA INPUT:	N/A	
CLIMATE DATA INPUT:	N/A	
BAS DATA INPUT:	N/A	
ENERGY DATA INPUT:	N/A	
BUILDING DATA (BIM) OUTPUT:	N/A	
MATERIAL DATA OUTPUT:	N/A	
CLIMATE DATA OUTPUT:	N/A	
BAS DATA OUTPUT:	N/A	
ENERGY DATA OUTPUT:	Report	Structured & unstructured text
PROGRAMMING LANGUAGE/ FRAMEWORK:	Visual Studio 2010, C#, asp.net, framework 3.5	

RYHTI Metrics

Type: Web Application, extended in HESMOS		**Main developer: OG**
Synopsis: RYHTI Metrics is a Web Application for building performance management during operation and maintenance.		
Features: • Reporting of Building performance management • Performance comparisons against targets		**Users:** • Facility manager • FM Consultant • Building owner and users
INPUT & OUTPUT	**Major Data Items**	**Type**
BUILDING DATA (BIM) INPUT:	1. Space attributes (name, ...) 2. Space footprint geometry	1. Objects 2. File
MATERIALDATA INPUT:	N/A	N/A
CLIMATE DATA INPUT:	Measured local climate data	Numbers
BAS DATA INPUT:	1. Spatial thermal parameters (temp., CO2, ...) 2. Building services main system parameters	1. Numbers 2. Numbers
ENERGY DATA INPUT:	Energy consumption of heating, cooling and electricity	Numbers
BUILDING DATA (BIM) OUTPUT:	N/A	
MATERIAL DATA OUTPUT:	N/A	
CLIMATE DATA OUTPUT:	N/A	
BAS DATA OUTPUT:	N/A	
ENERGY DATA OUTPUT:	Report	Structured and unstructured text
PROGRAMMING LANGUAGE/ FRAMEWORK:	Visual Studio 2010, C#, asp.net, framework 3.5	

3.5 Public Access Module

The Public Access Module aims at enabling use of the IVEL by non-professionals who have interest in the life-cycle energy behaviour of the facility. Such users can be owners, tenants, public authorities, investors, high-level decision makers). In HESMOS public access will be realized by a single component, the nD Navigator, encompassing all identified required functionality.

nD Navigator

<table>
<tr><th colspan="2">Type: Web Application, new development in HESMOS</th><th>Main developer: NEM</th></tr>
<tr><td colspan="3">Synopsis:
The nD Navigator is an easy to use IT tool for flexible navigation in the nD information space, enabling visual design control of project variants and the presentation of simulation results in detailing form but also in a simple form for preliminary design and overview inspection (e.g. comparing energy simulation results of different Project Variants).</td></tr>
<tr><td colspan="2">Features:
• Comfortable navigation in nD information space
• Presentation of simulation results</td><td>Users:
• Architects
• Engineers
• Planners
• FM Managers</td></tr>
<tr><td>INPUT & OUTPUT</td><td>Major Data Items</td><td>Type</td></tr>
<tr><td>BUILDING DATA (BIM) INPUT:</td><td>1. Allplan Native Data or
2. BIM/IFC 2x3 interface
3. eeBIM interface</td><td>1. Allplan objects
2. BIM File
3. eeBIM File</td></tr>
<tr><td>MATERIAL DATA INPUT:</td><td>1. Material defined in IFC2x3 BIM data
2. Material defined in eeBIM data</td><td>1. BIM File
2. eeBIM File</td></tr>
<tr><td>CLIMATE DATA INPUT:</td><td>1. Climate data defined in IFC2x3 BIM data
2. Climate data defined in eeBIM data</td><td>1. BIM File
2. eeBIM File</td></tr>
<tr><td>BAS DATA INPUT:</td><td>1. BAS data defined in IFC2x3 BIM data
2. BAS data defined in eeBIM data</td><td>1. BIM File
2. eeBIM File</td></tr>
<tr><td>ENERGY DATA (BIM) INPUT:</td><td>1. Energy data defined in IFC2x3 BIM data
2. Energy data defined in eeBIM data</td><td>1. BIM File
2. eeBIM File</td></tr>
<tr><td>PROGRAMMING LANGUAGE/ FRAMEWORK:</td><td colspan="2">C++, Java, Web Environment, XML</td></tr>
</table>

3.6 Monitoring Module

The Monitoring Module established the integration of BAS in the IVEL, thereby enabling comparisons of 'AS-DESIGNED' and 'AS-IS' building behaviour. However, in contrast to BIM-related components where harmonised model access for the building data can be provided via the standard IFC model, in building automation several standards and proprietary protocols exist. For the HESMOS prototype platform, the focus will be on the LON and the BACnet standard, which are widely used today. Integration will be provided by three components: (1) a general-purpose BAS Service, (2) a Component Repository, and (3) an existing Web Application, AutoSpy-LON.

BAS Service

Type: Web Service, extended in HESMOS		**Main developer: TUD-TIS**
Synopsis: This Service is a web application for access to the building automation system of an existing building.		
Features: • Access to BAS information		**Users:** • Civil Engineers • Home Owners • Site Managers, Facility Managers
INPUT & OUTPUT	**Major Data Items**	**Type**
BUILDING DATA (BIM) INPUT:	N/A	N/A
MATERIAL DATA INPUT:	N/A	N/A
CLIMATE DATA INPUT:	N/A	N/A
BAS DATA INPUT:	List of desired sensor/actuator IDs	File
ENERGY DATA INPUT:	N/A	N/A
DATA OUTPUT:	1. Measurement sequences from BAS 2. List of available BAS devices	1. File 2. File
PROGRAMMING LANGUAGE/ FRAMEWORK:	Dependent on the building (BAS)	

Components Repository including Ontology

Type: Web Service, new development in HESMOS	**Main developer: TUD-TIS**
Synopsis: Web service for matching sensors to rooms based on a specifically developed device ontology for the linkage of the sensors in eeBIM.	
Features: • Matching sensors to rooms	**Users:** • Energy Planners, • BAS editor (indirectly)

INPUT & OUTPUT	Major Data Items	Type
BUILDING DATA (BIM) INPUT:	List of rooms at the site	File
MATERIAL DATA INPUT:	N/A	N/A
CLIMATE DATA INPUT:	N/A	N/A
BAS DATA INPUT:	List of available BAS devices	File
ENERGY DATA INPUT:	N/A	N/A
DATA OUTPUT:	List of sensor IDs	File
PROGRAMMING LANGUAGE/ FRAMEWORK:	Web service (XML/Java)	

AutoSpy-LON

Type: Web Application, used in HESMOS		Main developer: TUD-TIS
Synopsis: This application is for monitoring and visualizing BAS related data.		
Features: • Monitoring • Visualization		**Users:** • Facility managers • Owners
INPUT & OUTPUT	**Major Data Items**	**Type**
BUILDING DATA (BIM) INPUT:	N/A	N/A
MATERIAL DATA INPUT:	N/A	N/A
CLIMATE DATA INPUT:	N/A	N/A
BAS DATA INPUT:	Measurement data	File
ENERGY DATA INPUT:	N/A	N/A
DATA INPUT:	Measurement data	File
PROGRAMMING LANGUAGE/ FRAMEWORK:	C++	

3.7 Energy Computing Module

Energy Computing constitutes the central function of the IVEL. The module should provide flexibility to solve different lifecycle energy analysis and simulation tasks. Therefore, to provide for proof of concept and achieve a directly exploitable environment, in HESMOS a number of tools will be integrated, ranging from the widely known EnergyPlus (DOE 2002), a set of tools of TUD-IBK (COND, DELPHIN, THERAKLES), each with a specific area of attention, RIUSKA by OG, which can be used as part of the FM toolset, and a third-party Climate Service, providing access to actual climate data.

