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INTELLIGENT SERVICES FOR ENERGY-EFFICIENT DESIGN AND LIFE CYCLE SIMULATION

Deliverable 2.2:
Architecture and components of the Virtual Lab Platform

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Project of SEVENTH FRAMEWORK PROGRAMME OF THE EUROPEAN COMMUNITY		
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PU	Public	
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CO	Confidential, only for members of the consortium (including the Commission Services)	**X**

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Executive Summary

The **objective** of the Deliverable 2.2 "Architecture and components of the Virtual Lab Platform" is to provide a concept for the cloud-based software architecture of ISES. This includes the components specification of all connected tools, services and databases that will be developed in WPs 3-7. The prerequisites of multiple parallel simulations will be defined and a loosely coupling of services aspired.

In **this report**, we describe the overall development approach, the developed principal software architecture and the service orchestration which provides a first proof of the concept and the expected benefits.

The overall ISES platform, i.e. the ISES Virtual Energy Lab (VEL) is being developed using the service-oriented architecture (SOA) approach. It will include: (1) services for energy and CO_2 emission simulation that would typically precede decisions for design or retrofitting tasks initiated in result of detected under-performances in the facilities' management, (2) services for operative energy-related analyses regarding facilities control, as well as (3) local background applications. The kernel of the platform will be provided by advanced BIM-based design tools extended to support preliminary and final architectural design but also capable of interacting with sophisticated energy analysis and simulation services. The virtual laboratory in ISES is an extension of the platform used in the EU project HESMOS (http://www.hesmos.eu/, 2012). Especially the cloud environment and the dynamic stochastic approach towards life-cycle energy simulation is an extensive extension of the VEL and leads to changes in many service interfaces.

This Deliverable D2.2 covers the overall work performed within the **tasks** T2.1 "Draft architecture and ICT components specification" and T2.3 "Final specification of the platform architecture and principal service orchestration" of WP2.

It is structured into **five parts**.

In **part one**, the concept of the cloud-based virtual laboratory is presented. It is based on the requirements documented in the ISES Deliverable D1.1.

In **part two**, the components inside the software architecture are defined. They comprise completely new developments as well as extensions of previous developments adapted to fulfil the ISES requirements. Technically, they are categorized into three distinct types, i.e. (1) web applications, (2) web services and (3) batch files which are encapsulated in services.

In **part three**, the cloud-based software architecture is outlined and the cloud services as well as their interrelated functional layers are described.

In **part four,** the principal workflows between the services on the VEL are presented. In addition, the order of service calls and events which leads to actual functional execution is proposed.

Finally, **part five** provides a short summary and an outlook for the development of the virtual laboratory.

All partners were involved and each partner has contributed from their expert viewpoint as follows:

- **TUD:** Lead, contributions to all tasks, with focus especially on the parts 1, 3 and 4 and the editing of the report.
- **OG, UL, SOF, NOA and NMI** – contributions to parts 2 and 4.

1. Overall Concept of the Cloud-based Platform

To optimize the energy efficiency of products for built facilities and facility components before their actual use in practice examination of as much as possible real-life scenarios should be performed. Thereby the semantic context of product developers, architects, civil and building services engineers, and facilities managers has to be taken into account. Only with such an overarching approach, the value chain can harvest the full potential offered by today's loosely connected numerical analysis solvers, modellers and graphical results presentation tools. Moreover, the random (stochastic) variation of energy profiles and consumption patterns over the years of the life cycle can be considered as well.

1.1 Objectives, Principal Concepts and Challenges

The **major objective** of WP2 is to make a concept for the integrated use of existing advanced ICT tools like CAD systems, facility management systems (FM), energy simulation, moisture calculation, fluid dynamic analysis and cost calculation tools, on the one side, and Building Information Modellers (BIM), on the other side, facilitated by the use of cloud middleware services. Such ICT tools are all strong in doing their core business tasks but are mostly stand-alone, loosely integrated applications. They have to be complemented with a set of new supporting services and tools, enabling simulation and evaluation of energy behaviour, including (a) an energy profile and use case combiner, (b) a multi-model manager enabling intelligent model filtering, and (c) a multi-model navigator.

The combination of these tools leads to a platform which represents a virtual laboratory for all addressed end users of ISES. Hence, an information logistic and intelligent access controller for the ICT system management (services, tools and data) has to be provided which is the interface to cloud facilities for enabling parallel computation of alternatives and/or parameter variations.

Existing data resources by three currently missing databases, namely stochastically based *climate/weather* data scenarios and *usage/user activity* profiles, both structured and formalised accor-ding to the stochastic life-cycle demands, as well as a database variant manager for alternatives and variations of new product designs will be extended for the ISES Virtual Energy Laboratory (VEL).

Almost all of the ICT building blocks and the system interoperability and management methods are planned to be generic. Hence, they can also be used in other domains or at the least serve as templates and best-practice cases.

The main **targeted use cases** of energy and emission reduction are the *early design phase* of the planning of new buildings and facilities and the *retrofitting phase* for the existing building stock. Another important use case is the *design of new products*, concurrently considering their own energy behaviour and their interaction with the embedding facility, simulated by a set of virtual building environments, such as the use of a façade element for different building typologies, different climatic conditions and different user behaviours.

A further challenging issue is the consideration of stochastics. The virtual energy lab has to be complemented by an adequate (semi-)stochastic component to represent the stochastic nature for the product and the facility life cycle, thereby replacing and improving today's deterministic consideration of life cycle analyses using characteristic one-year profiles. The semi-stochastic approach could be capturing the real variability of the life cycle, and hence improve energy-efficient design of products and facilities. Today, stochastic life cycle considerations in AEC are only common in civil engineering domains, like offshore platforms, nuclear power plants, large span bridges, hydroelectric power plants and dams or other outstanding structures featuring high- risk consequences, where the main life cycle aspect is structural safety.

We define **three major user roles and respective usage scenarios** for the VEL, namely: (1) for product developers, (2) for architects, civil and building services engineers, and (3) for facilities managers. Additionally, in all scenarios a number of energy solvers re-engineered to run as web services, as well as access services to different information resources (building model data, climate databases, material databases, product catalogues etc.) are defined in a cloud environment. The software architecture is developed on the basis of these findings, adapting a general distributed service and model-based approach to the specific requirements of the target domain.

A central issue for the realization of the VEL is the achievement of **information interoperability**, which is being done by enhancing the energy extended BIM (eeBIM) concept developed in the EU project HESMOS (Katranuschkov et al., 2011). Thus, the overall approach is to extend the VEL as an open cloud platform based on eeBIM, extended by the development of missing functionalities and services for intelligent high performance access to advanced energy analysis and simulation tools.

This comprises three new, partially conflicting **tasks**, namely

(1) the consideration of the stochastic nature of the energy performance and consumption profiles of the new product life cycle,

(2) the balanced design of the new products (components), their functionality and behaviour for the various possible life cycle demands,

(3) the balanced interaction of the product component with the facility, i.e. the context system in which the new product is applied (or built in).

In particular, for the design of a new product (HVAC component, façade element etc.) several characteristic facilities have to be analysed, which results in the design of several new *variant* products. However, for the use of the new product, the best-fitting variants of the product have to be selected and an optimal integration in the facility has to be realised. Each of the above three tasks requires several simulations with **feedback cycles** in order to reach an optimally balanced solution (see Figure 1). The first task requires a *simulation feedback cycle* in order to obtain the worst-case scenarios, which are the baseline of the subsequent two design tasks. The latter two need *design feedback cycles* for optimising the new product to be offered (heater, boiler, façade element, glazing element etc.) - task 2, and in an independent later stage, for the configuration of the new product in the design of a specific facility by an engineer or architect - task 3.

The design feedback cycles occur at different phases of design and production, whereby the first feedback cycle, i.e. the simulation feedback, is needed as sub-cycle in the two other feedback cycles. This implies that the number of resulting feedback cycles is multiplicative and requires not only a lot of computational power, which can be provided through the access to cloud computing facilities, but also a lot of model definition, adaptation and configuration work. If this work is done by hand, as it is the case at present, it would result in days or weeks of engineering work and therefore is not feasible. The essence of our approach is in the highly automated configuration, management and evaluation of the dozens of models needed for the various needed simulations by means of a set of innovative services and tools including navigation and inspection tools for architects, facility managers and engineers, allowing them to concentrate only on high-level decision making tasks.

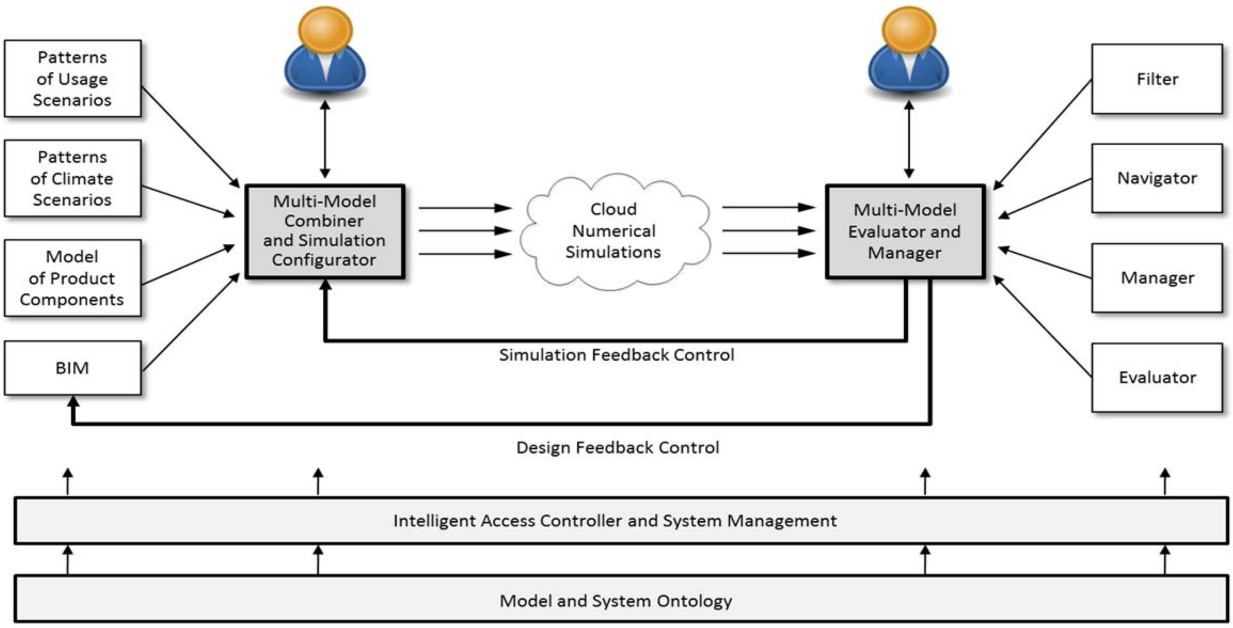

Figure 1: Logical structuring and functionality of the ISES Virtual Energy Lab (VEL)

The Virtual Energy Lab is principally structured into **four main tiers** as well as two supporting tiers.

The *first tier* (Figure 1, from left to right) is the domain modelling and input tier to the VEL. It comprises tools for (1) the modelling of the new product, (2) the modelling of the built facility, (3) the modelling of the energy profiles, and (4) the application of patterns of energy consumption, i.e. the climate and usage scenarios. These four domains are to be combined to one model and configured appropriately to the various approximated stochastic simulation input models. The procedure has to be automated with the support of the tools of the second tier to provide the necessary efficiency.

This process has to be repeated continuously for each design cycle. Because these are nested cycles, several dozens of simulations may be necessary to obtain an energy- and emission-efficient design solution. This cannot be carried out on reasonable scale on a single workstation, because one simulation run of a new product integrated in a virtual or actual building facility and considering (as the current practice) a characteristic time window of about one month with a time step of one hour results in several processing hours (a typical nightly run). Therefore in the *third tier*, access tools for cloud computing are allocated to provide the needed computing power.

Furthermore, the configuration of the various simulation models by an engineer would result in tens or more hours of labour, which is also not acceptable. Therefore, in the *second tier* the *multi-model combiner* that combines the different domain models to one investigation model is complemented with a *simulation configurator*, which has the task to configure the simulation models automatically according to a few general input directives by the engineer provided via an easy-to-use GUI. The objective is to configure concurrently as many as possible simulation models in order to reduce sequential simulation and hence overall simulation time to a usable scale for AEC/FM practice.

To support such highly automated concurrent analyses efficiently, the evaluation of simulations and the feedback directives have to be carried out highly automatically, at least for the simulation feedback. Therefore the *fourth tier* is dedicated to services and tools concerning the evaluation of multi-models, including the *prioritisation of the results* and four supporting services, namely *multi-model filter*, *navigator*, *evaluator* and *manager*, providing flexible user access with proactive support for requesting and selecting simulations to be compared. This fourth tier is the decision support and output tier. It features also the second GUI of the VEL platform. It allows focusing the end user's attention on decision-making, i.e. only on a few important simulations and aggregated results. Adequate comparison services (filter, navigator) should allow him to navigate easily and efficiently in the multi-model result space and hence support his efficient and informed decision-making.

