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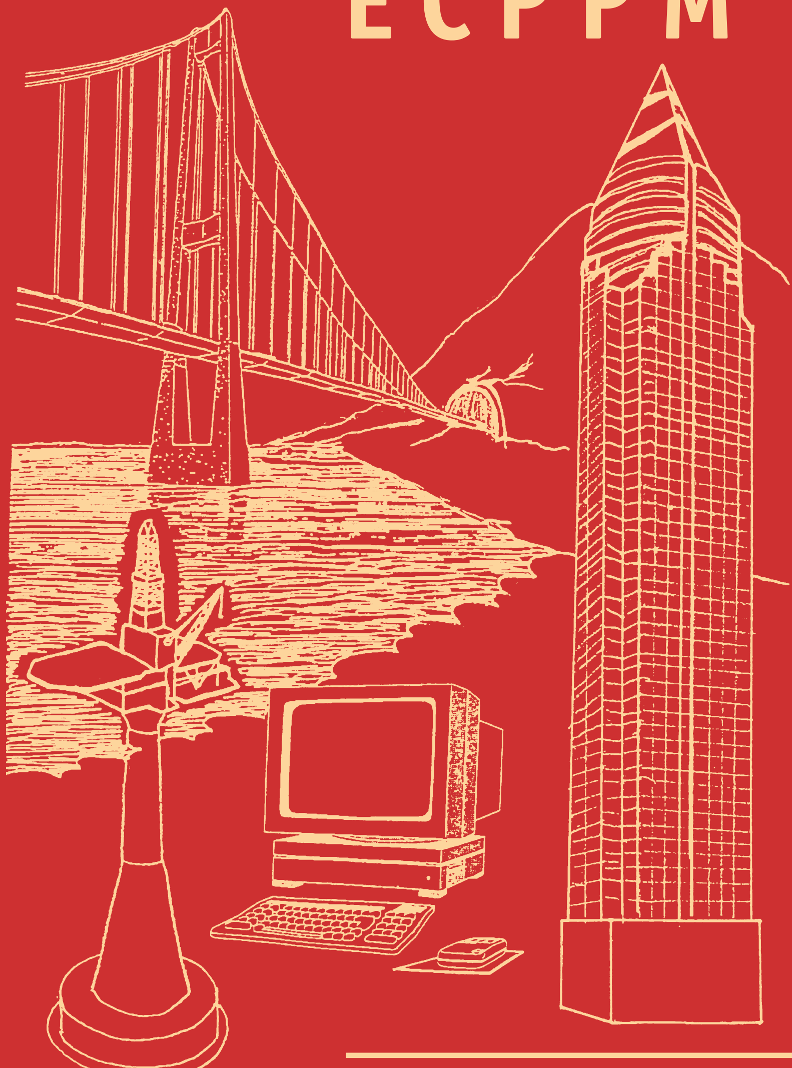

eWork and eBusiness in Architecture, Engineering and Construction

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A BALKEMA BOOK

Edited by Gudni Gudnason and Raimar Scherer

eWORK AND eBUSINESS IN ARCHITECTURE,
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eWork and eBusiness in Architecture, Engineering and Construction

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Preface

Product and Process Modelling is fundamental in facilitating ICT based solutions in the Architecture, Engineering, Construction and Facilities Management domain (AEC/FM). It has been a central and active research and standardisation issue for over 25 years, which underlines the importance of this research field in the development of ICT solutions as support for design, construction and operation of the built environment. Today, it is widely acknowledged that the dynamic and fragmented nature of the AEC/FM industry presents various challenges in developing integrated ICT solutions on similar scale as seen in other manufacturing industries. The undertaking requires collective international collaboration and liaison of researchers, developers and industry experts, which the series of European Conferences on Product and Process Modelling aims to provide.

While significant achievements have been realized in recent years through coordinated RTD roadmaps (ECTP, CIB-IDDS, FIATECH, BuildingSMART Alliance), integrated software development and most importantly international standardisation with regard to Building Information Modelling (BIM) although, still in an early phase. Yet, we are nonetheless a long way from achieving seamless integrated project work, value added life-cycle management and sustainable building and construction. These issues remain challenging research topics, which is well reflected by the two main themes that emerge from the 124 papers published in these proceedings, namely, Building Information Modelling and ICT for energy efficiency.

Overall the proceedings reflect the latest and most current developments and emerging directions in ICT RTD in the AEC/FM domain and provide detailed information on achievements and trends in research, development, standardisation and industry implementation of Product and Process Modelling technology.

The 3rd Workshop on eeBuildings Data Models (Energy Efficiency Vocabularies) initiated by the European Commission was held as part of the ECPPM 2012 for the first time. The workshop was organised by Rogelio Segovia, Unit ICT for Sustainable Growth and the European Projects HESMOS (http://hesmos.eu) and ISES (http://ises.eu-project.info). Previous workshops provided a broad view of the most current and significant results of European research projects focusing on this topic under the FP7 Programme. The 3rd workshop, however, focused on a more specific topic – energy efficiency vocabularies – with the aim to identify vocabularies and ontologies to foster interoperability of ICT solutions for energy efficiency in buildings and energy management systems that also extend beyond the building into public spaces, neighbourhoods and districts. The workshop further analysed their relevance and possible evolution towards formal standards. During the workshop eight European projects presented their results in three sessions' eeBIM, eeBEMS and ee beyond the building.

The 9th European Conference of Product and Process modelling is a joint effort of a strong and active community of academics, researchers, software developers and industry experts who contribute through their scientific participation and provide the drive for the organisation of the conference. We would like to warmly extend our appreciation to this community for making the conference a successful event and to the Programme Committee and the Scientific Committee for their dedication and commitment in ensuring the quality and promotion of the conference. Special thanks go to the team at the Institute of Construction Informatics, Technische Universität Dresden for their support to ECPPM and the hard work in organising the 3rd Workshop on eeBuildings Data Models (Energy Efficiency Vocabularies) as part of the ECPPM 2012. We would also like to extend our gratitude to Dr. Alain Zarli and Prof. Robert Amor for their unselfish contribution to the conference organisation.

Gudni Gudnason, Innovation Center Iceland
Raimar J. Scherer, Technische Universität Dresden
May 2012

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Keynote speakers

Dr. Martin Fischer, Professor and Director of Center for Integrated Facility Engineering at Stanford University

Martin Fischer is Professor of Civil and Environmental Engineering at Stanford University. He also serves as the Director of the Center for Integrated Facility Engineering (CIFE). CIFE is the world-leading, industry-sponsored, academic research centre on virtual design and construction. Dr Fischer is known globally for his work and leadership in developing virtual 4D modelling (time plus 3D) methods to improve project planning, enhance facility life-cycle performance, increase the productivity of project teams, and further the sustainability of the built environment. His research results have been used by many small and large industrial and government organisations around the world. He has lived and worked in Europe, South America, North America and Asia. Dr Fischer holds a PhD in Civil and Environmental Engineering and a MS in Industrial Engineering from Stanford University, and a Diploma in Civil Engineering from the Swiss Federal Institute of Technology in Lausanne, Switzerland.