EnergyPlus

EnergyPlus is probably the world's most popular energy application in AEC/FM. It is not further detailed here because of the existing comprehensive freely accessible documentation.

COND

Type: Batch Application, extended in HESMOS		**Main developer: TUD-IBK**
Synopsis: COND is a desktop application for hydrothermal steady state analysis of multi-layer components of the building envelope such as exterior walls, roofs etc.		
Features: • Moisture proof (DIN 4108-3) • Minimum heat protection (DIN 4108-2) • Optimization of the component's layered structure • Assessment of mould growth criteria etc.		**Users:** • Architects, civil engineers, energy planners (indirectly)
INPUT & OUTPUT	**Major Data Items**	**Type**
BUILDING DATA (BIM) INPUT:	1. Number of the wall layers 2. Thickness of the wall layers 3. Material parameters for each layer 4. Indoor air temperature [°C] 5. Indoor air relative humidity [%] 6. Outdoor air temperature [°C] 7. Outdoor air relative humidity [%] 8. Outdoor heat transfer resistance [m²K/W]	1. Number 2. Number 3. Object 4. Number 5. Number 6. Number 7. Number 8. Number
MATERIAL DATA INPUT:	1. Name of the material 2. Thermal transmittance resistance; lambda [mK/W] 3. Vapor diffusion resistance factor [-] 4. Moisture content at 80% relative air humidity [kg/m³] 5. Saturation moisture [kg/m³] 6. Water absorption coefficient [kg/m² h^(1/2)]	1. Text 2. Number 3. Number 4. Number 5. Number 6. Number

CLIMATE DATA INPUT:	1. Static average values for out-door temperature if outside is exposed to outdoor air 2. Static average value for relative humidity for outdoor air if out-side is exposed to outdoor air	1. Number 2. Number
BAS DATA INPUT:	N/A	N/A
ENERGY DATA INPUT:	N/A	N/A
DATA OUTPUT:	1. Heat conduction of each layer [m²K/W] 2. Vapour diffusion resistance of each layer [m/s] 3. Liquid water conduction resistance [m²s/kg] 4. Overall moisture depending heat loss coefficient [m² K/W] 5. Overall moisture depending heat conduction coefficient [m² K/W]	1. Real number 2. Real number 3. Real number 4. Real number 5. Real number
PROGR. LANGUAGE/ FRAMEWORK:	C++	

DELPHIN

Type: Batch Application, extended in HESMOS		**Main developer: TUD-IBK**
Synopsis: DELPHIN is a desktop application for numerical simulation of coupled heat and moisture transport inside opaque walls, roofs and floors.		
Features: • 1D, 2D and rotation symmetric 3D modelling • Optimization of the component's layered structure • Particular calculation of various characteristic values		**Users:** • Architects, civil engineers, energy planners (indirectly)
INPUT & OUTPUT	**Major Data Items**	**Type**
BUILDING DATA (BIM) INPUT:	1. Orientation, inclination and latitude of the wall [Deg] 2. Wall area [m²]	1. Number 2. Number
MATERIAL DATA INPUT:	1. (dry) bulk density [kg/m³] 2. (dry) specific heat capacity [J/kg K] 3. (dry) thermal conductivity [W/m K] 4. open porosity [m³/m³] 5. effective saturation [m³/m³] 6. water uptake coefficient [kg/m² s05] 7. water vapour diffusion resistance factor [-] 8. liquid water diffusivity at effective saturation [m²/s]	1. Number 2. Number 3. Number 4. Number 5. Number 6. Number 7. Number 8. Number

	9. Capillary saturation content [m³/m³] 10. Water retention curve 11. Reverse water retention curve 12. Liquid water diffusivity 13. Water vapour permeability thermal conductivity	9. Number 10. Object 11. Object 12. Number 13. Object
CLIMATE DATA INPUT:	1. Outdoor air temperature [°C] 2. Outdoor air relative humidity [%] 3. Wind direction [Deg] 4. Wind velocity [m/s] 5. Direct sun radiation [W/m²] 6. Diffuse sun radiation [W/m²] 7. Heat emission from surrounding ground [W/m²] 8. Atmospheric counter radiation [W/m²] 9. Rain flux density on a horizontal plane [l/m² s]	1. Number 2. Number 3. Number 4. Number 5. Number 6. Number 7. Number 8. Number 9. Number
BAS DATA INPUT:	N/A	N/A
ENERGY DATA INPUT:	1. Inside and outside exchange coefficient for heat flow [W/m² K] 2. Inside and outside exchange coefficient for vapour diffusion [s/m] 3. Reflection coefficient of the surrounding ground [-] 4. Absorption coefficient of the building surface [-] 5. Emission coefficient of the building surface [-] 6. Rain exposure coefficient [-] 7. Minimum rain temperature [°C] 8. Minimum normal rain intensity [l/m² s]	1. Number 2. Number 3. Number 4. Number 5. Number 6. Number 7. Number 8. Number
DATA OUTPUT:	1. Liquid content (Volume fraction) [Vol-%] 2. Relative humidity [%] 3. Temperature [°C] 4. Moisture mass density (liquid + vapour) [kg] 5. Over hygroscopic water mass density [kg]	1. Number 2. Number 3. Number 4. Number 5. Number
PROGRAMMING LANGUAGE/ FRAMEWORK:	C++	

THERAKLES

Type: Batch Application, extended in HESMOS		**Main developer: TUD-IBK**
Synopsis: THERAKLES is a desktop application for calculation of the thermal conditions (e.g. indoor air temperature, operative room temperature, temperature of the inner surface of envelops elements) inside a room depending from outdoor climate, room envelop and idealised HVAC-Equipment over short and long-term periods.		
Features: • Fast computation (compared to EnergyPlus) • Predefined weather data, construction data, material data and window data included • Concerning idealized heating and cooling equipment • Evaluation of thermal comfort based on operative temperature concerning EN 15251		**Users:** • Architects, civil engineers, energy planners (indirectly)
INPUT & OUTPUT	**Major Data Items**	**Type**
BUILDING DATA (BIM) INPUT:	1. Orientation and inclination of each element of the rooms envelop [Deg] 2. Effective ground surface [m²] 3. Ceiling height [m] 4. Layer structure of each layer for each envelope of the room including opaque and transparent areas 5. Thickness for each layer for each envelope of the room including opaque and transparent areas [m] 6. Area for each envelope of the room incl. opaque and transparent areas [m²] 7. Orientation of each element of the envelop [Deg] 8. Type of shading equipment [-] 9. Shading coeff. of the shading equipment [-] 10. (air) temperature of the adjacent room (if existent) for each element of the enve-lop [°C] 11. Constant thermal load [W/m²] 12. Existence of a heating System [-] 13. Heating set point temperature [°C] 14. Existence of a cooling System [-] 15. Cooling set point temperature [°C] 16. Ventilation rate for incoming air [1/h] 17. Time schedule of occupancy by people [-] 18. Occupancy related thermal load per person [W/P]	1. Number 2. Number 3. Number 4. Text 5. Number 6. Number 7. Number 8. Text 9. Number 10. Number 11. Number 12. Text 13. Number 14. Number 15. Text 16. Number 17. Number 18. Number