These four main tiers are complemented with two platform support tiers. The first comprises the services for the automated access to databases, product catalogues, building information models and the required middleware services, including the access service to the cloud computing facilities.

The second is responsible for the storage, access and management of the *VEL system model* represented in a description-logic based ontology. This ontology describes the lab system and its components but it describes also on a high semantic level the various model schemas, their combination possibilities, the automation algorithms and the evaluation and feedback control information.

The outlined principal approach poses various **technological challenges** that need to be resolved, especially with regard to information interoperability coupled with the identified stochastics, performance and parallel computing requirements. Using the overall design strategy of developing a distributed, cloud-based platform grounded on an integrative ontology and a set of open data model schemas, the principal software architecture and a first rapid prototype implementation of the envisaged VEL platform have been realised.

1.2 State of the Art

There exist many state-of-the-art software tools for component and building design, for cost analysis, for energy analysis, for facility management and for life cycle analysis. These tools have proven their efficiency and reliability in their particular domains, namely (1) CAD-STEP in product design, (2) CAD in building design, (3) Multizonal Building Energy Solvers (MBES) in energy consumption analysis and simulation, (4) Building Envelope Solvers (BES) in the analysis and simulation of heat and moisture transportation, (5) civil engineering analysis (structural, wind, earthquake, flood, fire) using the finite elements method, (6) facility management systems (FM) for the management of buildings concerning operation and maintenance, and (7) cost calculation and estimation in the different design construction and operation phases. A basic problem is that a common model and comprehensive model interoperability methods are still missing. Hence, an integrative holistic approach is not easy to achieve, making data gathering for any energy study a tedious and to a large extent manual effort.

A critical issue for running energy simulations is the data that is available about the component product and/or the facility to be built or renewed. BIM has become a key technology for collecting data about products within the AEC and FM industries (Eastman et al, 2008). It consolidates and manages available product data from different sources to provide high quality and up-to-date information about the buildings. It thus acts as a single point of information that shall be used by energy simulation services to avoid time consuming and costly re-entering of differently structured component product and building data.

Whilst BIM stands for a powerful collaboration concept, it needs to be implemented in software and data models. In this regard the international IFC Standard (IOS/PAS 16739, 2005) developed by the non-profit buildingSMART initiative is taking a leading role and is meanwhile supported by all major software vendors in the AEC and FM market.

However, the IFC is not qualified for storing all data of all involved actors in the building life cycle because (1) it does not provide all entity types of all involved domains, and (2) it is not adequate to use IFC property set extensions for the full (and large) amount of all unspecified information. Other data models such as the Open Green Building XML Schema (gbXML, 2010), or proprietary formats from software vendors may become interesting as well and thus cannot be excluded from the required data access specifications. A solution to this problem has been established by the IDM approach (cf. Wix and Karlshoj, 2010) that first concentrates on specifying business needs, which are independent from any particular data model. On that level an IDM (Information Delivery Manual) defines processes and exchange requirements that formally clarify the interaction with other participants such as architects, building services engineers or facility managers. The second, ICT-related step is to provide mappings to data models such as the IFC 2x4 release including appropriate implementation agreements (Hietanen, 2006). Both steps are necessary to improve the interoperability of BIM-based AEC/FM tools.

Some research has been done in the field of BIM data management systems using ontologies (Lima et al., 2005; Succar, 2009). The University of Delft, Netherlands, developed the complete IFC schema in an OWL ontology representation (Beetz et al., 2009). Other work was done concerning ontology-based virtual organization modelling in the construction industry for collaboration and management of numerical engineering computation such as structural analysis, geotechnical analysis and airplane dynamic analysis (Gehre and Scherer, 2008). However, ontology extensions are still only rarely adopted in commercial software tools.

To calculate and predict energy consumption appropriate simulation models are additionally needed. To serve all users adequately, such models should be reusable and interoperable in a distributed heterogeneous environment. The simulations themselves must be flexible and hence should be provided as services (SaaS). The integration of such services in a service oriented architecture (SOA) warranting the efficient collaboration of the involved users and their applications is seen as one of the most promising approaches today (Baumgärtel et al., 2011).

In (Stack et al., 2009) a standard set of interfaces based on SOA and defining extensible and reusable segments offered to all other components in an integrated system is described. The developed and used components provide services for energy simulation, maintenance, monitoring, sensors and actuators and the building product model. The core of the system is a data warehouse, which uses extracted data from different sources on three layers: (1) a network layer that senses and communicates performance data, (2) a data layer that stores the data, and (3) a tool layer that involves end-user tools and graphical user interfaces. However, even though many energy and facility management functions are covered, the whole life cycle and the interaction with architects and other designers in retrofitting cases are not addressed.

In (Nicolai et al., 2007) a coherent strategy for combined use of multiple simulation models and solvers is suggested, but the approach is limited to energy analyses/simulations and does not consider other related life cycle aspects, nor the aspects of parallel computation of alternatives.

Hence, whilst much research work has been done in recent years a consistent data management for an integrated virtual laboratory platform for life cycle building energy management is not available as yet.

2. Functional Components Specification

In this section, we describe the software components that will be integrated in the ISES cloud-based virtual energy laboratory. These components are local (interactive or batch) application that will be upgraded to (web) service components, libraries that 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 and the exchange requirements for the support of interoperability. 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.

The following definitions are used:

- *(Energy) Input data*: material, climate, energy, user behavior / comfort and building data related input
- *Output data*: differentiated where necessary to material, climate, energy and building data related output
- *Programming language/framework*: the used (one or more) software technologies
- *Adaptation to Cloud/Grid*: the extension to run the software in a grid or cloud environment if such extension is necessary for the described component.

2.1 Virtual Energy Lab Core Module

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

- *Platform management*, handling user/service registry and the overall platform connectivity (section 2.1.1);
- *Model management*, handling all multi-model related issues, such as model filtering, model linking and model transformations (section 2.1.2);
- *Simulation management*, responsible for the setting up, invocation and control of the simulation runs (section 2.1.3).

2.1.1 Platform Management

The VEL platform management is provided by a true web service (IAS), which incorporates subservices for the intelligent access to the various distributed information resources that have to be dealt with, a user registry and a communication controller. It binds all external distributed services and tools and can be accessed via the World Wide Web in homogeneous manner. Thus, it is a service requester and a service provider at the same time. Its development is based on work done in the HESMOS project, which will be extended to support the automated design and simulation cycles and high performance energy analyses and data storage in Grid/Cloud.

Intelligent Access Service (IAS)

<table>
<tr><th colspan="2">Type: Web Service, extended in ISES</th><th>Main developer: TUD-CIB</th></tr>
<tr><td colspan="3">Synopsis:
The IAS is the main entry point of the virtual laboratory. It interprets semantically requests from services and converts such requests into execution routines depending on the context. It provides also a User Registry which 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. As backend, a Communication Controller will be realised. It is dedicated to the management of the communication between (web) applications and web services. It will test the status of a requested web service and, if reachable, route the requests to it. If a web service cannot be accessed, it will provide a list of web services that fulfil the query requirements. Thus, it can help to choose another service that may also be applicable.</td></tr>
<tr><td colspan="2">Features:
• Interpreting requests from user and service clients
• Managing and dispatching of service requests
• User registry and access rights control
• Communication control</td><td>Users:
• All platform users (implicitly)</td></tr>
<tr><td>INPUT & OUTPUT</td><td>Major Data Items</td><td>Type</td></tr>
<tr><td>BUILDING DATA (BIM) INPUT:</td><td>Changes and selection of building elements</td><td>REST request</td></tr>
<tr><td>MATERIAL DATA INPUT:</td><td>Changes of material parameter</td><td>REST request</td></tr>
<tr><td>CLIMATE DATA INPUT:</td><td>Changes of climate parameter</td><td>REST request</td></tr>
<tr><td>ENERGY DATA INPUT:</td><td>Changes of energy parameter</td><td>REST request</td></tr>
<tr><td>USER BEHAVIOUR INPUT:</td><td>Changes of parameters describing the user occupancy profile, its stochastic distribution or set point comfort values (targets)</td><td>REST request</td></tr>
<tr><td>DATA OUTPUT:</td><td>Depending on the input</td><td>JSON, XML, HTML</td></tr>
<tr><td>PROGRAMMING LANGUAGE/ FRAMEWORK:</td><td colspan="2">Web service (XML/Java), REST based</td></tr>
<tr><td>ADAPTATION TO CLOUD/GRID:</td><td colspan="2">Not necessary</td></tr>
</table>

2.1.2 Model Management

Model Management consists of three inter-related yet independent parts: model manipulator, model combiner and model versioning. It connects relevant models with each other and guarantees a consistent state of all models.

Model Manipulator

<table>
<tr><th colspan="2">Type: Web Service, extended in ISES</th><th>Main developer: TUD-CIB</th></tr>
<tr><td colspan="3">Synopsis:
The model manipulator is responsible for the appropriate filtering of models such as BIM-IFC models and conversion / transformation of elementary models to eeBIM. It checks if the IFC model fulfils the minimal requirements of an energy simulation and enhances it as far as necessary and possible. 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 this service is the appropriate filtering of the building model to provide the needed focus and improve simulation performance. Consequently, it is possible to simulate easily energy requirements or performances for one building storey or only some specific rooms of the investigated facility.</td></tr>
<tr><td colspan="2">Features:
• Model filter
• Model conversion
• Model enhancement</td><td>Users:
• All users (indirectly)</td></tr>
<tr><th>INPUT & OUTPUT</th><th>Major Data Items</th><th>Type</th></tr>
<tr><td>BUILDING DATA (BIM) INPUT:</td><td>1. IFC2x3 BIM Data incl. space boundaries 2nd level
2. IFC2x3 BIM Data excl. space boundaries 2nd level</td><td>1. BIM file or data stream
2. BIM file or data stream</td></tr>
<tr><td>MATERIAL DATA INPUT:</td><td>Material defined in IFC2x3 BIM data, linked to material DB or file</td><td>BIM File or data stream</td></tr>
<tr><td>CLIMATE DATA INPUT:</td><td>1. Climate data defined in IFC2x3 as BIM data through Property Sets, linked to climate DB or file
2. Climate data from climate service</td><td>1. BIM File or data stream
2. XML File or data stream</td></tr>
<tr><td>ENERGY DATA INPUT:</td><td>N/A</td><td>N/A</td></tr>
<tr><td>USER BEHAVIOUR INPUT:</td><td>User profile data defined in IFC property set extension or in an external library</td><td>BIM file or data stream</td></tr>
<tr><td>DATA OUTPUT:</td><td>Depending on the input</td><td>eeBIM file, BIM file or text</td></tr>
<tr><td>PROGRAMMING LANGUAGE/ FRAMEWORK:</td><td colspan="2">Web service (XML/Java)</td></tr>
<tr><td>ADAPTATION TO CLOUD/GRID:</td><td colspan="2">Not necessary</td></tr>
</table>

Model Combiner

Type: Web Service, extended in ISES		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 data for a set of rooms, corresponding to some pre-defined criteria such as temperature or humidity threshold). It has a very important task in the cloud-based environment. Its purpose is to bring together the involved multiple data models and link them on instance level as necessary. To achieve such combinations we shall use the system ontology developed in WP3, which will capture and resolve references to the linked models.		
Features: • Model linkage • Multi-model management • Multi-model filtering • Retrieval of data from external information resources and their binding in the eeBIM		**Users:** • All Users (implicitly)
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
ENERGY DATA INPUT:	Related energy definitions for energy computations	Link file or data stream
USER BEHAVIOUR INPUT:	Related user profiles for the 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)	
ADAPTATION TO CLOUD/GRID:	Not necessary	

Model Versioning

Type: Web Service, extended in ISES		Main developer: TUD-CIB
Synopsis: The Model Versioning component is responsible for storing all data connected to each user in a database to guarantee the comparison of simulation result variants and/or to compare eeBIM versions. In particular, it stores metadata of the models in a control repository, whereas the model files themselves are saved in the Cloud. Therefore this component itself must not be adapted to the cloud.		
Features: • Model repository • Model version management		**Users:** • VEL 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
ENERGY DATA INPUT:	1. Energy data defined in IFC2x3 BIM Data 2. Energy data defined in eeBIM Data	1. BIM File 2. eeBIM File
USER BEHAVIOUR INPUT:	1. User profile data defined in IFC property set extension 2. User profile data defined in an external library integrated in eeBIM	1. BIM File 3. eeBIM File
DATA OUTPUT:	Depending on the input	Versioned eeBIM File or BIM File
PROGRAMMING LANGUAGE/ FRAMEWORK:	Web service (XML/Java)	
ADAPTATION TO CLOUD/GRID:	Not necessary, because only metadata will be extracted and the real models are stored in the cloud by standard cloud middleware services	

2.1.3 Simulation Management

Simulation Controller

Type: Web Service, extended in ISES		**Main developer: TUD-CIB**
Synopsis: The Simulation Controller is responsible for the management of simulation workflows. It analyses incoming user queries to create the right data format for the energy solver services. It may also request the manipulation of the building model to prepare for the energy simulation. Thus, the simulation controller defines and configures the overall simulation process. It includes the pre- and post-processing and checking of data inputs 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 the building from the eeBIM	BIM file or data stream
MATERIAL DATA INPUT:	Material data of walls, windows etc. from eeBIM or via a link to external database	File or data stream
CLIMATE DATA INPUT:	Actual climate data and climate requirements from eeBIM or via a link to external file/database	File or data stream
ENERGY DATA INPUT:	Energy requirements from eeBIM	File or data stream
USER BEHAVIOUR INPUT:	User behaviour profiles from eeBIM or via a link to external file/database	File or data stream
DATA OUTPUT:	Energy results from the executed energy tool(s) in the Cloud Services Module	File or data stream
PROGRAMMING LANGUAGE/ FRAMEWORK:	Web service (XML/Java)	
ADAPTATION TO CLOUD/GRID:	Partially - it will generate multiple simulation variants, which will be delivered to the cloud	

2.2 Design Module

The design module contains the BIM-CAD modelling environment*) and an extension with a product catalogue for prefabricated components in ISES.