Ilkka Romo, Vice President of Research and Development, Skanska Finland

Prior to his position as Vice President of Research and Development, Ilkka Romo was the head of Skanska's Global BIM Competence Center which is located in Finland. The Competence Center develops BIM applications, shares knowledge and organizes BIM training in Skanska globally. He is also in charge of R&D in the Business Unit Skanska Finland. Ilkka has worked for Skanska from 2006 being responsible for BIM development and implementation in Finland and Nordic BIM coordination (2006–2008). Before Skanska he worked for the Confederation of Finnish Construction Industries RT, leading the Confederation's R&D projects, including the Pro IT project (2001–2005) which developed and contributed national BIM design and production guidance and practices in Finland.

Dr. Thomas Liebich, AEC3 Germany

Dr. Thomas Liebich is the owner of AEC3 Germany, a consulting firm delivering dedicated services for specifying and applying building information modeling and interoperability for more than 10 years. He is leading the buildingSMART International team for developing the Industry Foundation Classes (IFC) as well as developing many services to facilitate their implementation, including simple ifcXML, mdvXML and currently the buildingSMART certification 2.0 program. Major projects he carried out in his professional career include the world's first automatic code checking system in Singapore, the CAD/GIS integration project in Norway, the technical support for the first international architectural contest requiring openBIM – the National Museum in Oslo Norway, and the development of the openBIM guidelines and validation process for the Army Corps of Engineers in Germany. He is the co-author of the recent expert report for the German construction ministry (BMVBS) about the influence of BIM on the scope of services and contractual arrangements for architects and engineers.

Thomas Liebich holds a PhD from the Bauhaus University Weimar. He has been involved in many leading R&D projects, including the recent EU projects InPro (open BIM environment) and Hesmos (energy-enhanced BIM framework) and the German Mefisto project (multi-model BIM collaboration).

Dr. William (Bill) East, Engineer Research and Development Center, U.S. Army Corps of Engineers

Dr. Bill East is Research Civil Engineer at the Engineering Research and Development Center's office in Champaign Illinois. Bill has put research into collaborative workflow into practice through a cloud computing suite for public design and construction. This platform currently supports over 50,000 public project stakeholders and is an experimental platform to conduct applied research. He is buildingSMART alliance project coordinator, where his Construction-Operations Building information exchange, or COBie, project is part of the US National BIM Standard. In the United Kingdom COBie is now mandated for public projects. Bill's leadership of the Specifiers' Properties information exchange, or SPie, project facilitated the publication of the first US consensus product data models. Bill has received awards from the U.S. Army Corps of Engineers, Federal Laboratory Consortium, Construction Specifications Institute, National Institute of Building Sciences, and the American Society of Civil Engineers where he is a Fellow. Bill is a licensed Professional Engineer. Bill's degrees in Civil Engineering are from Virginia Tech and the University of Illinois.

Mr. David Foley, Deputy Commissioner, Public Buildings Service U.S. General Services Administration

David Foley was appointed as Deputy Commissioner of the Public Buildings Service (PBS) of the United States General Services Administration on March 22, 2010. He serves as the Chief Operating Officer in charge of the PBS portfolio, project delivery and real estate acquisition, as well as maintaining a unified organizational structure and managing relationships with major customers. Mr. Foley also plays a key role in successfully executing PBS' $5.5 billion worth of American Recovery and Reinvestment Act projects, managing the associated funding and implementing the requirements.

Mr. Foley has served in key leadership roles in the Public Buildings Service since 1997. Prior to being named as Deputy Commissioner, he was the Deputy Assistant Commissioner for Portfolio Management. In this position he was responsible for portfolio analysis, policy and strategic planning for GSA's owned and leased building inventory. Mr. Foley has extensive regional experience as well working in several GSA regional offices including Atlanta and Kansas City, Missouri. His primary focus was in the areas of asset and facilities management and performance measurement. He began his career with GSA as a Management Intern in the Dallas, Texas field office.

Mr. Foley is a graduate of Missouri State University and has a MBA from Virginia Tech. He is a native of Missouri, and is married to April Foley. They have one son and reside in Fairfax, Virginia.

ICT for energy and building simulation

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System analysis and coupled modeling: toward integrated performance assessment of industrial facilities

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ABSTRACT: Traditionally, the main focus of the management and professionals in the industrial sector was to continuously increase the productivity, reliability, flexibility, and quality of the industrial process. More recently, increasing attention is being paid to the energy efficiency of the production process as well as the environmental performance of the production buildings. In this context, this paper presents results of a research effort concerned with a comprehensive computational environment for the integrative assessment of industrial production facilities. Specifically, characteristics and systems of such an environment are analyzed, including relevant entities and their representations, associated data exchange requirements, and coupled multi-domain modeling and simulation tools. Additionally, the potential benefits of coupled simulation are presented based on an illustrative parametric simulation case study of an industrial production facility.

1 INTRODUCTION

Manufacturing companies increasingly face challenges concerning the sustainability of their production facilities. Main contributors to this circumstance are rising energy prices on the one side and increased sensitivity to environmental impact on the other side. Traditionally, the main focus of the management and professionals in the industrial sector was to continuously increase the productivity, reliability, flexibility, and quality of the industrial process. Less emphasis was placed on the energy efficient design of production processes and facilities (Schröter et al. 2009). More recently, however, increasing attention is being paid to the energy efficiency of the production process as well as the environmental performance of the production buildings. Numerous studies explore the potential of certain industry branches in terms of energy and resource efficiency increase (Pardo Martinez 2010, Thollander et al. 2010, Leobner et al. 2011a). To support this rapidly emerging necessity for a comprehensive (both economical and environmental) assessment of industrial buildings, the respective current practices in representation, analysis, and evaluation must be advanced. The present contribution presents a related effort in this direction: a comprehensive computational environment for the integrative assessment of industrial production facilities is envisioned (Info 2011). Following up on previous studies (Dorn et al. 2011, Kovacic et al. 2011), this paper explores the characteristics and systems of such an environment, including relevant entities and their representations, associated data exchange requirements, and coupled multi-domain modeling and simulation tools. Additionally, illustrative simulation results of two sub-systems are presented.

2 SYSTEM ANALYSIS

The system analysis involves the identification of the relevant system factors and entities, including physical components such as buildings and their technical systems (energy supply, heating, cooling, ventilation, and lighting) as well as industrial production machines and devices. Moreover, boundary conditions and constraints pertaining to environment, economy, and social aspects are considered. Certain system elements are of immediate relevance for the coupled simulation of a facility's thermal and visual performance. Respective model components (or sub-models) of such elements pertain to the productions process, thermal behavior of the building fabric, HVAC systems (heating, ventilation, air-conditioning), lighting controls, etc. Each of these sub-models may be assumed to have both a number of parameters (or fixed attributes) and a set of variables with changing values (dynamic properties). Sub-models are to be realized in terms of respective simulation applications. Once sub-models are coupled, data exchange between them is facilitated. In a coupled simulation scenario, the facility's sub-models dynamically exchange the values of the pertinent variables toward simulation of the facility's (energetic, thermal, and visual) performance. Sub-model parameter attributes (e.g., thermal properties of walls and windows) do not change in the course of a simulation run. Within the framework of system analysis, 16 different components were identified, which are likely to exist in most industrial facilities. These 16 components are shown in Figure 1 (oval elements). Thereby, we distinguish between physical components (solid lines) and information components (dashed lines). Physical components include the building envelope, machinery, people, systems, etc. Information components denote strategies, algorithms, political factors, etc. Connecting lines denote component coupling, which accommodates data exchange between sub-models. Additionally, three sources of information (basic client requirements, building structure, and building services) have been considered in the scheme, which supply components with parameter attributes.