MATERIAL DATA INPUT:	Opaque envelop (as a part of the material data used in DELPHIN) 1. (dry) bulk density [kg/m³] 2. (dry) specific heat capacity [J/kg K] 3. (dry) thermal conductivity [W/m K] Transparent envelop: 4. Overall heat transfer coefficient (glazing + frame) [W/m K] 5. Transmissibility / Overall energy transfer coefficient g [%] 6. Frame factor f [%]	Opaque envelop: 1. Number 2. Number 3. Number Transparent envelop: 4. Number 5. Number 6. Number
CLIMATE DATA INPUT:	1. Outdoor air temperature [°C] 2. Outdoor air relative humidity [%] 3. Direct sun radiation [W/m²] 4. Diffuse sun radiation [W/m²]	1. Number 2. Number 3. Number 4. Number
BAS DATA INPUT:	N/A	N/A
ENERGY DATA INPUT:	1. Thermal load of the room equipment [W] 2. Time schedule of the thermal load of the room equipment [-] 3. Maximum heating power [W] 4. Maximum cooling power [W]	1. Number 2. Number 3. Number 4. Number
DATA OUTPUT:	1. For each hour of a hole year or summer period 2. Operative room temperature [°C] 3. Indoor air temperature [°C] 4. Evaluation of thermal comfort based on operative temperature concerning EN 15251 [-] 5. effective direct und diffuse solar short wave radiation flux [W/m²] 6. U-value of each layer of the rooms envelop 7. Thermal storage mass applied to part of the envelop [kg/m²] 8. Thermal storage capacity applied to part of the envelop [kJ/m²]	1. Number 2. Number 3. Number 4. Number 5. Number 6. Number 7. Number 8. Number
PROGRAMMING LANGUAGE/ FRAMEWORK:	C++	

RIUSKA

Type: Local Application, extended in HESMOS	**Main developer: OG**
Synopsis: Application for dynamic thermal comfort and energy analysis spatially for the whole building.	
Features: • Annual temperature constancy simulation • Air flow, cooling and heating capacity sizing based on comfort criteria • Energy consumption simulation on space group (e.g. air-conditioning service area) or whole building level • Uses DOE-2.1E as a simulation engine	**Users:** • Architects, civil engineers, energy planners (indirectly)

INPUT & OUTPUT	Major Data Items	Type
BUILDING DATA (BIM) INPUT:	1. Site, building, floors, spaces 2. Space boundaries 3. Type of the building elements (walls, slabs, windows, ...)	1. Object 2. Objects 3. Text
MATERIAL DATA INPUT:	1. Thermal transmittance resistance; lambda [mK/W] etc.	1. Number
CLIMATE DATA INPUT:	1. Hourly temperature	1. Number
BAS DATA INPUT:	N/A	N/A
ENERGY DATA INPUT:	N/A	N/A
DATA OUTPUT:	1. Spatial max/min temperatures 2. Sized spatial air flow, cooling and heating needs 3. Energy consumption of heating, cooling and electricity	1. Number 2. Number 3. Number
PROGRAMMING LANGUAGE/ FRAMEWORK:	Visual Basic	

Climate Service

Type: Web Service, used in HESMOS	**Main Developer: external**
Synopsis: The enrichment of the eeBIM involves climate data that is requested from a web service of a weather station. This is a free third-party web service with European (global) climate information. Its functions are specified via WSDL (Web Service Description Language) and it is reachable via SOAP (Simple Access Object Protocol) over the Internet. The service is called to get up-to-date weather information like temperature or humidity, as well as climate data over a period of time (usually one year) for the purpose of various simulations.	
Features: • Providing actual weather data	**Users:** • Designers, Operators, Facility Managers (indirectly)

INPUT & OUTPUT	**Major Data Items**	**Type**
BUILDING DATA (BIM) INPUT:	N/A	
MATERIAL DATA INPUT:	N/A	
CLIMATE DATA INPUT:	1. Latitude/Longitude 2. North direction 3. Date/Duration	1. Number 2. Text 3. Text
BAS DATA INPUT:	N/A	
ENERGY DATA INPUT:	N/A	
DATA OUTPUT:	Climate Data	Object

3.8 Reporting Module

Reporting is an auxiliary, yet important module of the IVEL, which is responsible for the generation of appropriate reports from energy/cost computations. In HESMOS, the main focus is on the flexible online presentation of analysis/simulation results in dependence of the particular actor role via the nD Navigator. Reporting will be provided by a lightweight Web Application to complete the IVEL functionality. In practice, this application can be replaced by some more comprehensive tool, or directly integrated into the user applications mentioned in sections 3.2-3.6.

Reporting Service

Type: Web Application, new development in HESMOS		**Main developer: TUD**
Synopsis: The reporting service is responsible for the creation of reports with regard to country-specific guidelines. The output is a document, which may include checks of minimum or maximum values or other synthesized results from the energy computations.		
Features: • Reports with regard to guidelines (e.g. ENEV)		**Users:** • Designers • Facility managers • Operators • Owners
INPUT & OUTPUT	**Major Data Items**	**Type**
BUILDING DATA (BIM) INPUT:	BIM data model	File or data stream
MATERIAL DATA INPUT:	N/A	
CLIMATE DATA INPUT:	N/A	
BAS DATA INPUT:	N/A	
ENERGY DATA INPUT:	1. eeBIM data 2. Energy computation results	1. File, data stream or directly accessed eeBIM Objects 2. File or data stream
DATA OUTPUT:	Document	Text
PROGRAMMING LANGUAGE/ FRAMEWORK:	Web environment (XML/Java)	

4. IVEL Workflows

4.1 Overview

The overall business process supported by HESMOS is complex, stretching over years, multiple actor roles and various software components. Therefore, to design and implement the HESMOS platform properly a clear definition of technical workflows and appropriate service orchestration are also needed. This will ensure the correct coverage of all identified user scenarios in the envisaged 'TO-BE' process.

In principle, each technical workflow is started by one of the user applications sending a valid login request to the IAS of the IVEL core. This login request is validated by the User Registry. The following actions depend on the specific user scenario. They are briefly outlined in the next subsections. In the further sections of this chapter (4.2 – 4.6), the technical (sub) workflows on the IVEL are defined. These technical workflows will be applied in appropriate combinations for the handling of each specific use case and lifecycle situation.