Product Catalogue Module

<table>
<tr><th colspan="2">Type: New development in ISES</th><th>Main developer: TRI</th></tr>
<tr><td colspan="3">Synopsis:
The product catalogue provides definitions of prefabricated components in IFC2x3. A designer can select and adapt the components in the CAD system and export the data to the VEL in an IFC file.</td></tr>
<tr><td colspan="2">Features:
• Definitions of prefabricated components (e.g. Walls)
• Retrieval of library components via keyword and/or geometry-related queries</td><td>Users:
• Product designers
• Architects</td></tr>
<tr><td>INPUT & OUTPUT</td><td>Major Data Items</td><td>Type</td></tr>
<tr><td>BUILDING DATA (BIM) INPUT:</td><td>N/A</td><td>N/A</td></tr>
<tr><td>MATERIAL DATA INPUT:</td><td>On the level of material name assignment as component attribute</td><td>Data field</td></tr>
<tr><td>CLIMATE DATA INPUT:</td><td>N/A</td><td>N/A</td></tr>
<tr><td>ENERGY DATA INPUT:</td><td>Physical values as component attributes</td><td>Data fields</td></tr>
<tr><td>USER BEHAVIOUR INPUT:</td><td>N/A</td><td>N/A</td></tr>
<tr><td>BUILDING DATA (BIM) OUTPUT:</td><td>Prefabricated components described via IFC2x3 such as (curtain) walls, slabs, roof elements, HVAC equipment etc.</td><td>BIM file
Objects</td></tr>
<tr><td>MATERIAL DATA OUTPUT:</td><td>Description in IFC</td><td>BIM file</td></tr>
<tr><td>OTHER DATA OUTPUT:</td><td>N/A</td><td>N/A</td></tr>
<tr><td>PROGRAMMING LANGUAGE/ FRAMEWORK:</td><td colspan="2">CAD internal database / language</td></tr>
<tr><td>ADAPTATION TO CLOUD/GRID:</td><td colspan="2">Not necessary</td></tr>
</table>

*) Off-the-shelve BIM-CAD system like Revit or ArchiCAD, not further detailed here. Communication / integration with the VEL is realised via IFC data exchange files using the SPF format or ifcXML.

2.3 Requirement Management Module

For the needs of requirement management, both specialised tools, dedicated to specific tasks, and complex FM systems can be applied. In ISES, software tools for FM tasks related to energy-efficient design are developed mainly by OG. However, due to the open software architectural approach, other systems complying with the defined requirements could also be integrated.

2.3.1 ROOMEX

Type: Web Application, extended in ISES		**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	
ENERGY DATA INPUT:	Energy targets	Text
USER BEHAVIOUR INPUT:	N/A	
BUILDING DATA (BIM) OUTPUT:	N/A	
MATERIAL DATA OUTPUT:	N/A	
CLIMATE DATA OUTPUT:	N/A	
ENERGY DATA OUTPUT:	Report	Structured as well as unstructured text as file or data stream
PROGRAMMING LANGUAGE/ FRAMEWORK:	Visual Studio 2010, C#, asp.net, framework 3.5	
ADAPTATION TO CLOUD/GRID:	Not necessary	

2.3.2 RYHTI Metrix

Type: Web Application, extended in ISES		Main developer: OG
Synopsis: RYHTI Metrix 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
ENERGY DATA INPUT:	Energy consumption of heating, cooling and electricity	Numbers
USER BEHAVIOUR INPUT:	User profile data from eeBIM (opt.) or from internal database	File or data stream
BUILDING DATA (BIM) OUTPUT:	N/A	
MATERIAL DATA OUTPUT:	N/A	
CLIMATE DATA OUTPUT:	N/A	
ENERGY DATA OUTPUT:	Report	Structured as well as unstructured text as file or data stream
PROGRAMMING LANGUAGE/ FRAMEWORK:	Visual Studio 2010, C#, asp.net, framework 3.5	
ADAPTATION TO CLOUD/GRID:	Not necessary	

2.4 Cloud Service Module

The Cloud Service Module, including a set of energy computing and data storage tools, constitutes the central functionality of the VEL. It shall provide the necessary flexibility and throughput to enable solving various lifecycle energy analysis and simulation tasks. In order to achieve early proof of concept and a directly exploitable environment, in ISES two comprehensive energy tools from partners TUD-IBK (NANDRAD) and OG (RIUSKA) will be integrated, along with a CFD thermal solver by partner SOF, a stochastic template processor and energy resource services providing access to energy related data by NMI and TUD-CIB, a reporting component for generating overviews of energy demands and various other decision support views on the analysed data by NOA / SOF etc.

Technically, the Cloud Service Module presents a single component in the overall platform architecture. However, from functional point of view three types of services can be distinguished:

- Energy-related Cloud Services (sections 2.4.1 – 2.4.5 below)
- Supporting Cloud Services (sections 2.4.6 – 2.4.8)
- Standard Cloud Middleware (outlined briefly in chapter 3).

2.4.1 NANDRAD

Type: Batch Application, extended in ISES	**Main developer: TUD-IBK**
Synopsis: NANDRAD is a desktop application for numerical simulation of various energy performance aspects such as the coupled heat and moisture transport inside opaque walls, roofs and floors. Its numerical kernel features partially faster and more precise computational methods than other well-known energy simulation tools such as EnergyPlus and DOE-2.	
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 [m^2]	1. Number 2. Number
MATERIAL DATA INPUT:	1. (dry) bulk density [kg/m^3] 2. (dry) specific heat capacity [J/kg K] 3. (dry) thermal conductivity [W/m K] 4. open porosity [m^3/m^3] 5. effective saturation [m^3/m^3] 6. water uptake coefficient [kg/m^2 s05] 7. water vapour diffusion resistance factor [-] 8. liquid water diffusivity at effective saturation [m^2/s]	1. Number 2. Number 3. Number 4. Number 5. Number 6. Number 7. Number 8. Number

	9. Capillary saturation content [m^3/m^3] 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/m^2] 6. Diffuse sun radiation [W/m^2] 7. Heat emission from surrounding ground [W/m^2] 8. Atmospheric counter radiation [W/m^2] 9. Rain flux density on a horizontal plane [l/m^2s]	1. Number 2. Number 3. Number 4. Number 5. Number 6. Number 7. Number 8. Number 9. Number
ENERGY DATA INPUT:	1. Inside and outside exchange coefficient for heat flow [W/m^2 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/m^2 s]	1. Number 2. Number 3. Number 4. Number 5. Number 6. Number 7. Number 8. Number
USER BEHAVIOUR INPUT:	User profile data from eeBIM (opt.) or from internal database	Depending on the specification from WP4 or in internal format
DATA OUTPUT:	1. Liquid content (Volume fraction) [Volume %] 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++	
ADAPTATION TO CLOUD/GRID:	Yes.	

2.4.2 RIUSKA

Type: Local Application, extended in ISES		Main developer: OG
Synopsis: RIUSKA is an application for dynamic thermal comfort and energy analysis spatially for the whole building. In order to facilitate fast response, it builds upon less sophisticated numerical algorithms than NANDRAD, focusing on practical user needs and interactions.		
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 • High BIM-IFC compliance		**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:	Thermal transmittance resistance; lambda [mK/W] etc.	Number
CLIMATE DATA INPUT:	Hourly temperature	Number
ENERGY DATA INPUT:	N/A	N/A
USER BEHAVIOUR INPUT:	User profile data from eeBIM (opt.) or from internal database (same as for NANDRAD)	Depending on the specification from WP4 or in internal format
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	
ADAPTATION TO CLOUD/GRID:	Yes (optional).	

2.4.3 CFD Thermal Solver

Type: Batch Application, extended in ISES	**Main developer: SOF**

Synopsis:

CFD analysis software for the coupling of indoor flow and the outdoor microclimate flow. It solves 3D Navier-Stokes equations for incompressible, turbulent flows. Heat transfer equation and radiation models are coupled with Navier-Stokes equation of the prediction of buoyant effects due to temperature gradients.

<table>
<tr>
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Features:

- Hybrid unstructured computational mesh
- Coupled indoor-outdoor flows.
- Include detailed heat sources inside rooms/models, including furnishing, and thermal sources such as occupants (100W), TV (300W), PC (300W) etc.
- The openings are a design parameter for the energy saving and natural ventilation
- Predicts airflow and Temperature distribution to determine the thermal comfort conditions
- Investigates natural ventilation in a part of a building of real-scale geometry
- Examines the effectiveness and efficiency of various HVAC systems by easily changing diffuser types and locations, supplies air conditions and system control schedules
- Increases energy efficiency of buildings by allowing passive HVAC strategies, such as using natural ventilation for summer and using wind break for winter
- Assessment of natural ventilation performance
- Implemented parallel processing algorithm

</td>
<td>

Users:

- Mechanical engineers
- Civil engineers
- Energy planners

</td>
</tr>
</table>

INPUT & OUTPUT	**Major Data Items**	**Type**
BUILDING DATA (BIM) INPUT:	1. Orientation and inclination of each element of the rooms envelop [Deg] 2. Geometry of building envelope and each room including furnishing, and thermal sources 3. Effective ground surface [m^2] 4. Openings description [m^2] 5. Outdoor temperature (K) and pressure (Pa) for each opening 6. Type of atmospheric boundary layer 7. Marking of the rooms for natural ventilation study in the BIM model	1. Number 2. Number 3. Number 4. Number 5. Number 6. Text or Number 7. Text 8. Text 9. Text/description 10. Text

	8. Marking of walls of the BIM extracted envelope that participate in thermal analysis or in coupled CFD/thermal analysis 9. Additional heat sources inside rooms/models for buoyant airflow calculations 10. Boundary conditions for thermal and airflow problems for each boundary of the computational domain	
MATERIAL DATA INPUT:	1. Walls thermal conductivity, k[W/m K] 2. Air thermal diffusivity, $\alpha[m^2/s]$ 3. Heat capacity of air at constant pressure, c_p[J/kg K] 4. Absorption coefficient of the medium/air [1/m] for thermal radiation 5. Scattering coefficient of the medium [1/m] 6. Wall emissivity for each surface, ε [-]	1. Number 2. Number 3. Number 4. Number 5. Number 6. Number
CLIMATE DATA INPUT:	1. Outdoor air temperature [°C] 2. Outdoor air pressure [Pa]	1. Number 2. Number
FLOW AND THERMAL FIELD DATA INPUT:	1. Reynolds number of outdoor flow field 2. Prandtl number as the ratio between momentum and thermal diffusivity, for the simulation of indoor climate 3. Grashof number as the ratio between buoyancy and viscous forces, for the simulation of indoor climate 4. Reyleigh number for natural convection simulation 5. Heating power of the heat sources inside rooms (occupants, TV, PC etc) 6. Type of problem to be solved (flow/thermal/coupled) 7. Type of turbulence model (k-ε, k-ω, Spalart Almaras, k-ω SST, k-ω SST SAS, LES) and type of the solid boundary treatment (RANS or wall functions) for thermal and flow fields	1. Number 2. Number 3. Number 4. Number 5. Number 6. Text 7. Text 8. Text and numbers 9. Number

	8. Specific parameters for the spatial and temporal accuracy and the convergence of the flow and thermal fields. 9. Limits for temperature, temperature gradient along the height and airflow velocity to preserve thermal comfort	
DATA OUTPUT:	1. Velocity components and pressure distribution all over the flow field (outdoor, indoor) 2. Temperature distribution all over the indoor flow field. 3. Temperature distribution on solid walls. 4. Pressure distribution on solid walls and openings 5. Extreme values of indoor air temperature and air velocities 6. Evaluation of thermal comfort based on operative temperature concerning EN 15251 [-]	1. Number 2. Number 3. Number 4. Number 5. Number
PROGRAMMING LANGUAGE/ FRAMEWORK:	FORTRAN 2003 (Windows and Linux systems)	
ADAPTATION TO CLOUD/GRID:	Yes. Together with NANDRAD it provides the most important compute cloud use.	