The relevant system components and their characteristic features are described in the following:

Environment (E)

This component depicts environmental influences, especially (standard) weather conditions at the factory location. It has one-way connection to the simulation environment (it provides data, but does not receive any input information).

Thermal building model (TBM)

The model computes indoor thermal conditions for various building zones. The model's heat balance equations take radiant and convective effects at surfaces (interior and exterior), conduction through building components, and convection within the zones as well as with the outdoor environment into account. Calculations are done repeatedly for all time steps within a specified simulation period. Fixed attributes of this model include the building structure, building location, thermal zone information (floor area, volume, area of building elements, and tightness of the envelope) and material properties of building components. Further input data (supplied by other components), which changes during the simulation process, includes weather information, heat emissions of machines, equipment, people, and HVAC components.

Thermal energy supply (TS)

The component "Thermal energy supply" contains all equipment used to supply thermal energy (production, storage, distribution) for heating, cooling, and ventilation of the building's zones, water preparation, and – if necessary – process heating and cooling (machines and large computer systems). This models must be flexible enough to accommodate different technical solutions for the provision of the production facility's thermal energy demand. An extensive model library with different energy conversion, storage, and distribution systems is needed.

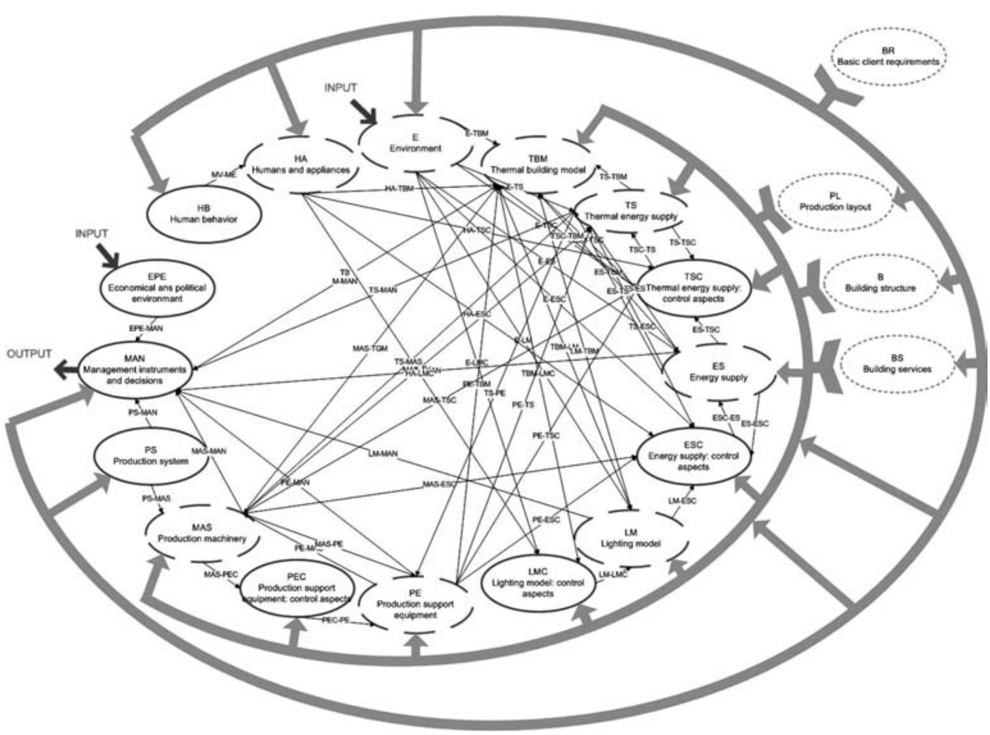

Figure 1. A general scheme for the representation of processes and associated information exchange requirements in industrial facilities.

Thermal energy supply: control aspects (TSC)

This component describes the control strategies that are applied to all the equipment related to the thermal energy supply, no matter if they are implemented in automation systems or deployed manually.

Energy supply (ES)

"Energy supply" denotes the supply of machines or equipment with non-thermal energy resources (usually electrical, chemical, and mechanical). This includes external supply, internal production, storage, and distribution. Simulation model requirements are similar to those of the model "Thermal energy supply".

Energy supply: control aspects (ESC)

The strategies represented by this component coordinate the cooperation of the equipment contained in the component "Energy supply" in order to cover the non-thermal energy demand of all other components.

Lighting model (LM)

The model calculates the available illuminance levels within the building. It takes daylight, artificial light sources, and shading devices into account. Fixed attributes of this model include the building structure, its location, external obstacles, building components properties, and luminaires. Further input data, which can change during the simulation process includes weather information, the status of the light sources (on/off, dimming level) and shading devices as provided by other models or components.

Lighting model: control aspects (LMC)

This component describes the strategies applied to provide illumination and prevent glare by using the devices contained in the "Lighting model" component.

Production support equipment (PE)

This component contains equipments and resources needed to support the production machinery and the production process. This includes, for instance, auxiliary supply systems (pressurized air, lubricants) or logistic devices.

Production support equipment: control aspects (PEC)

This component describes operation strategies for the component "Production support equipment".

Production machinery model (MAS)

The model calculates heat emissions and energy demand of machines and equipment, which are involved in the production process within the industrial facility. Machine types include milling and turning machines, laser cutting machines, and curing ovens. Information on resulting heat emission rates are provided to the building fabric model. A challenging part of model development in this field is to relate the energy demand of the production machinery to the produced goods. Since full physical models for the machinery would be far too complex for the coupled simulation, empirically-based data models would be needed. However, respective correlations are difficult to derive, especially in factories with flexible production systems and small batches.

Production system (PS)

The production system describes the production planning and scheduling as well as the processes. The information contained in this component allows estimating the utilization of machines and equipment for any certain period of time.

Management instruments and decisions (MAN)

This component connects the technical and financial key data provided by the other components in order to assess the system layout with respect to economical criteria (operating results) and ecological criteria (climate relevant emissions). It is an output component, which processes the simulation results and delivers them in the form that is useful to decision makers. The component has no output variables back into the modeling environment.

Economical and political environment (EPE)

Here, pertinent factors pertaining to the economical and political environment are described. These factors are essential for the "Management instruments and decisions" component in view of processing the simulation results. This is an input component that cannot be influenced by the system.

Human behavior (HB)

Human behavior considers when (and how many) people are present, where they are in the building, what they do, and which appliances (not production machinery) they operate.

Human and appliances (HA)

This part of the system describes the direct measurable influence due to the presence and activities of people in the building and the appliances they operate (e.g., computer, coffee maker).

3 DATA EXCHANGE

The scalability and flexibility requirements of the envisioned assessment environment imply that the implementation is modular and accommodates explicitly specified data exchange between constituent system components. Furthermore, the dynamic behavior

Table 1. Facility's sub-models and corresponding simulation applications.