4.1.1 Design Scenario

An architect will use her/his CAD system to model the building in the design phase or to update the model in the refurbishment phase. After s/he has logged in, the IAS can search previous uploaded building models and can inform the CAD system if there are model versions that can be used. The chosen working model can then be uploaded to IVEL. This is done with the help of the IVEL Connector, which will also take care to register the user and start the IVEL session. Now the user can choose specific elements or predefined model views in which s/he is interested by using the EQL of the IAS. S/he can send a request to the IVEL, which will be interpreted by the IAS and the SiCo will be invoked to prepare the energy simulation. SiCo may then call MoMa to filter the BIM data in order to validate the model, reduce redundancy and avoid verbosity. After optimizing the BIM data in such a way, the eeBIM will be composed by the MoCo and dispatched to the energy simulation service. The eeBIM will be analyzed and the appropriate energy solver(s) will be started. The performed simulation will enrich the eeBIM with the simulation results. The IAS waits until the simulation is finished and transfers the results to the SiCo, which will store them in a respective eeBIM version to allow for eventual comparison with other alternative solutions at a later time. The eeBIM file can also optionally be transferred to the nD Navigator, where it will be visualized with charts, tables or other appropriate views. Thus, the designer can get obtain a quick overview of possible weak points and can update the building model in parallel with her/his work with the CAD system to take care of energy-relevant issues as early as possible and avoid detected problems.

4.1.2 FM Scenario

The workflow in the FM scenario is similar to the above, but enhanced by some additional features. The facility manager uses her/his FM tool where s/he can upload a building model in IFC format to the IAS of the IVEL core, or can select a previous model connected with her/his profile. Besides performing comfort analysis of the building, s/he has the ability to define requirements for all or specific rooms (e.g. due to change of usage) and then proceed more or less along the same process steps as in the scenario above. An additional functionality is the live monitoring of one or more buildings. This is done via requests to the IAS, which will create the connection to the appropriate BAS web service of the building. Thus, it is possible to obtain sensor data from the building to start a real-time energy simulation with actual site information. The FM tool can call directly the BAS with exact data parameters and will get the data from the sensor(s) for a specified time interval. The FM tool will show the sensor data to the user and the user can define his queries to make a new energy simulation with the given (varied) sensor values. This will improve the energy simulation by more exact input and enables monitoring performances over the whole life cycle. As above, the energy results can be shown in the nD Navigator enabling comparison of the results with older ones, as well as history overview over the energy situation of the whole building.

4.1.3 Stand-Alone (Public Access) Scenario

In the case of public access to the IVEL, any registered user who is permitted to access the laboratory can use the nD Navigator to obtain quickly an overview of energy performance via selected key indicators, examine earlier simulation results or check certain alternatives. Dependent on his access rights he can start new simulations (e.g. in the case of an energy planner), or can navigate through the results using appropriate visualization aids (e.g. in the case of building owner, tenants etc.).

The visualization involves multiple views like the display of energy weak points and improvement suggestions. The data transfer to and from the IVEL Core is based on the workflows outlined above, but involves a smaller number of components and is in general less complex, faster and more restricted with regard to the available functionality.

4.2 Service Level Workflows

The starting point of every workflow is the initialization of the IVEL. This is done by the service registration and the overall user management.

4.2.1 Service Registration

The service registration in the Integrated Virtual Energy Laboratory follows the service-oriented approach. A service provider can publish a service at a service registry where a service requester can find it. The registry will give the address of the service to the requester and it can create a binding if it is suitable (Figure 4, right). In the IVEL, the core is the service registry, provider and the requester similarly. All other services will register themselves at the IVEL connector and can find all registered services (Figure 4, left, dashed arrows).

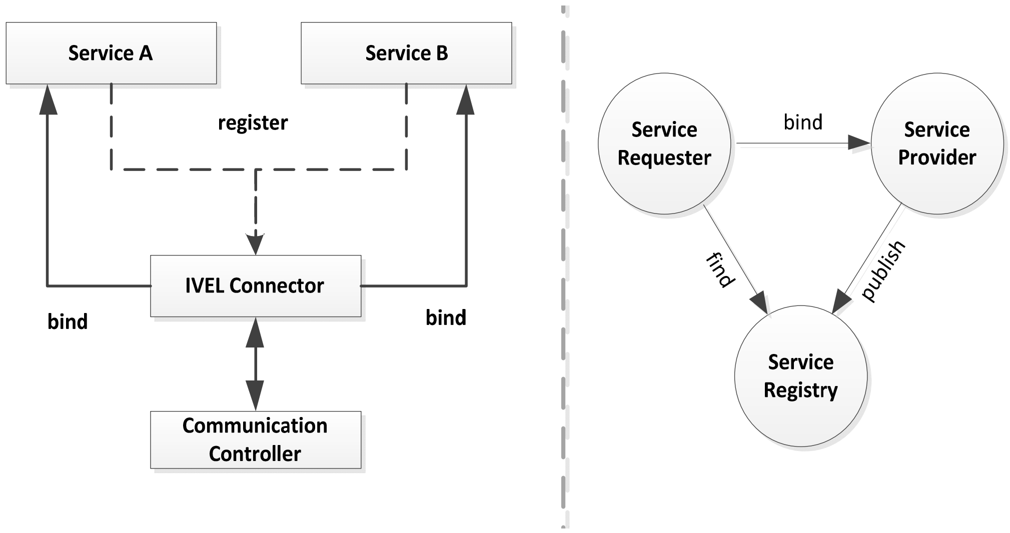

Figure 4: Service registration

The binding will be created by the IVEL Connector and controlled by the Communication Controller (continuous arrows). The CoCo checks the availability and secures the connections. After this check it transfers data from Service A to Service B and vice-versa.

4.2.2 User Management

An intelligent user management is important for the HESMOS business process. There are many users involved, which have very different aims. For example, the tender management is not interested in detailed energy aspects while it wants to know how much costs can be saved by optimizing the building. To cover such interests and permission of restricted information the IVEL core have to provide logins and passwords for each user which will be checked by the registration of persons. Figure 5 shows an overview of the approach in HESMOS. Users can be registered in the IVEL core with a login name and with a password. In the User Registry this information are stored together with access rights to applications and data. If a user will login, the IVEL core creates a temporary session identifier and creates a cookie in the web browser. Dependent on her/his access rights the user can now use all permitted applications without logging in every time. Multiple users will be regarded separately with their session identifiers. The user profile includes information like uploaded and released BIM files, eeBIM data or personal settings.

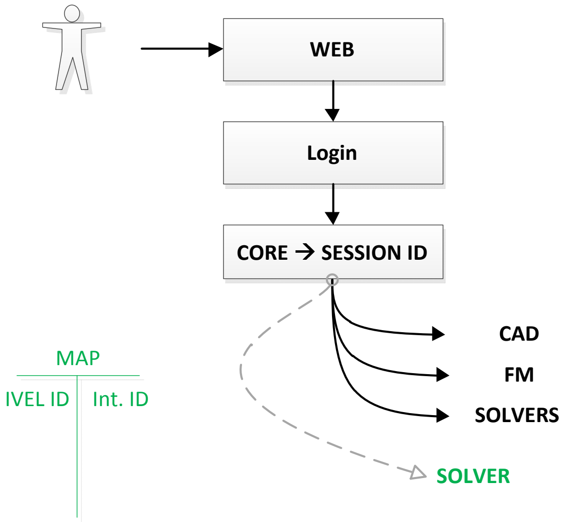

Figure 5: User Management

4.3 CAD to IVEL Core

The linkage of the CAD to the IVEL core allows the creation of new or modifying of existent BIM files and the calculation of investment costs. On the one side, the architect can start simulations in the design phase and on the other side, this allows the update during the retrofitting and refurbishment phase. Figure 6 shows the data exchange between Allplan and the IVEL Core. Arrow number 1 shows the upload of the modelled BIM file from the CAD to the IVEL Core. With this interaction, the architect signalises the release of a version, which is ready for a simulation. After the simulation, the updated BIM file can be sent back to the CAD if the architect has to check the whole building model for completeness and discrepancies (arrow number 2). Possible updates of the building model can be done slightly in the nD Navigator by energy consultants (energy experts) by changing parameters like material. The energy optimization can be done in a cyclic way until all participants agreed with a version. After finishing the optimisation, the CAD can calculate the investment costs and send it to the IVEL Core where all authorised users have access to it.