2.4.4 Stochastic Template Processor (STP)

Type: Web Service, new development in ISES	**Main Developer: NMI**
Synopsis: The Stochastic Template Processor (STP) is a XML based scripting and a processing engine for dynamic eeTemplates. Stochastic data sets, described in eeTemplates will be dynamically generated by probabilistic software via the STP. eeTemplates will use embedded instructions (custom tags and scripting code) encoded using W3C XML syntax for execution in the STP. The eeTemplate data model further enables access to the many underlying energy related data models that are bound to external data sources for consolidation in the eeBIM.	
Features: • Stochastic and probabilistic processing of energy data • Dynamic access to energy data networked data sources • Custom logic processing	**Users:** • Energy experts, civil engineers (indirectly)

• Extendible by custom tags • Processing pipeline integration		
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
ENERGY DATA INPUT:	eeTemplate	XML file
USER BEHAVIOUR INPUT:	If included in the eeTemplate	see above
DATA OUTPUT:	1. eeTemplate 2. Data for eeBIM	1. XML file 2. eeBIM file
PROGRAMMING LANGUAGE/FRAMEWORK:	Web Service (XML/JAVA)	
ADAPTATION TO CLOUD/GRID:	Not necessary.	

2.4.5 Energy Resource Service

Type: Web Service, new development in ISES		**Main Developer: NMI, TUD**
Synopsis: Web service for access to energy related networked data sources for consolidation in eeBIM. The networked data sources may be available in heterogeneous data stores, such as databases, web services, web sites or in different data repository systems and be of type eeTemplate, weather profile, occupancy profile, building element, material and material property etc.		
Features: • Retrieval of physical data stored in networked data sources		**Users:** • Architects, civil engineers, energy planners (indirectly)
INPUT & OUTPUT	**Major Data Items**	**Type**
DATA INPUT: (all data types)	Resource descriptor identifying the interface of networked data sources and data types	XML
DATA OUTPUT:	Depending on resource descriptor type	eeBIM file
PROGRAMMING LANGUAGE/FRAMEWORK:	Web Service (XML/JAVA)	
ADAPTATION TO CLOUD/GRID:	No.	

2.4.6 Geometry Modeller

Type: Windows application, extended in ISES	**Main developer: SOF**
Synopsis: An application for the generation of CAD-type models, their preparation for mesh generation and subsequent numerical calculations. It is based on the Open Cascade© Open Source Library and can be operated via a GUI in OpenGL, in Command Line Mode or can generate complex objects in silent Batch Mode.	
Features: • Parametric generation of complex 3D models containing various geometrical operations • The geometric objects are parameterised and interdependent and include Bezier, BSpline, offset curves, surfaces and volumes. • The Modeler can import IGES 5.3 and STEP AP203/214 schemata and DXF CAD models as well as BREP (Open CASCADE internal format) and export surfaces for the mesh generation. • Extracts model for mesh generation of outdoor and indoor fields. • Extracts materials and air properties to CFD-Thermal Solver.	**Users:** • Mechanical engineers • Civil engineers • Energy planners

INPUT & OUTPUT	**Major Data Items**	**Type**
BUILDING DATA INPUT:	1. Import of geometrical model from a CAD system (dxf format) 2. Orientation and inclination of each element of the rooms envelop [Deg] 3. Geometry of building envelope and each room 4. Surface geometry of the surrounding domain 5. Extends and shape of outer boundaries of the outdoor domain	1. Number 2. Number 3. Number 4. Number 5. Number
MATERIAL DATA INPUT:	1. Walls thermal conductivity, k[W/m K] 2. Air thermal diffusivity, $\alpha[m^2/s]$ 3. Heat capacity of air at constant pressure, c_p[J/kg K] 4. Absorption coefficient of the medium/air [1/m] for thermal radiation 5. Scattering coefficient of the medium [1/m] 6. Wall emissivity for each surface, ε[-]	1. Number 2. Number 3. Number 4. Number 5. Number 6. Number
CLIMATE DATA INPUT:	1. Outdoor air temperature [°C] 2. Outdoor air pressure [Pa]	1. Number 2. Number

USER BEHAVIOUR INPUT:	N/A	N/A
FLOW AND THERMAL FIELD DATA INPUT:	1. Reynolds number of Outdoor flow field 2. Prandtl number as the ratio between momentum and thermal diffusivity, for the simulation of indoor climate 3. Grashof number as the ratio between buoyancy and viscous forces, for the simulation of indoor climate 4. Reyleigh number for natural convection simulation. 5. Heating power of the heat sources inside rooms (occupants, TV, PC etc) 6. Type of problem to be solved (flow/thermal/coupled) 7. Type of turbulence model (k-ε, k-ω, Spalart Almaras, k-ω SST, k-ω SST SAS, LES) and type of the solid boundary treatment (RANS or wall functions) for thermal and flow fields 8. Specific parameters for the spatial and temporal accuracy and the convergence of the flow and thermal fields 9. Limits for temperature, temperature gradient along the height and airflow velocity to preserve thermal comfort	1. Number 2. Number 3. Number 4. Number 5. Number 6. Text 7. Text 8. Text & numbers 9. Number
DATA OUTPUT:	1. Geometry description for mesh generation procedure 2. Input data file for the CFD-Thermal Solver	1. Number 2. Number
PROGRAMMING LANGUAGE/ FRAMEWORK:	OpenGL, C++, QT (Windows and Linux systems)	
ADAPTATION TO CLOUD/GRID:	Optional. Cloud use will be principally possible using the batch mode feature of the application. The actual scope of cloud use depends on the detailed workflows that will be elaborated in WP 6.	

2.4.7 Mesh Generator (FRONT3D)

Type: Batch Application, extended in ISES		**Main developer: SOF**
Synopsis: A stand-alone 3D unstructured mesh generator (FRONT3D) for the discretization of complex 3D computational domains that could concern structural, mechanical or aeronautics applications. It is based on the advancing front technique in three dimensions and generates tetrahedral elements of high quality with user imposed density. The mesh generator is further enhanced with the capability of automatic generation of prismatic thin inflated mesh of structured-type layers along the solid walls for the simulation of the turbulent boundary layer, keeping constant distance of the first grid line from the solid boundary, as it is required for low-Re variants of the turbulence models.		
Features: • Generation of complex 3D numerical meshes including special handling of boundary layer mesh zones • Interoperates with modeller and CFD-Thermal solver		**Users:** • Mechanical engineers • Civil engineers
INPUT & OUTPUT	**Major Data Items**	**Type**
BUILDING DATA INPUT:	1. Import of surfaces surrounding flow domain from geometrical modeller 2. Global mesh density parameter [m] 3. Inflated zones definition (thickness of the zone, number of mesh layers, mesh growth factor or distance of the first zone from the solid wall) 4. Specific mesh refinement by defining “sources” with finer mesh in a prescribed radius.	1. Number 2. Number 3. Number 4. Number
OTHER DATA INPUT:	N/A	N/A
DATA OUTPUT:	Numerical mesh for CFD-Thermal analysis software.	Number
PROGRAMMING LANGUAGE/ FRAMEWORK:	FORTRAN 2003 (Windows and Linux systems)	
ADAPTATION TO CLOUD/GRID:	Optional. Cloud use will be principally possible using the batch mode feature of the application. The actual scope of cloud use depends on the detailed workflows that will be elaborated in WP 6.	

2.4.8 Cloud Data Repository Service

Type: Web Service, new development in ISES		**Main Developer: NMI, TUD**
Synopsis: A web service Interface to the Cloud based ISES Data Repository providing support for intelligent search and retrieval of meta-data about templates, profiles, building elements, products, materials and other energy related information.		
Features: • Search data sources based on parametric data • Browse data sources using classification		**Users:** • Architects, Civil engineers, Energy planners (indirectly)
INPUT & OUTPUT	**Major Data Items**	**Type**
BUILDING DATA (BIM) INPUT:	1. Building Zone and Space types 2. Building elements, names and types 3. Building materials, names and types 4. OmniClass™ ID	1.-3. Structured query 4. OmniClass™ code
MATERIAL DATA INPUT:	1. Building elements, names and types 2. OmniClass™ ID	1. Structured query 2. OmniClass™ code
CLIMATE DATA INPUT:	1. Latitude 2. Longitude 3. Elevation	1. Number 2. Number 3. Number
ENERGY DATA INPUT:	N/A	N/A
USER BEHAVIOUR INPUT:	N/A	N/A
DATA OUTPUT:	Meta-data describing eeTemplates, weather profiles, occupancy profiles, load profiles, energy control profiles, building elements, building materials and material properties as related to the input	Text file
PROGRAMMING LANGUAGE/FRAMEWORK:	Web Service (XML/JAVA)	
ADAPTATION TO CLOUD/GRID:	Not necessary (cloud middleware to be used directly).	

2.5 Reporting Module

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

PEA

Type: .NET Console application, extended in ISES	**Main developer: NOA**
Synopsis: PEA is a console application for assessment of the energy performance and ranking (energy class) of buildings, along the lines of energy performance certificates in EPBD, based on the quasi-steady state monthly calculation procedures, for heating, cooling, mechanical ventilation, domestic hot water and lighting.	
Features: • Fast calculations • Use of external libraries for weather data and fuel data • Assessment of energy performance of building based mainly on the following EN Standards - Heating / Cooling *EN ISO 13790, EN ISO 13370* - Domestic Hot Water *EN ISO 15316-3-1/2/3 EN ISO 15316-4-3* - Lighting *EN ISO 15193*	**Users:** • Architects • Civil engineers • Mechanical engineers • Energy experts • Consultants • Decision makers

INPUT & OUTPUT	Major Data Items	Type
PROJECT DATA INPUT: (Description of the whole project):	1. Project description 2. Reference to libraries to be used. 3. References to the buildings taking part of the project.	1. Text 2. Text 3. Text
LIBRARIES DATA INPUT: (Definition of the libraries to be used in the calculations for this model):	1. Full path and name of the national constants library. 2. Full path and name of the climate library. 3. Full path and name of the library with definition of the fuels.	1. Text 2. Text 3. Text
BUILDING DATA INPUT: (Definition of the libraries to be used in the calculations for this model):	1. Name of the building. 2. Reference to all building spaces in the building (zones, unheated spaces, sun spaces, PV cells, CHP). 3. Reference to list of systems associated with the building (heating, cooling, domestic hot water system, solar collectors)	1. Text 2. Text 3. Text

BUILDING SPACE ZONE OBJECT DATA INPUT: (Description of building space object ZONE):	1. Name of the zone. 2. Gross area, m² 3. Specific internal heat capacity, kJ/m² K 4. Specific internal coupling coef., W/m² K 5. Use given specific internal coupling coefficient 6. Fraction Persons present, [-] 7. Occupants, W/m² 8. Fraction Appliances are on, [-] 9. Appliances, W/m² 10. Emergency lighting 11. Stand-by energy 12. Total installed lighting power, W 13. Daylight time usage per year, hours 14. Non-daylight time usage per year, hours 15. Daylight dependency factor, [-] 16. Occupancy factor, [-] 17. Fraction not removed by exhaust ventilation, lighting Investment 18. List of references to external envelope elements 19. List of references to ground envelope element. 20. Internal Set Point Temp Heating, °C 21. Internal Set Point Temp Cooling, °C 22. Infiltration, m³/s 23. Natural vent, m³/s 24. Fraction Nat Vent is present, [-] 25. Average DHW consumption, m³/m²/year 26. Boiler Temp, °C 27. Cold-water Temp., °C 28. List of references of internal separations 29. Reference to heating object 30. Reference to cooling object 31. Reference to dhw object 32. Reference to humidification object 33. Reference to solar collector object	1. Text 2. Number 3. Number 4. Number 5. Text 6. Number 7. Number 8. Number 9. Number 10. Text 11. Text 12. Number 13. Number 14. Number 15. Number 16. Number 17. Number 18. Text 19. Text 20. Number 21. Number 22. Number 23. Number 24. Number 25. Number 26. Number 27. Number 28. Text 29. Text 30. Text 31. Text 32. Text 33. Text
BUILDING SPACE UNHEATED OR SUN SPACE OBJECT DATA INPUT: (Description of building space object UNHEATED OR SUN SPACE):	1. Name of the unheated or sun space. 2. Gross area, m² 3. Fraction Persons present, [-] 4. Occupants, W/m² 5. Fraction Appliances are on, [-] 6. Appliances, W/m² 7. Emergency lighting, .T. or .F. 8. Stand-by energy, .T. or .F. 9. Total installed lighting power, W 10. Daylight time use per year, hours 11. Non-daylight time use per year, hours	1. Text 2. Number 3. Number 4. Number 5. Number 6. Number 7. Text 8. Text 9. Text 10. Number 11. Number