	Sub-model	Simulation environment
1	Production machinery model	Matlab
2	Building fabric model	EnergyPlus
3	Lighting model	Radiance
4	HVAC systems model	Dymola

and interdependency of components makes a continuous data exchange during the simulation run indispensable. Specifically, we considered the necessary exchange of data between multiple computational routines that would allow for the assessment of industrial buildings' aggregate energy performance due to both industrial production processes and buildings' thermal performance. This is unlikely to be achievable within a single homogenous computational application (Leobner et al. 2011b). Thus, to implement a multi-routine environment and the corresponding data exchange processes, the "Building Controls Virtual Test Bed" (BCVTB) is considered (BCVTB 2012, Wetter 2011a). This is based on the Ptolemy II software environment. It allows users to couple different simulation programs (Wetter 2011b). BCVTB is currently linked with EnergyPlus, Dymola, Radiance, Matlab, Simulink, and BACnet, enabling co-simulation with a fixed time step. Within the framework of the present research project, a number of specific sub-models are selected. Their respective simulation environments are to be coupled via BCVTB. The following Table summarizes these sub-models together with the respective simulation environments.

4 ILLUSTRATIVE SIMULATION EXAMPLE

To demonstrate and explore the utility of a coupled modeling environment for industrial production facilities, we focus on thermal processes involved. Thereby, two sub-models were generated, addressing *i*) heat emission of production machines (MAS) and *ii)* thermal and visual processes pertaining to building fabric and lighting devices (TBM).

The starting point is the analysis of an existing production facility in terms of work flows (delivery, storage, and production), energy flows, emissions (oil, dust, humidity, noise, and heat losses), and occupancy parameters (working hours and shifts for offices and production). Measurements of the heat emissions from the machines (lasers, machine centers, etc.) were conducted over a period of multiple weeks and provided the empirical basis for the respective production machinery model. The collected information was further processed to develop an adequate architectural layout for a new building (see Fig. 2). This layout provides the basis of the initial building performance simulation model generated with the designated thermal simulation tool (EnergyPlus 2011).

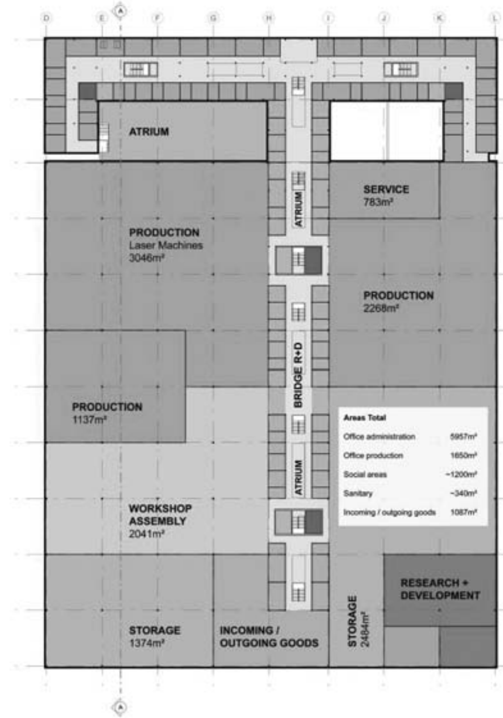

Figure 2. Floor layout in the new facility design.

Given the TBM sub-model, parametric thermal simulations were conducted to compute the relative impact of various design and operational scenarios. Accordingly, a number of scenarios were generated, as summarized in Table 2. They pertain to façade type, window area (in terms of the percentage of glazing in the façade), the assumed air change rate (with effective air change rates ranging from 0.2 to $1\,h^{-1}$), as well as the presence or absence of lighting and shading controls. The lighting control scheme operates the electric lights according to the availability of daylight, and maintains an indoor illumination level of 250 lx. The shading control option operates the shades once the incident irradiance on the façade goes beyond $120\,W \cdot m^{-2}$. Descriptions of different façade types are summarized in Table 3.

To execute the parametric simulations, the TBM sub-model needed to communicate with the MAS sub-model in order to obtain valid data on the effective heat emission rate of the production machines. While this link has not been fully implemented yet in the BCVTB environment, it was emulated here (via file-based data exchange) to explore the benefits of a coupled modeling regime.

The simulation results, i.e., the production facility's annual area-specific cooling and heating loads $[kWh \cdot m^{-2} \cdot a^{-1}]$, are shown in Figures 3 and 4 for all scenarios (Table 2).

This illustrative example shows the impact of different design and operational options (e.g., ventilation

Table 2. Scenarios for simulation runs.

	Facade type	Percentage of glazing [%]	Additional polycarbonat [%]	Summer ACH [h^{-1}]	Winter ACH [h^{-1}]	Lighting control	Shading
S1	A	10	–	1	0.2	YES	YES
S2	A	15	–	1	0.2	YES	YES
S3	A	20		1	0.2	YES	YES
S4	A	10	25	1	0.2	YES	YES
S5	A	10		1	0.2	NO	NO
S6	A	15		1	0.2	NO	NO
S7	A	20		1	0.2	NO	NO
S8	A	10	25	1	0.2	NO	NO
S9	B	15		1	0.2	YES	YES
S10	B	15		1	0.2	NO	NO
S11	C	15		1	0.2	YES	YES
S12	C	15		1	0.2	NO	NO
S13	C	15		0.5	0.5	NO	NO
S14	C	15		0.2	0.2	NO	NO
S15	C	15		0.5	0.2	NO	NO
S16	C	15		1	0.2	YES	NO
S17	C	15		1	0.2	NO	YES

Table 3. Variation of façade options.

Façade type	Exterior panel	Insulation	U-value [$W \cdot m^{-2} \cdot K^{-1}$]
A	Metal	Mineral wool	0.26
B	Metal (zinc coated)	Polyurethane foam	0.1
C	Metal (zinc coated)	Wood fiber insulation panel	0.27

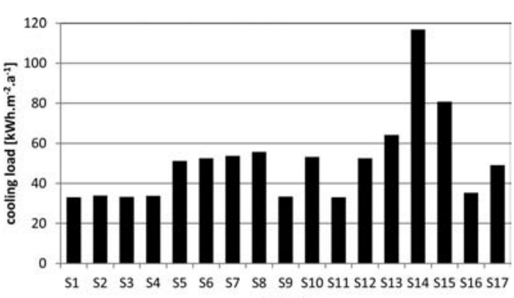

Figure 3. Simulated annual cooling load for all scenarios [$kWh \cdot m^{-2} \cdot a^{-1}$].

rates, lighting and shading control) on the indoor climate and energy performance of the industrial facility studied. Specifically, the results underline the relative importance of the cooling loads (as compared to heating loads), which is a consequence of the production machines' high heat emission rates (modeled via the MAS sub-model). On the other hand, scenarios pertaining to different façade types did not show a noteworthy impact on the thermal performance of the industrial facility. The results of the coupled simulation underline the importance of effective operation regimes (for lighting, shading, and ventilation system).

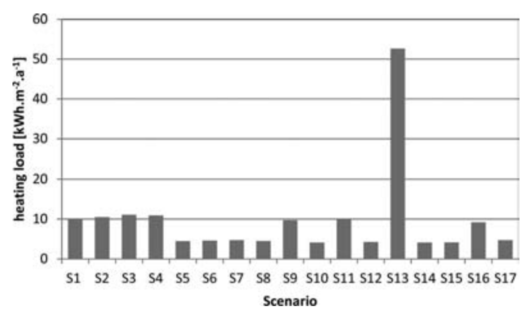

Figure 4. Simulated annual heating load for all scenarios [$kWh \cdot m^{-2} \cdot a^{-1}$].