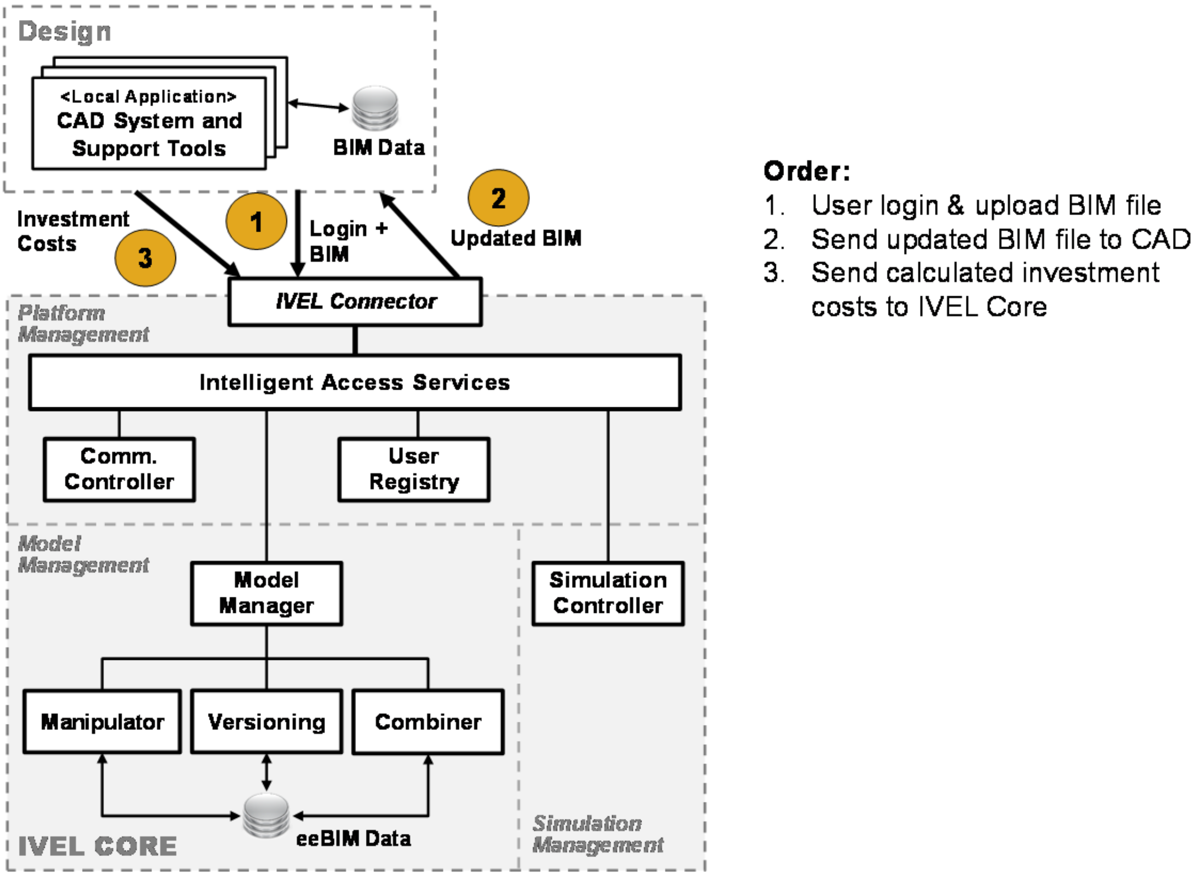

Figure 6: Workflow 'CAD-to-IVEL Core'

4.4 FM & BAS to IVEL Core

The data transfer between the FM tools and the IVEL Core starts similarly to the nD Navigator with sending login data of the user (Figure 7, number 1). In a second step, he can define EQL queries to get specific information of the observed building like requesting sensor data. Therefor the user can get an overview of all rooms or can specify rooms where s/he is interested in with the specification of a time interval.

The queries will be interpreted from the IAS and control the linking of heterogeneous data models e.g. IFC and sensor data from the BAS. The IVEL Core requests the sensor data from the BAS web service (number 3) and receives the actual data set (number 4). The result will be analysed in the IVEL Core and stored in the eeBIM repository, and finally sent to the requesting FM tool (number 5).