	12. Daylight dependency factor, [-] 13. Occupancy factor, [-] 14. Fraction not removed by exhaust ventilation, [-] 15. Lighting Investment 16. List of refs. to external envelope elements 17. List of refs. to ground envelope elements 18. Air flow rate, m³/s	12. Number 13. Number 14. Number 15. Number 16. Text 17. Text 18. Number
BUILDING SPACE PV CELLS OBJECT DATA INPUT: (Description of building space object PV CELLS):	1. Object name 2. Collector area, m² 3. System efficiency, [-] 4. Shading correction factor, [-] 5. Investment per area 6. Reference to a direction object	1. Text 2. Number 3. Number 4. Number 5. Number 6. Text
BUILDING SPACE CHP OBJECT DATA INPUT: (Description of building space object CHP – cogeneration of heat & power unit):	1. Object name 2. Annual heat delivery efficiency, [-] 3. Annual electrical delivery efficiency, [-] 4. Name of fuel type (in the fuel library) 5. Investment cost	1. Text 2. Number 3. Number 4. Text 5. Number
BUILDING INTERNAL SEPARATION OBJECT DATA INPUT: (Description of an internal separation object, used to establish relations b/n a zone & unheated or sun space):	1. Name of the object 2. Air flow rate, m³/s 3. List of references to internal sunspace elements 4. References to unheated space or sun space	1. Text 2. Number 3. Text 4. Text
BUILDING ENVELOPE EXTERNAL OBJECT DATA INPUT: (Description of an external envelope object):	1. Name of the object 2. Area, m² 3. Thermal transmittance, W/m²K 4. Investment cost per area 5. Partial shading cor. factor for the horizon, [-] 6. Partial shading correction factor for overhangs, [-] 7. Partial shading correction factor for fins, [-] 8. Reference to opaque properties or transparent properties object 9. Reference to a direction object	1. Text 2. Number 3. Number 4. Number 5. Number 6. Number 7. Number 8. Text 9. Text
BUILDING ENVELOPE GROUND OBJECT DATA INPUT: (Description of a ground envelope object):	1. Name of the object 2. Area, m² 3. Thermal transmittance, W/m²K 4. Investment cost per area 5. Correction factor for heat transmission to ground for heating, [-] 6. Correction factor for heat transmission to ground for cooling, [-]	1. Text 2. Number 3. Number 4. Number 5. Number 6. Number

BUILDING ENVELOPE INTERNAL SUNSPACE OBJECT DATA INPUT: (Description of an internal sunspace object):	1. Name of the object 2. Area, m² 3. Thermal transmittance, W/m²K 4. Investment cost per area 5. Reference to an opaque properties or transparent properties object 6. Reference to a direction object	1. Text 2. Number 3. Number 4. Number 5. Text 6. Text
BUILDING ENVELOPE OPAGUE PROPERTIES OBJECT DATA INPUT: (Description of an opaque properties object):	1. Name of the object 2. Absorption coefficient for solar radi-ation, [-] 3. Ext. surface heat resistance, m²K/W 4. Emissivity for thermal radiation, -	1. Text 2. Number 3. Number 4. Number
BUILDING ENVELOPE TRANSPARENT PROPERTIES OBJECT DATA INPUT: (Description of a transparent properties object):	1. Name of the object 2. Total solar transmittance of the transparent part of the element, [-] 3. Total solar transmittance of the transparent part of the element with closed shutter, [-] 4. Thermal transmittance of window and closed shutter, W/m²K 5. Fraction of time window has shutter down for nocturnal insulation, [-] 6. Fraction of time window has shutter down for shading reduction on solar heat sources, [-]	1. Text 2. Number 3. Number 4. Number 5. Number 6. Number
BUILDING ENVELOPE DIRECTION OBJECT DATA INPUT: (Description of a direction object):	1. Name of the object 2. Orientation, deg. North = 0 3. Tilt angle, deg, horizontal = 0	1. Text 2. Number 3. Number
BUILDING SYSTEMS OBJECT DATA INPUT: (Description of systems associated with a building):	1. Name of the object 2. Reference to PV cells 3. References to CHP units 4. Reference to AHU's (air handing units) 5. Reference to heating systems 6. Reference to cooling systems 7. Reference to DHW systems 8. Reference to humidification systems	1. Text 2. Text 3. Text 4. Text 5. Text 6. Text 7. Text 8. Text
BUILDING SYSTEMS AHU OBJECT DATA INPUT: (Description of an air handling unit object):	1. Object name 2. Supply temperature increase due to fans, °C 3. Fraction of time that the mechanical ventilation is on, [-] 4. Investment cost of this part 5. Reference to an ahu heat object 6. Reference to an ahu cool object 7. Reference to an ahu hum object 8. Reference to an ahu aux object 9. Reference to zone serviced by the ahu	1. Text 2. Number 3. Number 4. Number 5. Text 6. Text 7. Text 8. Text 9. Text

BUILDING SYSTEMS AHU HEAT OR COOL OBJECT DATA INPUT: (Description of an ahu heating or cooling object):	1. Object name 2. Heating part is active, [-] 3. Supply temperature of the air entering the zone, °C 4. Air flow rate, m³/s 5. Heat recovery efficiency, [-] 6. Recirculation factor, [-]	1. Text 2. Text 3. Number 4. Number 5. Number 6. Number
BUILDING SYSTEMS AHU HUM OBJECT DATA INPUT: (Description of an ahu humidification object):	1. Object name 2. Humidification part is active, [-] 3. Efficiency of humidification recovery, [-] 4. Humidity of the supply air at tempe-rature, g/kg	1. Text 2. Text 3. Number 4. Number
BUILDING SYSTEMS AHU AUX OBJECT DATA INPUT: (Description of an ahu auxiliary object):	1. Object name 2. Specific electricity consumption for fans per flow rate, W s/ m³	1. Text 2. Number
BUILDING SYSTEMS HEATING OR COOLING OR DHW OR HUMIDIFICATION OBJECT DATA INPUT: (Description of a heating or cooling or dhw object):	1. Object name 2. Reference to an emission object 3. Reference to a distribution object 4. Reference to one or more generation objects 5. Factor on fuel consumption, due to use of building management system, [-] 6. Reference to a solar collector (for heating or dhw object) 7. Reference to an auxiliary object (for heating or cooling object)	1. Text 2. Text 3. Text 4. Text 5. Text 6. Text 7. Text
BUILDING SYSTEMS HEATING OR COOLING AUX OBJECT DATA INPUT: (Description of a heating auxiliary object):	1. Object name 2. Weight factor for pumps control system, [-] 3. Specific installed power of pumps, W/m² 4. Reference to a period vals object for operation time fraction for each month	1. Text 2. Number 3. Number 4. Text
BUILDING SYSTEMS SOLAR COLLECTOR OBJECT DATA INPUT: (Description of a solar collector object):	1. Object name 2. Collector area, m² 3. Shading correction factor, [-] 4. Annual fraction of incoming solar radiation to domestic hot water use, [-] 5. Annual fraction of incoming solar radiation to space heating use, [-] 6. Investment per unit area 7. Reference to a direction object	1. Text 2. Number 3. Number 4. Number 5. Number 6. Number 7. Text

BUILDING SYSTEMS GENERATION OBJECT DATA INPUT: (Description of a generation object):	1. Object name 2. Investment cost 3. Efficiency, [-] 4. COP or EER value, [-] 5. Reference to a period vals object for operation time fraction delivery for each month 6. Name of fuel type (in the fuel library) or reference to a CHP object	1. Text 2. Number 3. Number 4. Number 5. Text 6. Text
BUILDING SYSTEMS DISTRIBUTION OR EMISSION OBJECT DATA INPUT: (Description of a distribution or emission object):	1. Object name 2. Investment cost 3. Efficiency, [-] 4. Reference to the zone the emission take place (for emission object)	1. Text 2. Number 3. Number 4. Text
BUILDING SYSTEMS PERIOD VALS OBJECT DATA INPUT: (Definition of operation time fraction for each month):	1. Object name 2. List of 12 references to period value objects given in the order from January to December	1. Text 2. Text
BUILDING SYSTEMS PERIOD VAL OBJECT DATA INPUT: (Definition of operation time fraction for specific month):	1. Object name 2. Description 3. Operation time fraction for this month, [-]	1. Text 2. Text 3. Number
CLIMATE DATA INPUT:	1. Latitude for the location 2. Longitude for the location 3. Time zone for the location 4. Name of the month 5. Month number 6. Outdoor temperature, °C 7. Outdoor humidity, g/kg 8. Horizontal solar irradiation, MJ/m² 9. Solar irradiation on a 45 ° tilted surface facing N, NE, E, SE, S, SW, W, NW, MJ/m² 10. Solar irradiation on a 90 ° tilted surface facing N, NE, E, SE, S, SW, W, NW, MJ/m²	1. Number 2. Number 3. Number 4. Text 5. Number 6. Number 7. Number 8. Number 9. Number 10. Number
CONSTANT LIBRARY DATA INPUT:	1. Frame factor for glazing element, heating, [-] 2. Frame factor for glazing element, cooling, [-] 3. Correction term for thermal transmittance due to thermal bridges, W/m²K 4. Correction factor for the transmission heat transfer coefficient to the ground for heating mode, [-] 5. Correction factor for the transmission heat transfer coefficient to the ground for cooling mode, [-]	1. Number 2. Number 3. Number 4. Number 5. Number 6. Number 7. Number 8. Number 9. Number 10. Number 11. Number

	6. Relative variation of lighting power consumption, month values, jan, feb, ..., dec, [-]- 7. Correction factor for thermal radiation from the sky, [-] 8. Reference numerical parameter for gain utilization for heating, [-] 9. Reference time constant for gain utilization for heating, [-] 10. Reference numerical parameter for gain utilization for cooling, [-] 11. Reference time constant for gain utilization for cooling, [-]	
FUEL LIBRARY DATA INPUT:	1. The national currency used for financial calculations 2. List of references to fuel objects defined in the following section of the file 3. Fuel object 4. Description, (optional) 5. Fuel name 6. Conversion factor from fuel input (in MJ) to a more conventional unit (as on the fuel meter), e.g. to m³ for gas 7. Conversion from MJ to this unit 8. Conversion factor from fuel input (in MJ/year) to primary energy (in MJ/year) 9. Conversion factor from fuel input, including electricity, (in MJ/year) to CO_2 emission (in kg/year) 10. Cost per unit in specified currency	1. Text 2. Text 3. Text 4. Text 5. Text 6. Number 7. Number 8. Number 9. Number 10. Number
BENCHMARK LIBRARY DATA INPUT:	1. Building use 2. Climatic zone 3. Annual primary energy consumption, upper limit for energy ranking class A+ to G	1. Text 2. Number 3. Sequence of Numbers
DATA OUTPUT:	1. Building name 2. Annual primary energy consumption, kWh/m^2 3. Energy ranking (class)	1. Text 2. Number 3. Text
PROGRAMMING LANGUAGE/ FRAMEWORK:	.NET	
ADAPTATION TO CLOUD/GRID:	Yes	

<u>Note</u>: The provided comprehensive exchange requirements (I/O) specification shows the full scale of energy results that need to be taken into account by the VEL presentation system. However, not all shown issues may be supported by the prototype energy analysis / simulation tools in the scope of ISES.

2.6 Common Access Module

The Common Access Module aims at enabling the use of the VEL 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 ISES common access will be realized by a single component, the nD Navigator, encompassing all identified required functionality.

nD Navigator

Type: Web Application, extended in ISES		**Main developer: TUD-CIB**
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).		
Features: • Comfortable navigation in nD information space • Presentation of simulation results		**Users:** • Architects • Engineers • Energy Planners • FM Managers • Decision makers
INPUT & OUTPUT	**Major Data Items**	**Type**
BUILDING DATA (BIM) INPUT:	1. BIM/IFC 2x3 interface 2. eeBIM interface	1. BIM File 2. eeBIM File
MATERIAL DATA INPUT:	1. Material defined in IFC2x3 BIM data 2. Material defined in eeBIM data	1. BIM File 2. eeBIM File
CLIMATE DATA INPUT:	Climate data defined in eeBIM	eeBIM File
ENERGY DATA (BIM) INPUT:	Energy data defined in eeBIM	eeBIM File
USER BEHAVIOUR INPUT:	User behaviour data defined in eeBIM	eeBIM File
PROGRAMMING LANGUAGE/ FRAMEWORK:	C++, Java, Web Environment, XML	
ADAPTATION TO CLOUD/GRID:	Not possible.	

3. Cloud-based Software Architecture

Based on the requirements of WP1 and the functional components specification of Task T2.1 documented in the preceding chapter, the software architecture of the ISES platform is proposed. It includes a middleware component for all services, the VEL Core*,* which is responsible for processing runtime information received from end users of the platform and for the workflow management, as well as a set of local and cloud-enabled user services and tools. Domain models are inter-linked in the VEL Core and transformations are done by services which are generating new levels of details. The basis of the modelling framework is an ontology which facilitates data gathering, processing, filtering and management. This chapter outlines the proposed approach, specifically focusing on the Cloud Environment. The underlying platform ontology is briefly explained, but it will be presented in more details in the Deliverable D3.1 dedicated to its conception and formal specification.