5 CONCLUSION AND OUTLOOK

This paper presents a detailed system analysis toward a coupled multi-domain simulation environment for production facilities. The goal is to evaluate a production facility not separately for individual mandates pertaining to production process, building envelope, and systems, but in a coupled and integrated fashion. As the starting point, multiple sub-model specifications have been generated including the production process, the thermal performance of the building, the HVAC systems, the management instruments, etc. For data exchange between the separate models, the "Building Controls Virtual Test Bed" (BCVTB) was considered. The potential benefits of coupled simulation were explored based on an illustrative parametric simulation case study of an industrial production facility.

Currently, work is being done to implement two sub-models for energy supply and building services using the simulation environment Dymola. Thereby, the complexity of the existing Modelica-libraries for building simulation represents a challenge in view of

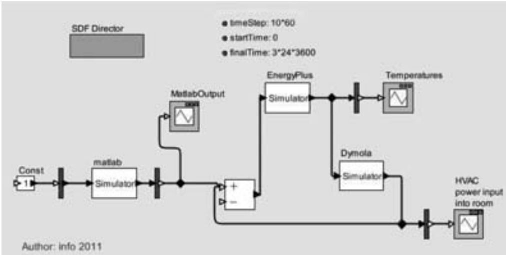

Figure 5. Example of coupled sub-models in BCVTB environment.

prolonged simulation runs and decreased stability. Additional implementation work shall address the effects of a waste heat recovery system from the production machinery on the facilities' thermal energy performance.

Further ongoing work involves a fully implemented coupled model consisting of a thermal performance sub-model (using the EnergyPlus application), an energy supply- and heating system model realized in Dymola (Dymola 2011), and a production machinery model (generated in Matlab). Thereby, the BCVTB environment is being utilized for data exchange between the sub-models (see Fig. 5). The experiences made in this process will be used in further steps toward a fully coupled simulation and analysis environment for the comprehensive (multi-aspect) evaluation of industrial production facilities.

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Design and software architecture of a cloud-based virtual energy laboratory for energy-efficient design and life cycle simulation

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ABSTRACT: Today, built facilities consume nearly 40% of the global energy and produce about 30% of CO_2 emissions and solid waste. To decrease these rates, the evaluation, simulation and optimisation of energy efficiency of products for built facilities and facility components should be performed in various real-life scenarios before their actual use in practice. This paper presents a suggested Virtual Energy Laboratory where the involved multiple players can monitor the energy efficiency of a facility in all phases of the building life cycle by examining simultaneously various climatic, usage and design variations. To enable such simulation studies the Virtual Laboratory will provide for a huge number of parallel computations with varying simulation parameters from product data catalogues, climate data, user profiles and BIM model data using cloud technology. Moreover, it will also allow examining energy relevant product components like HVAC equipment or façade elements in different virtual building scenarios by simultaneously running simulations of the same component on different BIM data or climatic conditions. The paper describes the first steps of the Virtual Laboratory realisation including the developed principal software architecture and a first rapid prototype implementation. The presented work is done in the frames of the EU projects HESMOS (2010–13) and ISES (2011–2014).

1 INTRODUCTION

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

Taking these issues into account the EU project ISES (2011–2014) develops an industry-driven holistic approach for sustainable optimization of energy performance and emissions reduction through integrated design and simulation, while integrating, complementing and empowering existing tools for design and operation management (FM) to a Virtual Energy Laboratory (ISES, 2011). In this paper, we describe the overall development approach, the developed principal software architecture and a first rapid prototype implementation of the Virtual Laboratory (VL), which provides a first proof of the concept and the expected benefits.

2 OBJECTIVES AND CHALLENGES

The major objective of the research is to make use of existing advanced ICT tools like CAD systems, facility management systems (FM), energy simulation, moisture calculation, fluid dynamic analysis and cost calculation tools, Building Information Modellers (BIM) and Building Automation Systems (BAS), which are all strong in their core business but mostly stand-alone, loosely integrated applications, and:

1. Provide them with a sound interoperability structure on ontology-extended BIM and SOA basis through development of a new system ontology;
2. Complement them 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;
3. Provide a new information logistic and intelligent access controller for the ICT system management (services, tools and data) and for the interfacing to cloud facilities thereby enabling parallel computation of alternatives and/or parameter variations;
4. Extend existing data resources by three currently missing databases, namely stochastically based climatic data scenarios and usage/user activity profiles, both structured and formalised according to

the stochastic life-cycle demands, and a database variant manager for alternatives and variations of new product designs.

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 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.

3 ICT STATE OF THE ART IN ENERGY EFFICIENT DESIGN AND LIFE CYCLE SIMULATION

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 very 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.

Whereas 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 involved actors in a 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 (Wix & 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 scheme 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 & 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 a service (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 yet available.

4 OVERALL DEVELOPMENT APPROACH

We define three major user roles and respective usage scenarios for the VL, 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 VL 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 build the VL as an open cloud platform based on eeBIM and FM-CAD, extended by the development of missing functionalities and services for intelligent access to ICT control systems on the one side and advanced energy analysis and simulation tools on the other side.

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, and (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).

This means for the design of the new product (HVAC component, façade element etc.) that 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 below). 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 subcycle 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.

The VL is principally structured into *four main tiers* as well as two supporting tiers (see Figure 1). The process is organized in two feedback cycles, one for handling the stochastic life-cycle nature of climatic and usage conditions and one for the optimisation of the design – to lay out the most beneficial variants for the new product and to select, configure and assemble the right product variants in the designed or refurbished building facility.

The *first tier* (Figure 1, from left to right) is the domain modelling and input tier to the VL. It comprises tools and databases for (1) the modelling of the

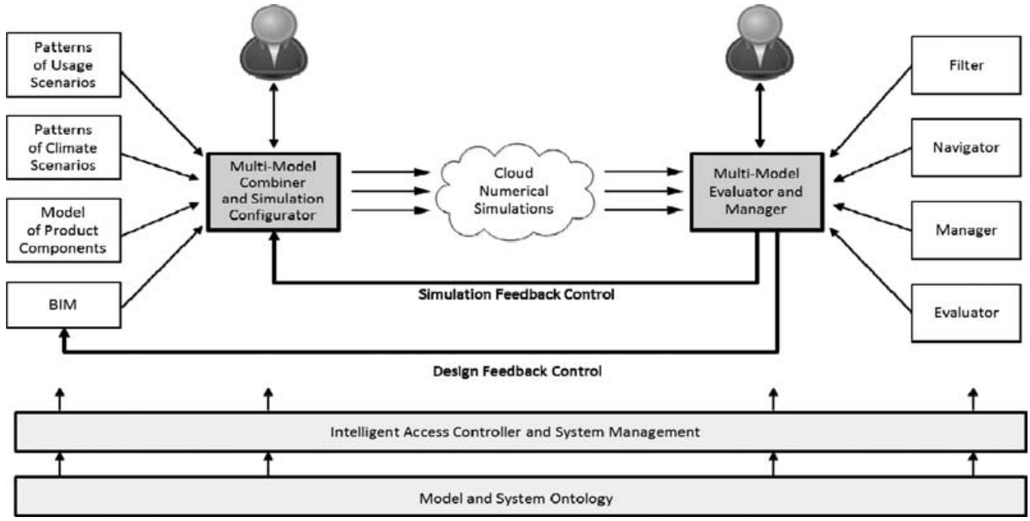

Figure 1. Logical structuring and functionality of the VL.

new product, (2) the modelling of the built facility, (3) the modelling of the energy profiles, and (4) patterns of energy consumption, i.e. the climate and usage scenarios. These four domain models 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, at least for the simulation feedback, have to be carried out highly automatically. 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 easy 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 VL platform. However, the end user attention should thereby be focused 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 VL 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.