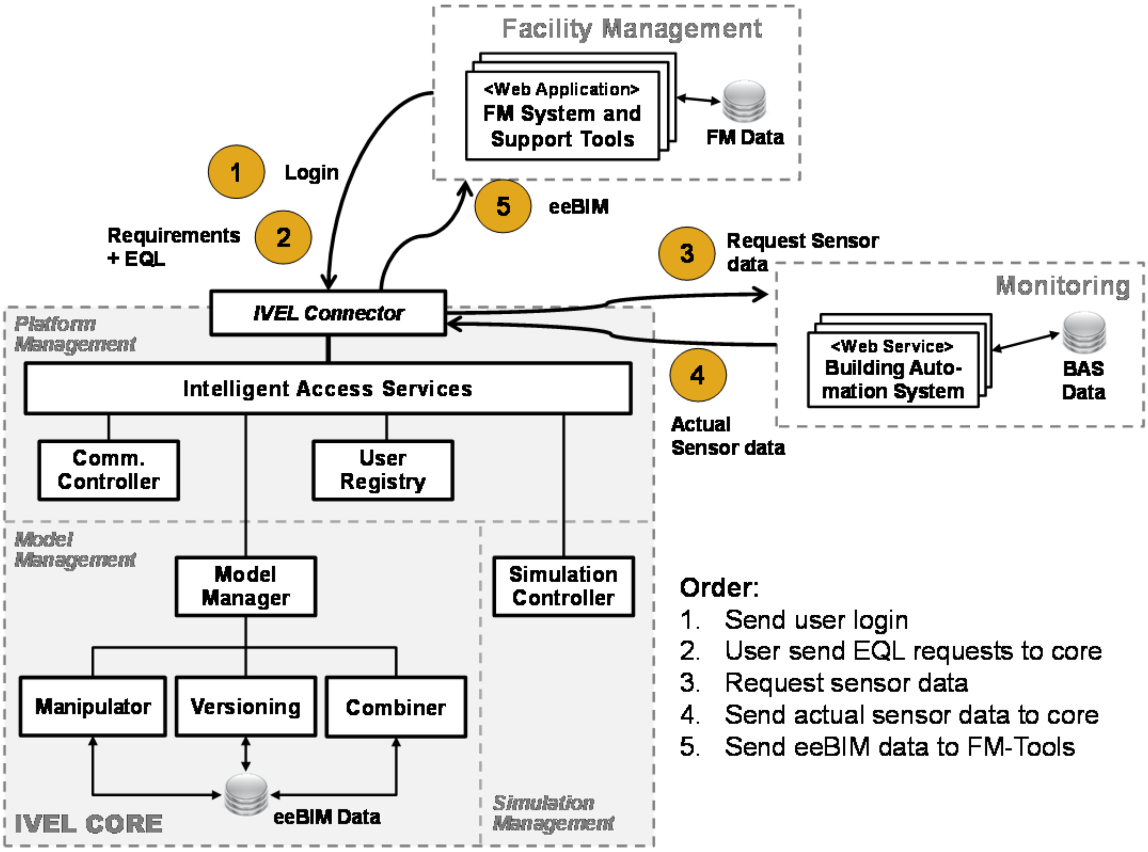

Figure 7: Data exchange, FM Tools to IVEL Core to BAS

Figure 8 presents the internal workflow of the Monitoring module in the IVEL. The request from the IVEL Core consists of a room (space) identifier in IFC and the requested physical quantities. A main function of the Monitoring web service is the linkage of sensor data and IFC data, which is done by an ontology. The ontology find all devices in the given space(s), find the functional profiles of the devices and then match this profiles to the requested physical quantities. The ontology returns relevant devices, their coordinates, and how to get the data from the BAS or database (ontology development in WP4). After that, the web service uses the results for starting the process of accessing the actual sensor data from the BAS.

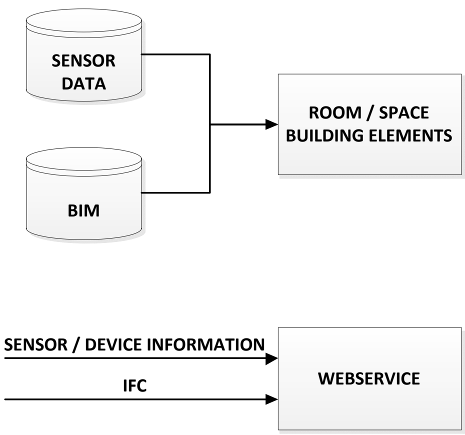

Figure 8: Sensor data linked with the BIM

4.5 nD Navigator to IVEL Core

The GUI of the IVEL Core is in general cases the nD Navigator, which prepares the presentation of the eeBIM data for the user. It starts with the user login, which will be verified in the User Registry (Figure 9, number 1). In a second step, the eeBIM data will be transferred and can be analysed from the user in the web browser. The nD Navigator shows this data in user interface components like tables, charts or other presentation approaches to support multiple dimension views. The user has the possibility to write queries in the EQL syntax, which will be sent to the IVEL Core (number 3). The EQL will be interpreted in the IAS of the core and model views created. These views are sent to the navigator where the user gets a detailed presentation of data he is interested in (number 4). After that a new workflow will start at number 3 of Figure 9.

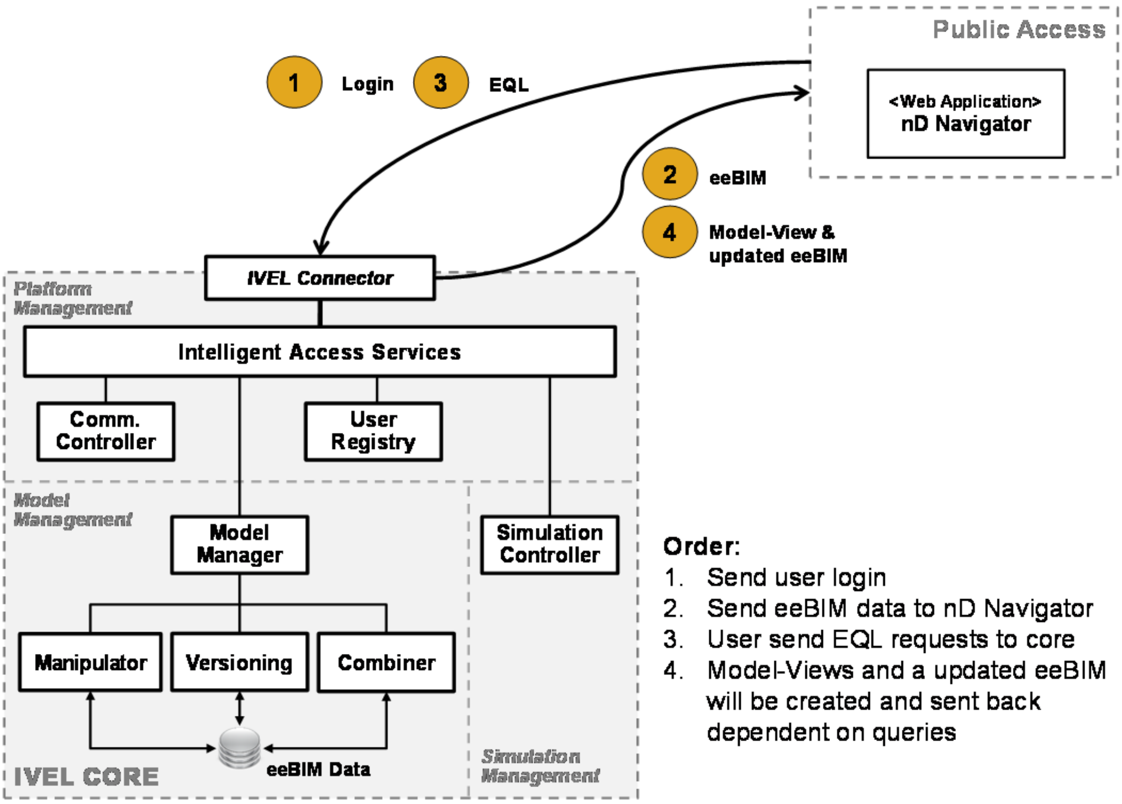

Figure 9: Data exchange, IVEL Core to nD Navigator

4.6 IVEL Core to Energy Simulation

The energy workflow is a comprehensive and computationally intensive process, which is divided in several sub processes. We will define three sub-processes, which are prerequisites for the actual energy simulation process, the BIM validation where we have to check if all required IFC instances are defined in the building model, the access to material and climate data dependent on the building model and the generation and dispatchment of the eeBIM for the Energy Solvers.

4.6.1 BIM Validation and Enhancement

The creation of the basic building model is done in the CAD and exported in IFC. While it contains most of the geometry and semantic which is needed generally it is possible that it will be not sufficient for a complete energy simulation. Two problems have to be solved so that the energy solvers can fulfil their work. Firstly, Allplan (as most current BIM-CAD systems) does not support the whole definition of room requirements in IFC, and secondly it is only possible to export 1st level and not 2nd level space boundaries. However, the latter are needed to calculate a detailed building energy performance (Bazjanac, 2008).