3.1 Overview

Figure 2 shows a generalised view of the proposed software architecture of the VEL with its principal component modules, services and applications. As a technical architecture that has to provide the required functionality in practical terms, it differs from the logical structuring of the platform presented in Figure 1. Hence, it is another valid view on the VEL platform.

Overall, the architecture applies the SOA concept, following a general modular approach. It comprises several types of services and applications, bound together by the **VEL Core Module** that acts as the middleware providing the required data and functional interoperability. Modularisation of the components is consistent with the identified use cases and can easily be extended. Consequently, the following modules are defined as basis for the prototype implementation of the platform in the WPs 3-8:

1 **Design module**, comprising a BIM-based CAD system, a product catalogue module for the selection and testing of new products and supporting tools capable to produce and export IFC model data (main users are architects and other building designers as well as product developers).

2 **Requirement management module**, comprising a FM system and related energy and costing tools (main users are facility managers and operators).

3 **Common access module**, providing a general-purpose interface to the VEL via a web application and enabling light-weight easy-to-do studies of the building performance with regard to energy and life cycle costs. In this module, it is also possible to change simulation parameters like product data and load templates for calculating different variants (intended main users are product developers and decision makers, but it can be freely used by all other identified actors).

4 **Cloud Service**, providing the energy related analysis and simulation services and tools, a simulation model configurator and reporting tools for the generation of various kinds of aggregated reports for decision makers. Here, unlike traditional approaches that presume as main users highly specialised 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 and respective workflow facilities will be developed. It will provide access to several distributed information resources like product data catalogues, climate data bases, stored stochastic templates and user profiles as well as the BIM data.

Each of these modules, with the exception of the VEL Core module, is principally exchangeable due to the existing standardised data models and the developed information exchange specifications and APIs. The VEL Core module itself controls the binding to all other services and provides all workflows and model mappings to various data formats. The interoperability to all external services and tools and to the cloud computing facilities is provided by the Intelligent Access Service (IAS), which offers a homogeneous interface via REST technology.

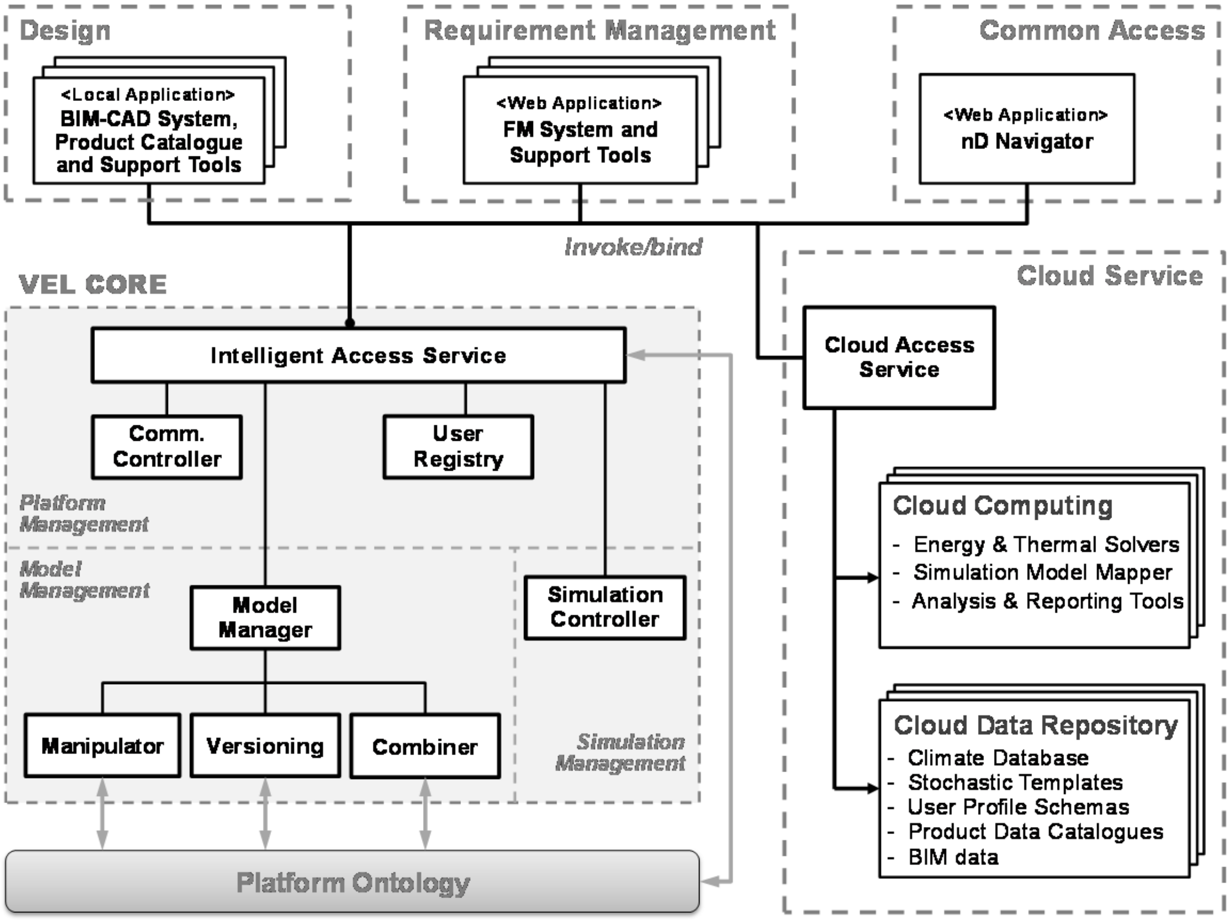

Figure 2: Cloud-based software architecture

3.2 Platform Ontology

As basis of the VEL Core, a Platform Ontology will be developed and set up. Its goal is to provide for loose integration of the multi-model information resources needed to support lifecycle energy performance simulations, monitoring and efficiency assessment. It will allow avoiding rigid integration into a single, difficult to maintain model, taking into account that information/model evolution is spread among different parties, each with its own interests, responsibilities, preferences and permissions. Furthermore, the ontology of the VEL platform shall contain the inter-linked information that is needed during runtime to satisfy the actual user needs. This involves some high level information contained in the building model (IFC file) which is necessary for the simulation tasks. This information will be energy enhanced through space usage templates, construction templates, material templates and user behaviour templates, as well as detailed climate and material property data.

Ontology development continues and extends the work on the eeBIM link model started in the HESMOS project (cf. Liebich et al., 2011). However, the static HESMOS model is being considerably extended with Meta data and rules enabling system level reasoning. The ontology will be specified in OWL so that all advanced link types, such as multiple and transitive associations, can be modelled using genuine ontology techniques. For that purpose, the **Protégé** modelling tool will be used ((http://protege.stanford.edu/). Currently, links from various appropriate IFC entities to various templates are implemented, including climate, material and space usage where requirements and energy relevant parameters are stored. An excerpt of already developed ontology constructs with linked real data from eeBIM can be seen in the following Figure 3.

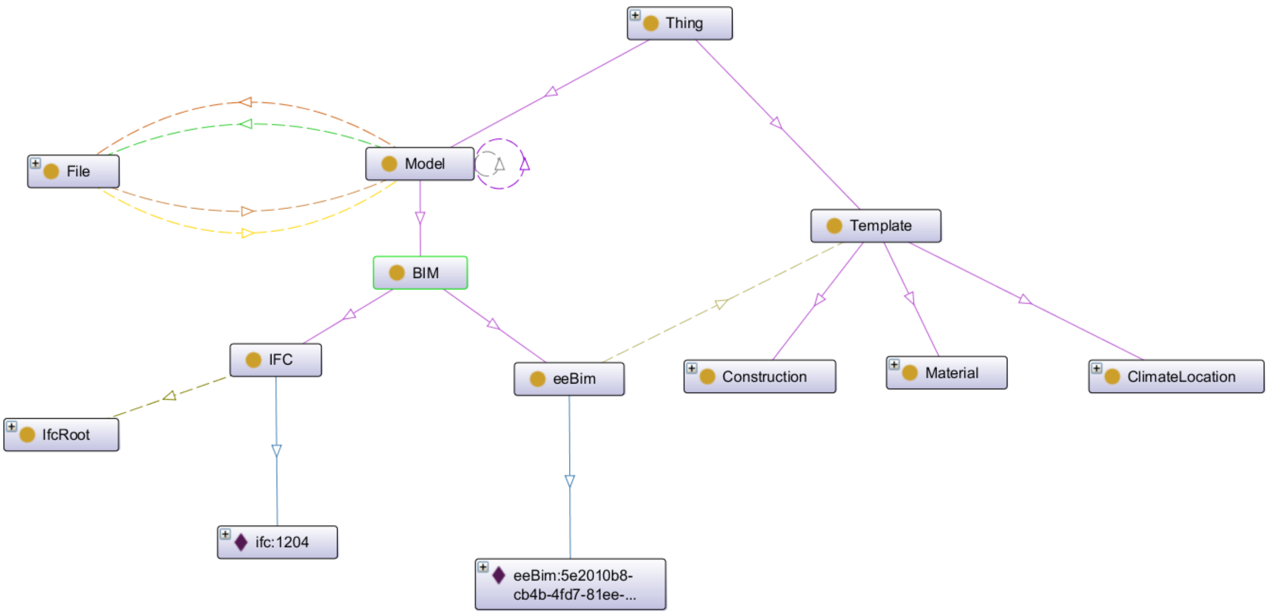

Figure 3: Ontology example for the linkage of data models

3.3 Cloud

Development and use of cloud services includes the cloud computing module and a data repository module. It includes also a common interface for both modules to access cloud resources and computation nodes in uniform manner. This interface will be based on REST or SOAP technology and is connected to the VEL Core. Since all simulation tools are provided through batch files, concurrent computation is always possible and the tools can be distributed as needed. Figure 4 shows the cloud service in detail.

The common interface is provided through the *Cloud Access Service* which directs requests to and sends back responses from the *Cloud Registry & Storage* and controls the *Cloud Simulation Model Configurator*. The Cloud Simulation Model Configurator enhances conceptually the Simulation Controller of the VEL Core by creating multiple tasks to enable concurrent computing of one simulation model template. The simulation model template includes parameters of the building model and has placeholders where parameter variants can be included. The Cloud Registry registers available computation nodes and contains a queue where tasks are held in there order of execution. This includes also nodes where data can be stored. If a task can be executed by a certain node, the Cloud Registry dispatches it to the available node and saves its Meta data in a specific protocol so that the task status can be tracked and the execution monitored. In this way the Cloud Registry provides for parallel simulation of many possible variants by applying the cloud computing paradigm based on the *OpenStack* framework (openstack, 2012). This ensures access to hundreds of computation nodes and hundreds of gigabytes for data storage.

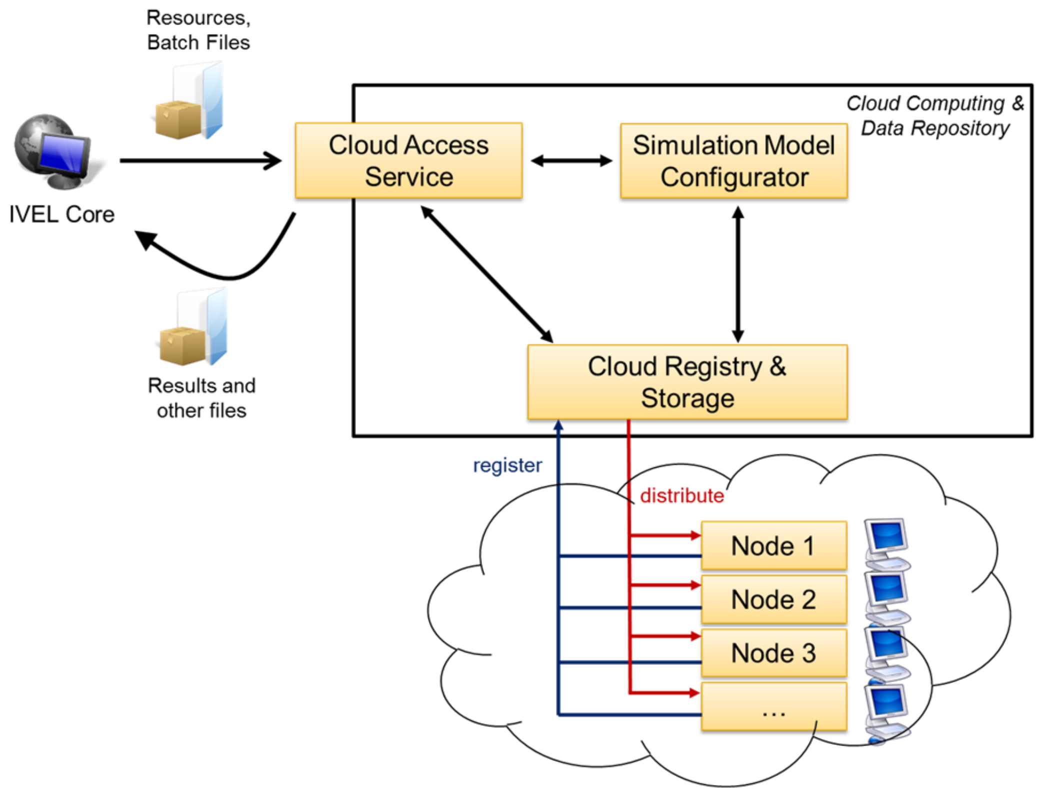

Figure 4: Principal schema of the cloud service

The Cloud Service has three layers (Figure 5):

- Process Layer
- Model Layer
- Hardware Layer.