5 CURRENT DEVELOPMENTS AND RESULTS

The outlined principal approach poses various technological challenges that need to be resolved, especially

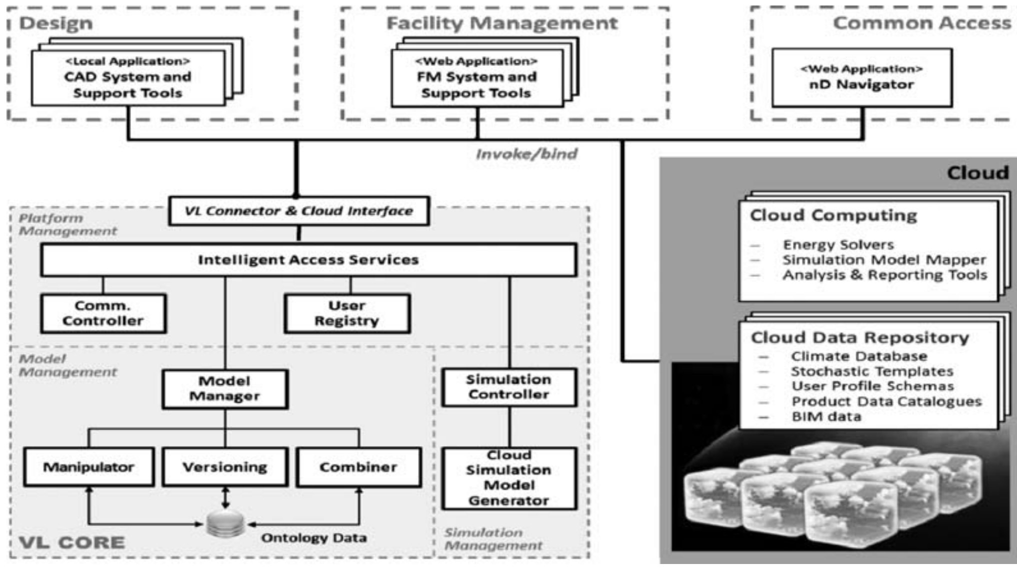

Figure 2. Software Architecture of the VL.

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 VL platform have been realised. They are presented in the following sections of this chapter. Planned further work is discussed in the concluding chapter of the paper.

5.1 *Principal Software Architecture*

Figure 2 shows a generalised view of the developed software architecture of the VL 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 VL platform.

Overall, the architecture applies the SOA concept, following a general modular approach. It comprises several types of services and applications, bound together by a VL 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:

1. *Design module*, comprising a BIM-based CAD system and supporting tools capable to produce and export IFC model data (main users are architects and other building designers).
2. *Facility management module*, comprising a FM system and related FM and costing tools (main users are the facility managers and operators).
3. *Common access module*, providing a general-purpose interface to the VL via an nD Navigator and enabling light-weight easy-to-do studies of the building performance with regard to energy and life cycle costs (the intended main users are product developers, but it can be freely used by all other identified actors). In this module, it is also possible to change simulation parameters like product data and load templates for calculating different variants.
4. *Cloud computing module*, providing the energy related analysis and simulation services and tools, a simulation model mapper 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 is suggested.
5. *Cloud data repository*, providing access to several distributed information resources like product data catalogues, climate data bases, stored stochastic templates and user profiles as well as BIM data.

Each of these modules, with the exception of the *VL Core Module* described further below, is principally exchangeable due to the existing standardised data models and the developed information exchange specifications and APIs. The VL Core 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 a so-called *VL Connector*, which offers a homogeneous interface via SOAP technology.

5.2 *Components of the VL Core*

The VL Core comprises a set of specialised middleware services that provide for user registration, data manipulation and the workflow of energy simulations. It is responsible for various data manipulation tasks such as model mapping, model conversion, multi-model linking, filtering and model versioning enhanced with business logic based on a link model to allow the adaptation and (semi-)automatic execution of user workflows. It is logically subdivided into three layers: (1) platform management, (2) simulation management and (3) model management.

The interface to the VL Core is provided by the *VL Connector* and the supporting *Intelligent Access Services*. The VL Connector binds all external distributed services and tools and can be accessed via the web in homogeneous manner. It is a service requester and a service provider at the same time.

The *User Registry* 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.

The *Communication Controller* is dedicated to the management of the communication between (web) applications and web services. It tests the status of a requested web service and, if reachable, routes 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.

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.

The *Cloud Simulation Model Generator* enhances the Simulation Controller by creating multiple tasks to enable concurrent computing, thereby enabling parallel simulation of many possible variants by applying the cloud computing paradigm based on the *Hadoop* framework (Apache Software Foundation, 2011).

The *Model Manipulator* checks if the IFC model fulfils the minimal requirements of an energy simulation and enhances it as far as 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 the performance of the simulation. Consequently, it is possible to simulate easily energy requirements or performances for one building storey or only some specific rooms of the investigated facility.

The *Multi-Model Combiner* 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 use the system ontology, which captures and resolves references to the linked models following and extending the suggestion from (Fuchs et al., 2010).

Finally, the *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.

5.3 *First rapid prototype implementation of the VL*

The presented concepts and technical components of the suggested Virtual Energy Laboratory are still in an early development phase. Nevertheless, a first rapid prototype implementation of the VL featuring the integrated use of a CAD system, components of the VL Core and the nD Navigator and two integrated simulation tools is already available. It does not yet involve Cloud Computing facilities but is otherwise fully compliant to the technical software architecture described in the previous sections of this chapter. The linkage of the involved data to a consistent modelling framework is provided via the link model, which is part of the system ontology, still under development. It is currently implemented as a XML schema where models are connected via their URIs, and elements in a model via their provided identifiers. To enable higher semantic content, we will enhance it later to an OWL-based system ontology where data can be enriched and verified on the fly. Basically, in the current targeted scenarios links must be established to catalogue product data (e.g. to façade building elements), the original IFC file from CAD (BIM version 0), manipulated IFC files (BIM versions 1…n) including conversion to second level space boundaries from the first level space boundaries in the original architectural BIM (cf. Weise et al., 2011), user profiles for each room in the facility that has to be examined, climate data for the location of the facility and templates for energy requirements.