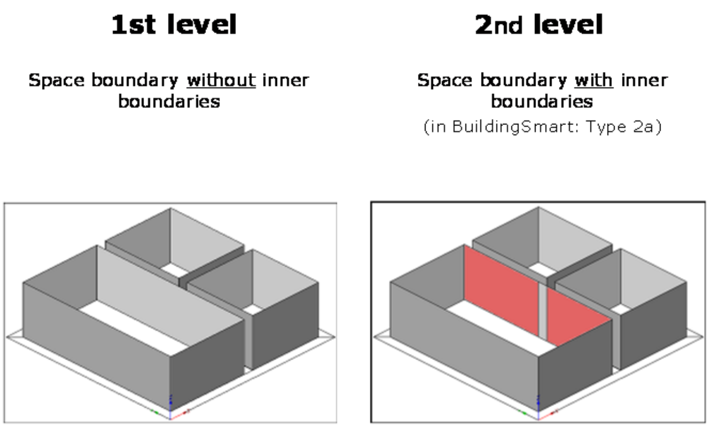

Figure 10: Space Boundary levels (1st and 2nd, buildingSMART)

The former problem is solved by Roomex (section 3.4) where the user can define room requirements and usage, which will enhance the BIM with more semantic details. The latter can be solved e.g. with the help of an engine developed by OG and called *BSpro*. It converts 1st level to 2nd level space boundaries (Figure 11, definition in Figure 10).

The conversion of 1st level to 2nd level space boundaries is done geometrically. In HESMOS, we will analyse whether it makes sense to export a new IFC file which includes the newly generated 2nd level space boundaries or if we only take the result and include it into the eeBIM. However, the generation of 2nd level space boundaries and linking of material and climate data are prerequisites for the proper definition of eeBIM and for most of the needed energy simulations.

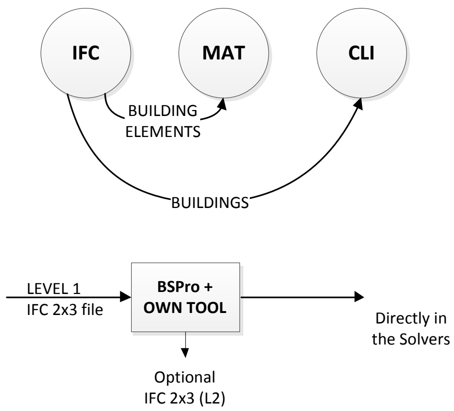

Figure 11: Generating the prerequisites of the eeBIM

4.6.2 Climate and Material Data Enhancement

The request of actual climate and material data of a location is done via web services and included in the eeBIM in in the IVEL Core with the Model Manager. The climate data is provided from a weather service and mostly structured as XML (Figure 12). It contains temperature, air humidity, air pressure and more for a date and approximated values for time periods like a year.

Material data is connected with building elements like walls and must be unique in the CAD and the energy solvers. Tools like DesignBuilder (DesignBuilder Software, 2011) have a monolithic approach where all data is stored together and therefor homogeneous.

While we favour the SOA approach we have multiple databases where we have to watch out for the mapping of data (see Figure 3). Allplan export material data for each building element in an IFC2x3 file with the relation *IfcRelAssociatesMaterial*. The energy solvers provide their own material data set which is used for the simulation. To overcome this problem we define a mapping table for all material identifiers. In the case of exchanging the CAD or the solvers we only have to adapt this table. While it doesn't make sense to include such component-dependent functionality in the IVEL Core, the location of this mapper is inside the Energy Computing module.

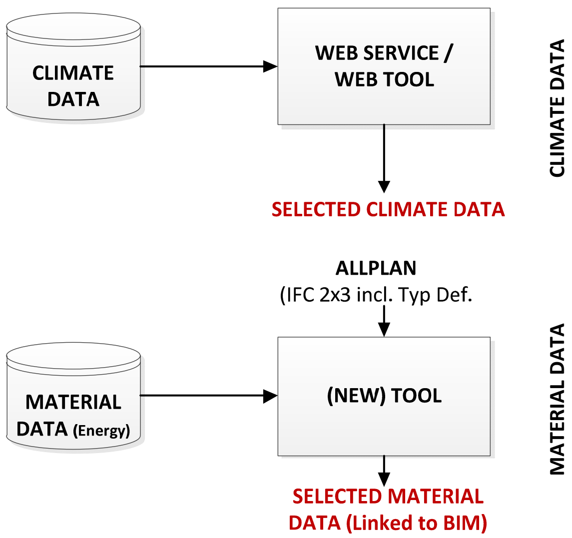

Figure 12: Request of Climate and Material Data

4.6.3 eeBIM to Energy Solvers

The generation of the eeBIM and the transfer to and enrichment with the energy solvers is a comprehensive workflow and divided into several tasks. The process starts in the Model Manager of the IVEL Core with the creation of a new eeBIM file. All needed information which is given by user input and data transfer are updated and held there. Further data model will be linked, manipulated and versioned.

The input for the energy solvers are the simulation configuration (like time period), the spaces with relating building elements and their space boundaries, the location (latitude, longitude), types of use, orientation and thermal, lighting and air quality requirements etc. of the building (Liebich, 2011). Figure 13 presents the transfer of the input out of the eeBIM to the energy solvers (number 1) and the enrichment with climate data through a weather web service by the Energy Computing module (number 2). The climate data is structured in XML and provided through the request for a location. The messages are transferred via SOAP. The climate data involves the expected values for a time period which is requested from the simulation configuration. The process of the overall energy simulation will be developed in WP5, which includes the interfaces to the climate and material databases.

The selection of the appropriate solver(s) is done in the SiCo by checking the user profile and the eeBIM data. For the simulation of multi-layer components of the building envelope such as walls COND (section 3.7) is chosen, while THERAKLES is an alternative for the calculation of thermal conditions inside rooms depending from outdoor climate. In this case, the SiCo requests the climate data of the weather web service. The moisture analysis inside opaque walls, roofs and floors is done with DELPHIN and in the case of simulating the whole building the SiCo choose RIUSKA.