The **Processes Layer** represented by the Cloud Access Service controls the execution of long running processes, which have to execute many thousand energy simulations. The execution of such long running processes can take up days and may be aborted by unexpected software or hardware failures. The process layer tolerates unexpected system failure or shutdown through *Check-Pointing*. This is a method from system engineering which continually ensures persistence of done work and restores the system state after unexpected system failure or shutdown to the last valid state (Wyld et al., 2011). The Process Layer supports different process execution strategies, e.g. a sequential execution strategy for solving model candidates on a standalone web server or a parallel execution strategy for solving processes using Grid/Cloud computing. A process can contain multiple jobs, where every job references a model candidate. Every model candidate will be generated from a template model stored in the database and filled by the Simulation Model Configurator.

The generation of model candidates from template models depends on the used solver software and is encapsulated in the **Model Layer**. The solver software can be exchanged through new implementation of the model layer to adapt the Cloud Service to other solver software.

The **Hardware-Layer** is responsible for solving of single model candidates. In a simple case it uses operating system resources like shell and file system to solve passed model candidates and is installed on a standalone web server. The Hardware Layer implementation for Grid and Cloud uses standard middleware services to invoke the required computational and file storage services/tools on the target computers.

Figure 5 shows the principal interoperability of the three layers of the service.

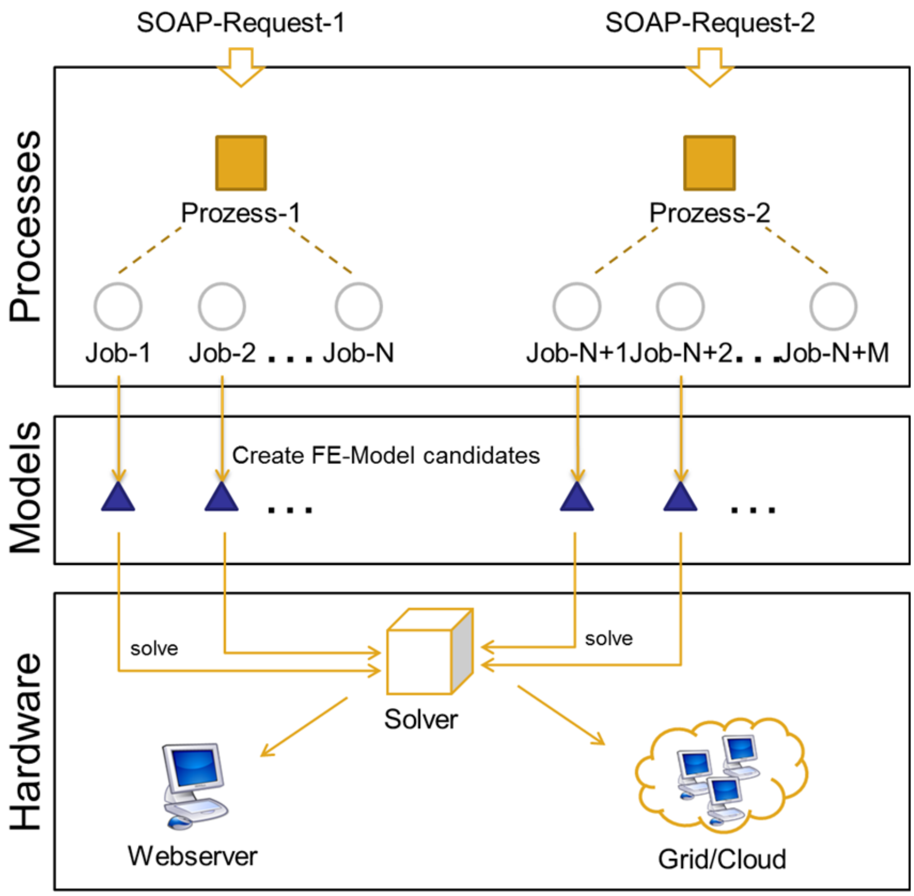

Figure 5: Application Layers in the Cloud Service

4. Service Orchestration and Workflows

In this chapter we describe the principal workflows which will be supported by the cloud-based virtual laboratory. The overall business process supported by ISES is complex, stretching over years, multiple actor roles and various software components. Therefore, to design and implement the platform properly a clear definition of technical workflows and appropriate service orchestration are needed.

In principle, each technical workflow is started by one of the user applications sending a valid login request to the IAS of the VEL 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, the technical (sub) workflows on the VEL are defined. These technical workflows will be applied in appropriate combinations for the handling of each specific use case and lifecycle situation.

4.1 Service Registration

The service registration 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. In the VEL, the Intelligent Access Service is the service registry, provider and the requester similarly. All other services will register themselves at the IAS and can find all registered services.

The binding will be created by the IAS and controlled by the Communication Controller. The controller checks the availability and secures the connections. After this check it transfers data from Service A to Service B and vice-versa.

4.2 User Management

An intelligent user management is important for the ISES business process. There can be many users involved, which can have very different aims. For example, the product designer is not interested in detailed energy aspects of a particular facility but he wants to know the performance of the particular product component in different environments. To cover such interests and control the permission to restricted information, the VEL Core has to provide logins and passwords for each user which will be checked by the registration of persons. Figure 6 shows an overview of the approach in ISES. Users can be registered in the VEL Core with a login name and with a password. In the User Registry this information is stored together with access rights to applications and data. When a user logs in, the VEL core creates a temporary session identifier and creates a cookie in the web browser. Depending on her/his access rights the user can now use all permitted applications without logging in to each of them. Multiple users will be regarded separately with their session identifiers. The user profile shall include information like role in the project, uploaded and released BIM files, eeBIM data, personal settings etc.

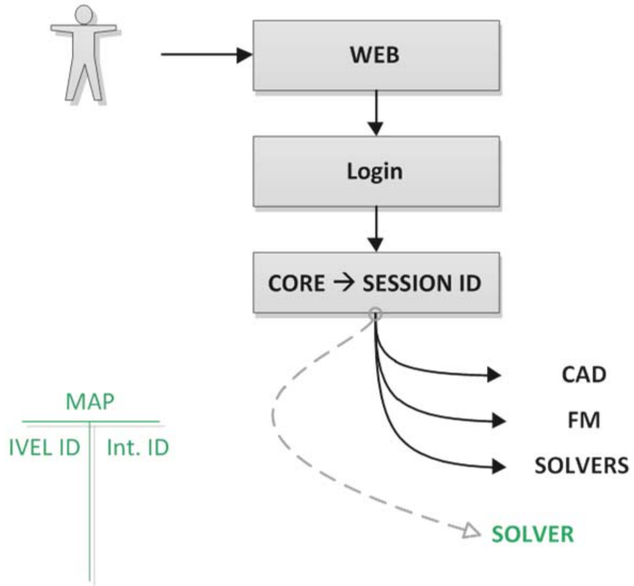

Figure 6: User Management

4.3 Design of Product Host Models (BIM)

At the beginning an architect or product designer is modelling the building information model based on IFC. Therefor he uses the CAD tool of his choice where a product data catalogue is integrated (Figure 7). In ISES we are using as proof of concept the Qbiss catalogue of partner TRIMO where prefabricated components are specified. When the model is completed it is exported as an IFC file which will be uploaded to and distributed by the VEL Core web service.

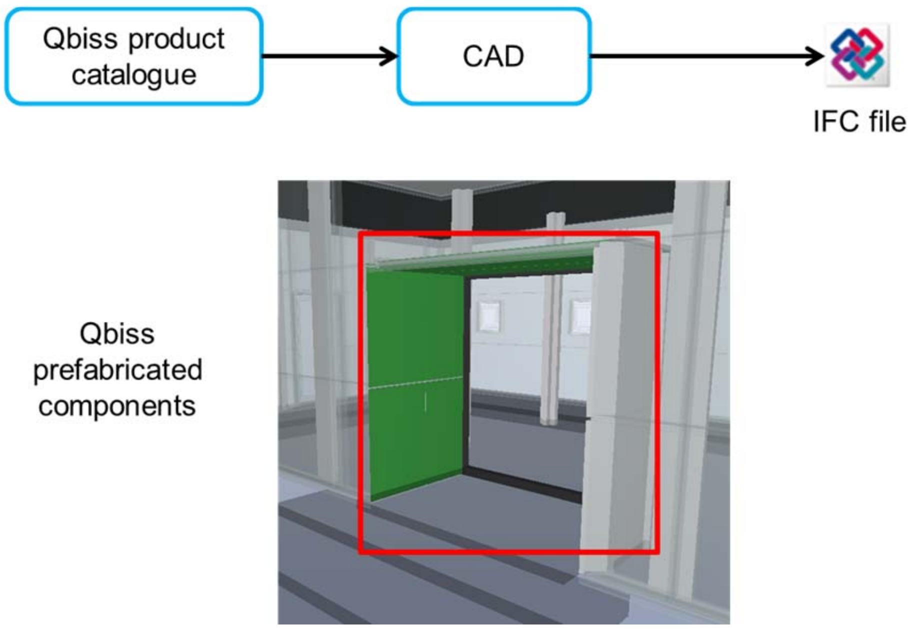

Figure 7: Design with prefabricated components of the product catalogue of ISES partner TRIMO

4.4 BIM Validation and Enhancement

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

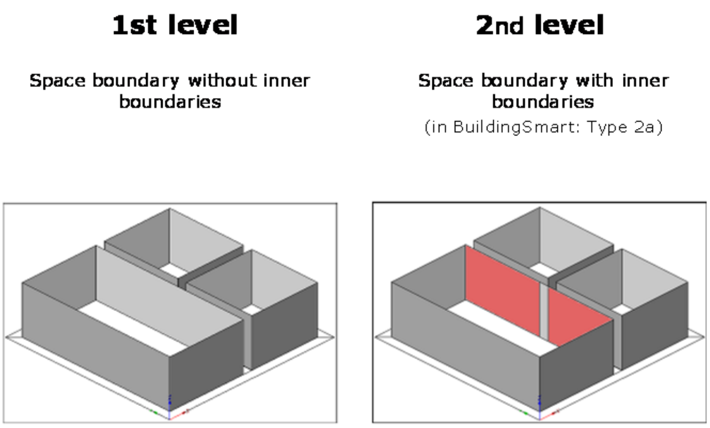

Figure 8: Space Boundary levels (source: buildingSMART)

In ISES, the former problem can be solved by ROOMEX 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 the ISES partner Granlund and called *BSPro*. It converts 1st level to 2nd level space boundaries (see Figure 9 below). This conversion is done geometrically. In HESMOS, we developed the export of a new IFC file which includes the newly generated 2nd level space boundaries and thus enables further eeBIM processing including 2nd level space boundary representation. This development will be used and embedded in the overall ISES process validation.

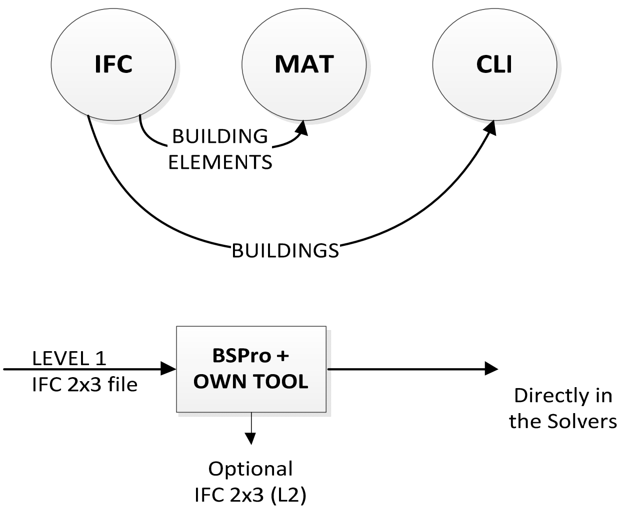

Figure 9: Generating the prerequisites of the eeBIM

4.5 Requirement Management

The requirement management contains functions for defining target schedules for the building energy performance. Mainly two components are used: ROOMEX for room requirements and RYHTI for analysing the building performance. RYHTI is supported by RIUSKA which is an energy analysis tool. Both, ROOMEX and RYHTI are using the IFC file as input for generating the user reports (Figure 10).