We developed a simulation model generator, which extracts these data from their respective distributed data sources and converts them to the target schema of the energy solvers. By generating the simulation model, we map materials from one database to another because the provided material information in CAD systems differs from the energy solver databases. Figure 3 below shows an excerpt of the generated model with regard to the IFC schema. We take geometric information like room height and room area, which are implicit data in IFC, by evaluating the space boundaries of the rooms. The prerequisite is that the model must contain second level space boundaries (Weise et al., 2011). However, this is typically not the case. Therefore, we use and extend the existing tool BSPro (cf. Olof Granlund Oy, 2012) to generate the second level space boundaries and write them back in the IFC model. Further implicit data to be generated are the

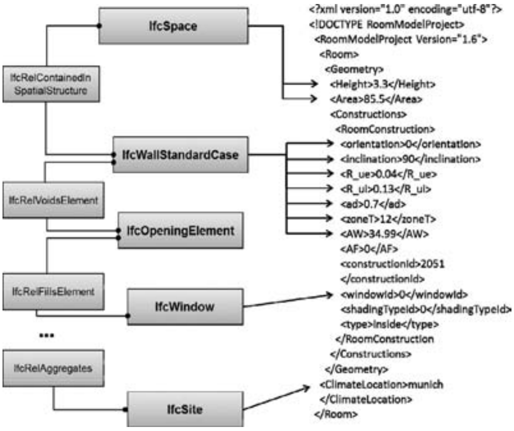

Figure 3. Simulation Model Generation.

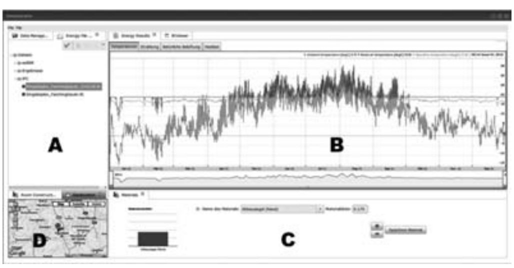

Figure 4. Screenshot of the GUI of the implemented first rapid prototype of the VL.

net areas of building elements. Explicit information in the model comprises the building elements themselves, their designated material construction and the relationships between them.

The implemented first platform prototype is deployed on a server within the HESMOS project and can be accessed via web browser by the VL users (Laine et al. 2012). Figure 4 shows an example screenshot of the current partial navigator GUI. The application provides upload and selection of IFC files (section A in Figure 4) and of simulation results. Additional information like geographical position of the facility and add-on semantic data are displayed in section D. Simulation results are visualized in the main GUI window (section B) and show, for example, the temperature profile of a selected room for one year as well as the aggregated deviations from the set usage requirements. Section C is a property view where certain parameters of the simulation model can be manually modified to run an alternative simulation. This is especially important when different design or refurbishment options regarding for example the use of different materials, different thickness of insulations etc. need to be quickly checked and compared. Currently it is possible to change, add or remove material of the building elements (walls, slabs, windows, doors) and set the thickness.

With the integration of a cloud environment, we will be able to generate multiple simulation models automatically so that variants can be examined simultaneously using one or several different solvers as appropriate. Currently we are using a solver, which simulates the room air temperature depending on the outside climate temperature and the building physics properties of the room and its enclosing elements (Nicolai et al., 2007).

6 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 need to be dealt with.

Firstly, the suggested VL 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 VL, these products can be tested and validated during the development in the hosting facility or even on a number of virtual facility models. 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 VL provides a concurrent computation service to building designers allowing them to test and optimize energy efficiency under virtual stochastic life-cycle conditions. Thus, today's 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 overcome.

When it is fully developed, the VL 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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Customizable continuous building simulation using the design performance toolkit and Kepler scientific workflows

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ABSTRACT: By combining the Design Performance Toolkit with a scientific workflow system, we empower architects to experiment with dynamic energy simulations at an early design phase. Using the Design Performance Toolkit, simulation input is automatically extracted from a BIM modeling environment. The Kepler workflow system is used to provide a visual customization interface for this process. We present a standard simulation workflow implemented using the Design Performance Toolkit and the Kepler workflow system. Based on this standard simulation workflow, we present variations of the workflow for simulating parameter studies. The creation of custom workflows helps explore the design space continuously while staying focused on the design activity itself.

1 INTRODUCTION

Previous work has shown that in order for architects to be able to design buildings that emit little or no CO_2 during operation, the design process itself needs to be addressed (Schlueter 2010). Tools like the Design Performance Viewer (DPV) (Schlueter and Thesseling 2009) allow rapid assessment of energy consumption and related CO_2 emissions during the early design phase of a building. This leads to an iterative design process that includes simulation of early building designs.

We have recently replaced the static energy simulation kernel of the DPV (based on the Swiss SIA 380.1 norm) with EnergyPlus (DOE 2011) thus providing simulations that take the dynamics of the building into account. While the new simulation kernel provides more detailed data, the interface to the user remained largely unchanged, with the exception that simulation times have increased by at least an order of magnitude.

The development of the RevitPythonShell scripting environment for Autodesk Revit Architecture added the possibility to customize the simulation run itself, by allowing access to the core DPV functionality. As a result, the DPV legacy code was split up into modules that can be independently accessed by the scripting environment for further processing.

Although simulation tools are generally tailored to engineers, the DPV philosophy has always stressed giving architects the means to acquire a rough idea of the performance of their designs at the earliest possible stage.

Scripting the DPV with the RevitPythonShell allows detailed control over the simulation experiments performed but requires intimate knowledge of the DPV legacy code structure and a fluency in Python scripting. These requirements do not fit well with the vision of the DPV being a tool to aid architects in the early design phase.

Just as the adoption of BIM software by architects made tools like the DPV possible, we believe a growing acceptance of visual programming languages in the design community, e.g. Grasshopper in Rhinoceros (Schneider, Koltsova et al. 2011), opens up possibilities to provide an intuitive interface to custom simulation workflows.

An example of such a workflow language is the Kepler scientific workflow system (Altintas, Berkley et al. 2004).

We combine the Kepler system with the Design Performance Toolkit, resulting in a system for exploring building designs that affords parameter studies and other alternate simulation workflows while employing parallelism to reduce simulation time.

In Section 2 we introduce the Design Performance Toolkit and the Kepler scientific workflow system. Section 3 presents a standard simulation workflow as a basis for developing alternate simulation workflows. In Sections 4 and 5 we present example variations of the standard simulation workflow. These demonstrate basic techniques such as iterative simulation runs in Section 4 and parallel processing of simulations in Section 5. Finally, Section 6 concludes the paper.

2 BACKGROUND

2.1 *The Design Performance Toolkit*

The Design Performance Toolkit (DPTK) is an ecosystem of tools grouped around the core functionality of the legacy DPV code. This functionality includes routines for extracting building geometry and energy relevant information from Autodesk Revit Architecture.

The result is in an internal representation model for the extracted information. The DPTK provides transformations on this model for simplification of building surface geometries, conversion of the internal representation model to the input format for EnergyPlus (IDF) and tools for viewing the extracted geometry, manipulating IDF files, extracting results from multiple simulation runs and generating charts from simulation data. These tools can either be accessed via a scripting interface inside the BIM modeling software using the RevitPythonShell plugin (Thomas 2012) and auxiliary scripts or via the command line using the DpvTk.exe program which exposes most of the basic DPV workflow steps to batch scripting and the DpvSh.exe program which provides access to the legacy DPV code via an Iron Python interface. A database of materials and constructions for walls, windows, roofs and floors is included in the toolkit as well as graphical user interfaces to edit these. Finally, a testing harness exists to check the geometry extraction routine with a variety of building geometries and summarize the results.

2.2 *The Kepler workflow system*

The Kepler workflow system (Altintas, Berkley et al. 2004) provides a graphical environment for executing data driven workflows that are comprised of actors and directors. Directors govern the activation of actors, which in turn consume data on input ports and produce data on output ports.