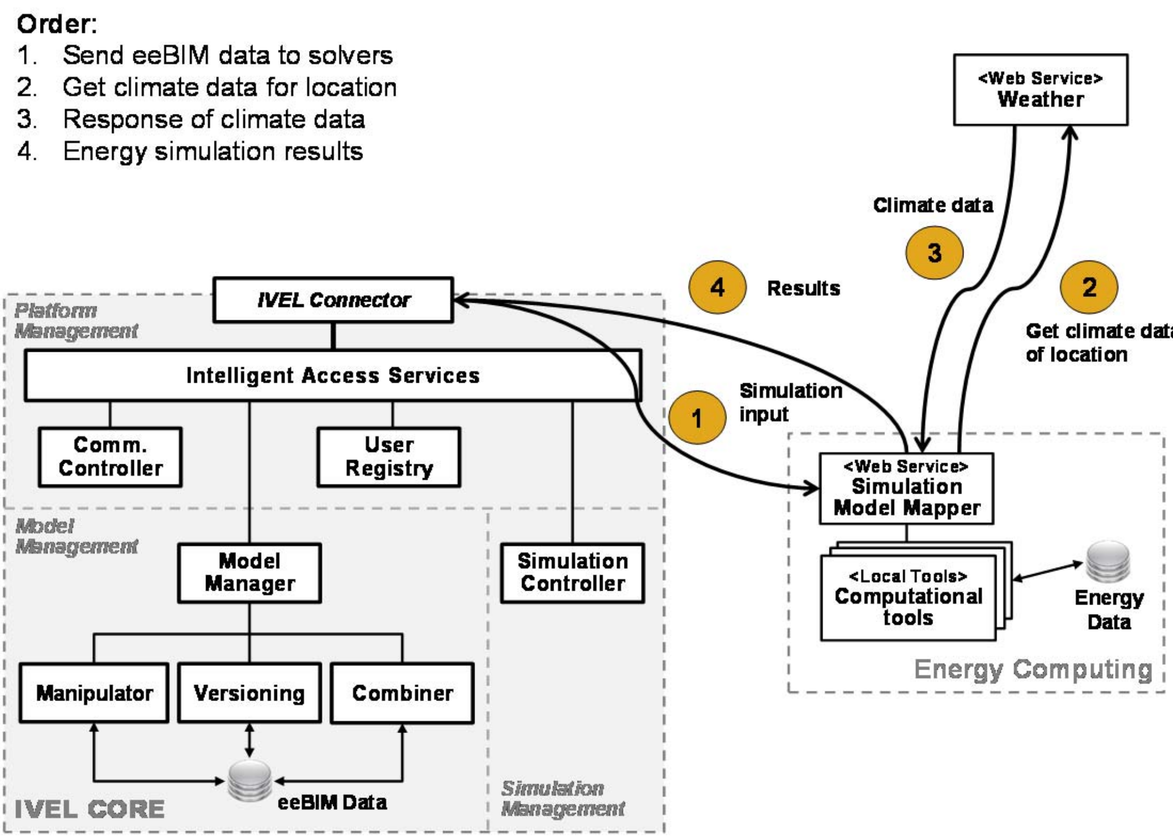

Figure 13: Data exchange, eeBIM-to-Solver and climate request

Literature Sources

Bazjanac, V. 2008. *IFC BIM-Based Methodology for Semi-Automated Building Energy Performance Simulation*, Lawrence Berkeley National Laboratory, Vols. LBNL-919E, University of California, CA, United States.

Bort B., Geißler M.C., Guruz R., van Woudenberg W., Baumgärtel K., Kaiser J., Hensel B., Zellner R., Laine T., Jonas F., Liebich T., Katranuschkov P. 2011. *HESMOS Deliverable D1.1: Use Case Scenarios, Gap analysis and Requirements Specification,* © HESMOS Consortium.

Christensen E., Curbera F., Meredith G., Weerawarana S., W3C, *Web Services Description Language (WSDL),* Specification, 2001

DesignBuilder 2011. DesignBuilder Software [Online Documentation] http://www.designbuilder.co.uk/content/view/29/44/, cited: July 12, 2011.

DOE 2002. *EnergyPlus Energy Simulation Software: Documentation*, © U.S. Dept. of Energy, http://apps1.eere.energy.gov/buildings/energyplus/documentation.cfm

Fuchs S., Katranuschkov P., Scherer R.J. 2010. *A Framework for Multi-Model Collaboration and Visualisation*, in Proc. 8th European Conference on Product and Process Modelling (ECPPM), Cork, Ireland.

Haupl P., Fechner H., Grunewald J., Stopp H. 1997. *The Thermohygric Performance of Insulated Building Structures Under Conditions of Use*, ASTM Publ.

Jokela M., Keinänen A., Lahtela H. 1997. *Integrated Building Simulation Tool – RIUSKA*, © Insinööritoimisto Olof Granlund Oy, Helsinki.

Kabitzsch K., Vasyutynskyy V. 1999. Tele-Diagnosis at Networked Automation Systems. *In: FeT'99 Fieldbus Technology Conference,* Springer.

Katranuschkov P., Liebich T., Guruz R. 2011. *Requirements and Gap Analysis for BIM Extensions to an energy-efficient BIM Framework*, in Proc. CIB W78 Conference, Nice, France.

Katranuschkov P., Scherer, R.J., Turk, Z. 2001. *Intelligent Services and Tools for Concurrent Engineering - An Approach Towards the next Generation of Collaboration Platforms,* ITCon, Special Issue "Information and Communication Technology Advances in the European Construction Industry", Vol. 6/2001.

Katranuschkov P., Wagner U., Weise M., Scherer R.J. 2006. *Supporting Model-based Cooperation in Distributed Web Spaces,* in Proc. ECPPM "eWork and eBusiness in Architecture, Engineering and Construction", Valencia, Spain, publ. by Taylor & Francis Group, London, UK.

Liebich, T., Stuhlmacher, K., Guruz R., Baumgärtel K., Geißler M.C., van Woudenberg W., Kaiser J., Hensel B., Zellner R., Laine T., Jonas F. 2011. *D2.1 BIM enhancement specification.* 2011.

Nicolai A., Zhang J.S., Grunewald J. 2007. *Coupling Strategies for Combined Simulation Using Multizone and Building Envelope Models*, in Proc. IBPSA, 2007, Beijing, China.

Niemz. P, Petzold H., Häupl P. 2003. *Untersuchungen zur Messung und Simulation der Feuchteänderung von dreischichtigen Massivholzplatten bei Klimawechsel*, Springer Verlag.

Packham I., McNulty N., Vanderstockt Y., Byrne M. 2008. *Intelligent Control of Energy – A reality for Building Management Systems*, in: Rafiq Y., de Wilde P., Borthwick M. (Eds.) ICE08 – Proc. 15th workshop of the European Group for Intelligent Computing in Engineering (EG-ICE), UK, 2008, Plymouth, UK.

Papazoglou M.P., Georgakopoulos. 2003. Service-Oriented Computing. *Communications of the ACM, Vol. 46,* 2003.

Scherer R.J., Suarez T. 2008. *Lecture Notes on Energy Efficiency in Building Construction*, EU Project ICT-2007.6.3 REEB, Deliverable D5.32, 2008.

Stack P., Manzoor F., Menzel K., Cahill B. 2009. A Service Oriented Architecture for Building Performance Monitoring, in Proc. *18th Int. Conf. on the Application of Computer Science and Mathematics in Architecture and Civil Engineering,* Weimar, Germany.

Therakles 2009. *Das thermische Raummodell 1.5.0* (Programmdokumentation in Deutsch & Englisch), TU Dresden, Germany.

Appendix I: Acronyms

Allplan BCM	Allplan Building Cost Management
BAS	Building Automation Systems
BIM	Building Information Model
BPMN	Business Process Model and Notation
CAD	Computer-Aided Design
DIN	Deutsches Institut für Normung (German Standardisation Institute)
DOE	Department of Energy of the U.S.A.
eeBIM	Energy-enhanced Building Information Model
EN	European Committee for Standardization
EQL	Engineering Query Language
ER	Exchange Requirements
FM	Facility Management
GUI	Graphical User Interface
HVAC	Heating, Ventilation and Air-Conditioning
ICT	Information Communication Technology
IFC	Industry Foundation Classes
IVEL	Integrated Virtual Energy Laboratory
LCC	Life Cycle Costs
MSD	Model-Subset-Definition
MVD	Model View Definition
PPP	Public Private Partnerships
SOA	Service Oriented Architecture
SOAP	Simple Object Access Protocol
SPF	STEP Physical File (ISO 10303-21)
STEP	Standard for the Exchange of Product model data (ISO 10303 series)
UML	Unified Modeling Language
WP	Work Package
WSDL	Web Service Definition Language
XML	Extensible Markup Language