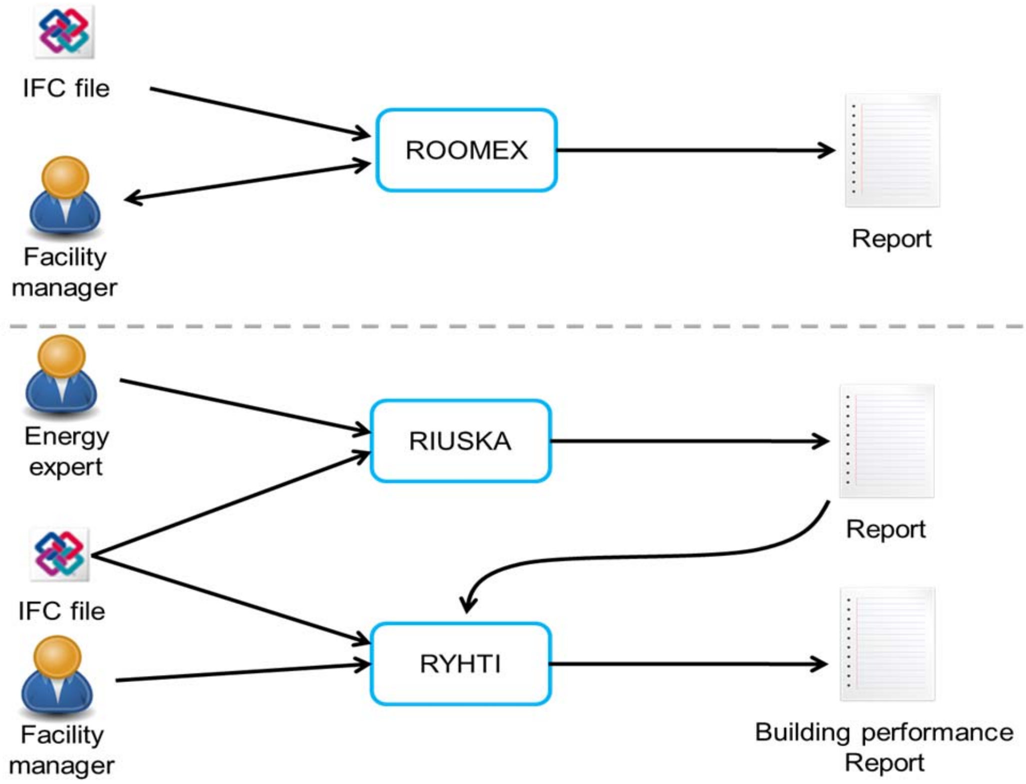

Figure 10: Requirement management for building performance reports

4.6 Common Access Scenario

Common access to the VEL shall be provided to all types of actors considered in ISES. 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 will involve multiple views like the display of energy weak points and improvement suggestions. The data transfer to and from the VEL 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.

4.7 Product Data Model Integration and Mapping

Product data is integrated via IFC as already explained (see Figure 11, bottom). The energy solvers use their own definitions which are mostly different from the BIM definition and the structuring of the product data catalogues. Therefore we will develop a mapping between these definitions (Figure 11, right) so that simulations can be uniformly performed using whatever simulation tool chosen. The mapping is defined via a table (data file) where all mappings will be explicitly defined or encoded by mapping rules that will be enacted at runtime.

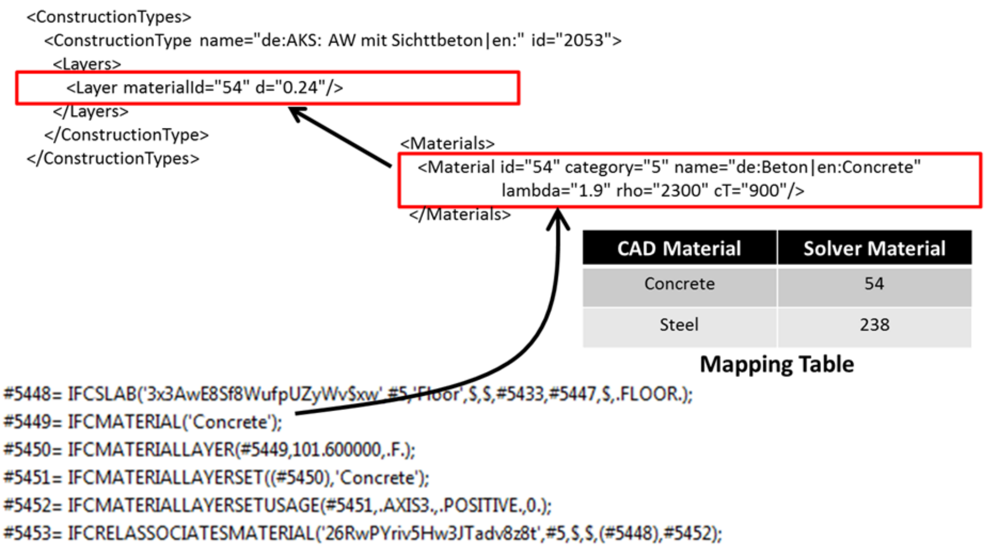

Figure 11: Product data integrated via IFC and mapped to definitions of the solvers

4.8 Simulation Model Configurator

The simulation model configurator creates model variants based on simulation model templates (Figure 12). To enable consideration of stochastic aspects, it can use the stochastic template processor described in section 2.4.4. Placeholders are defining variable parameters which can be replaced by parameters found through the stochastic approach. Figure 13 shows an example excerpt of a template where materials and construction will be included if available and are the outcome of the stochastic processor.

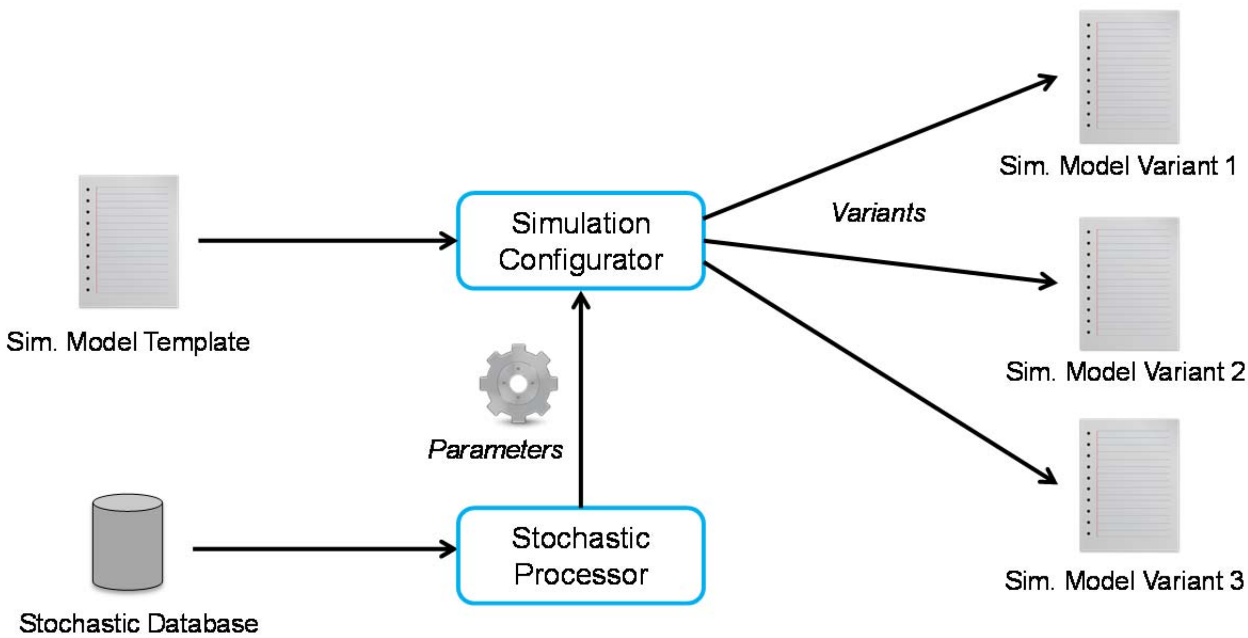

Figure 12: Simulation model variant generation

```
<EmbeddedDataBase>
    #set( $materials = $query.criteria("materials") )
    #set( $constructions = $query.criteria("constructions") )
    <Materials>
    #foreach( $mat in $materials )
        #if ( $mat != null )
        <Material cT="${mat.ct}" category="${mat.category}" id="${mat.id}" lambda="${mat.lambda}" name="${mat.name}" rho="${mat.rho}"/>
        #end
    #end
    </Materials>
    <ConstructionTypes>
    #foreach( $constrtype in $constructions )
        <ConstructionType id="${constrtype.id}" name="${constrtype.name}">
        #if ( $constrtype.hasLayers() )
            #set( $layers = $query.criteria("layers") )
            <Layers>
            #foreach( $layer in $layers )
                <Layer d="${layer.d}" materialId="${layer.materialId}"/>
            #end
            </Layers>
        #end
        </ConstructionType>
    #end
    </ConstructionTypes>
```

Figure 13: Simulation model template

The result of the example is shown in Figure 14 below where eight materials and three construction types are created with their specific attribute values.

```
<EmbeddedDataBase>
    <Materials>
        <Material cT="900.0" category="5" id="54" lambda="1.99" name="Beton" rho="2100.0"/>
        <Material cT="834.0" category="3" id="96" lambda="0.996" name="Altbauziegel (Rand)" rho="1980.0"/>
        <Material cT="900.0" category="11" id="246" lambda="1.0" name="Fliesen mit Mörtel" rho="2000.0"/>
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Figure 14: Interpreted simulation model variant

5. Conclusions

We described an approach for the development of a Cloud-based Virtual Energy Laboratory for life cycle building energy management, which will provide a common platform for all involved actors and gives answer to a number of ICT challenges that have to be dealt with.

Firstly, the suggested VEL can be used by product developers, which allows the development of highly energy efficient and at the same time cost-balanced component products. With the ISES VEL, these products can be tested and validated during the development in the intended hosting facility or even on a number of virtual facility models, thereby supporting differentiated environments and scenarios and hence diversification of the product line. This will close a big gap that exists today and which has been identified as one of the main reasons why the target energy efficiency of component products cannot be fully realised yet.

Secondly, the ISES VEL provides a concurrent computational service to building designers allowing them to test and optimize energy efficiency under virtual stochastic life-cycle conditions. Thus, todays architectural practice of designing buildings independently from their energy analysis done by service engineers, and moreover, by assumed deterministic one-year time histories for the climate can be essentially improved.

Thirdly, the ISES VEL provides an extensive model management supported by ontologies which allows a fast search of model definitions and the reasoning of parameters used for simulations. It includes the stochastic approach conceptually developed also in WP2 and documented in the Deliverable D2.1

Fourthly, the ISES Cloud Service will allow simultaneous processing of a huge number of model variants which are generated with the support of the stochastic approach. This will lead to better and more sophisticated energy simulations, examination of sensitive and weak points in the design and hence to greatly improved architectural and facility developer decision making.

When it is fully developed, the VEL will offer an integrated energy design and testing service platform on open SOA basis with full modelling of any relevant built facilities, thereby enabling the integration of catalogue component products, complex computational methods and BIM.

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Appendix I: Acronyms

AEC	**A**rchitecture, **E**ngineering, and **C**onstruction
BIM	**B**uilding **I**nformation **M**odel/**M**odelling
CAD	**C**omputer-**a**ided **d**esign
eeBIM	**e**nergy **e**nhanced **BIM**
ER	**E**xchange **R**equirement
FM	**F**acility **M**anagement
gbXML	Open **G**reen **B**uilding **XML** schema (industry standard developed to facilitate the transfer of BIM data to a wide variety of engineering analysis tools using the extensible mark-up language XML)
GUI	**G**raphical **U**ser **I**nterface
GUID	**Gl**obal **U**nique **I**dentifier
HTTP	**H**yper**T**ext **T**ransfer **P**rotocol
HVAC	**H**eating, **V**entilation, and **A**ir **C**onditioning
IAS	**I**ntelligent **A**ccess **S**ervice
IDM	**I**nformation **D**elivery **M**anual (ISO 29481)
IFC	**I**ndustry **F**oundation **C**lasses (ISO 16739)
VEL	**V**irtual **E**nergy **L**aboratory
OWL	**W**eb **O**ntology **L**anguage
REST	**Re**presentational **S**tate **T**ransfer
SaaS	**S**oftware **as a S**ervice
SOA	**S**ervice **O**riented **A**rchitecture
SOAP	**S**imple **O**bject **A**ccess **P**rotocol
STEP	ISO standard 10303
TCP/IP	**T**ransmission **C**ontrol **P**rotocol/**I**nternet **P**rotocol
WSDL	**W**eb **S**ervice **D**efinition **L**anguage
XML	e**X**tensible **M**ark-up **L**anguage