The Kepler workflow system provides a library of actors for specific tasks such as reading from files, querying databases and web services. An abstraction mechanism for embedding subworkflows inside a composite actor facilitates workflow composition (Curcin and Ghanem 2008).

2.3 *Encapsulating the Design Performance Toolkit as a web service for use in the Kepler workflow system*

We encapsulated the core functionality of the DPTK into a web service, the Design Performance Web Service (DPWS). This provides easy integration of DPTK functionality in Kepler workflows by employing the standard Kepler Web Service actor. Where access to the DPV internal model representation is needed, a serialization to XML of that model is passed as an argument to the DPWS. Such a serialization can be extracted from an Autodesk Revit model using the RevitPythonShell to interface with the DPTK model extraction routines. Once extracted, the model can be saved to disk for later use in Kepler workflows.

3 DPV STANDARD SIMULATION RUN AS A KEPLER WORKFLOW

Translating the DPV standard simulation run to a Kepler workflow is as follows: The basic steps (model extraction, model augmentation, model simplification, model transformation, simulation, analysis/post processing and visualization of results) are performed sequentially, with the output of each step being a requirement for the following step.

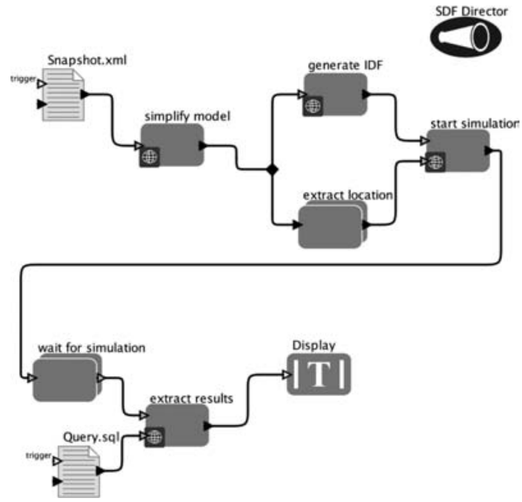

Figure 1. The standard DPV simulation workflow.

3.1 *Overview of the standard DPV simulation workflow*

The standard DPV simulation workflow is shown in Figure 1. The internal model of the building is read from disk and its geometry is simplified to accommodate restrictions imposed by the simulation engine EnergyPlus. This simplified model is then serialized to IDF and fed to EnergyPlus for simulation. Once simulation is complete, a defined set of results are extracted and displayed to the user.

The workflow can be roughly divided into three stages: Preprocessing, simulation and post processing. The types of data flowing through the work-flow actors are divided into two categories, pivoted by the simulation step: During preprocessing, model representations of the building flow through the actors. The simulation step denotes a finalization of these model transformations and assigns a simulation ID (SID) to the final model representation. This SID then flows through the post processing actors to represent the model and its simulation data.

Sections 4 and 5 demonstrate variations of this workflow, intended as examples of simulation workflow composition strategies.

4 OPTIMIZING THE ENERGPLUS SIMULATION TIMESTEP VALUE

The main advantage of the combination of the DPTK and the Kepler workflow system is the ability to execute multiple variations of a simulation run. As an example of such a parameterized simulation run, the following workflow VARYTIMESTEP (see Figure 2)

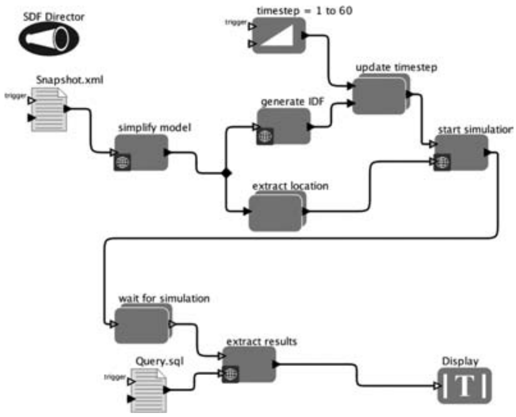

Figure 2. The VARYTIMESTEP workflow.

iterates over a range of values for the EnergyPlus TIMESTEP parameter (DOE 2011). The TIMESTEP parameter indicates the count of simulation steps performed per hour. An optimal choice for the TIMESTEP parameter balances simulation runtime and desired accuracy: The lower the TIMESTEP value is, the less accurate the simulation results. A higher TIMESTEP value increases the simulation run time.

4.1 *Overview of the VARYTIMESTEP workflow*

The workflow VARYTIMESTEP is only a small variation on the standard DPV workflow: The actors timestep = 1 to 60 and update timestep introduce the required variation. The timestep = 1 to 60 actor is a standard Kepler Ramp actor, set to fire 60 times, starting at 1 with an increment of 1 for each iteration of the workflow. The update timestep actor employs DPTK functionality to update the TIMESTEP entry in the IDF file with the current output value of the Ramp actor.

Thus, a relatively small change to the DPV standard workflow results in a parameter study consisting of 60 simulation variants. This technique can be used to vary other parameters of interest to the designer, while maintaining a high level of workflow abstraction.

4.2 *Results of the VARYTIMESTEP workflow*

In this specific case, the extracted results include the simulation time and the end uses for heating. When plotted (see Figure 3), we observe that the simulation time does not change continuously. This is a side effect of EnergyPlus only allowing values for TIMESTEP that are evenly divisible into 60 and rounding all other values to the nearest such value.

We can also immediately see that the convergence of the calculation of end uses heating for values of TIMESTEP between 3 and 15 does not change very much, but the simulation runtime increases from 60 seconds to 287 seconds, suggesting a TIMESTEP of 6 to be a reasonably good value for quick simulations of this model.

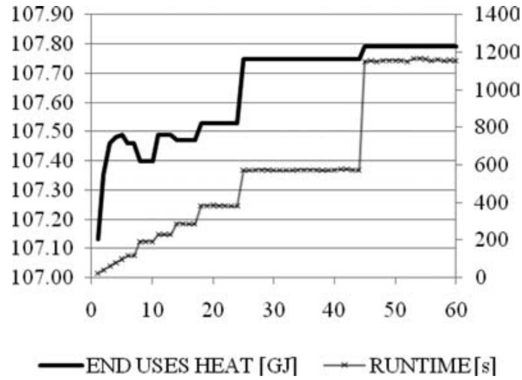

Figure 3. End uses heat vs. simulation runtime.

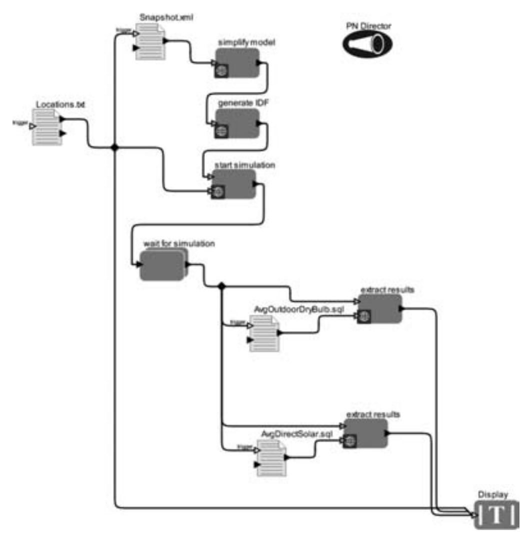

Figure 4. The CALCULATEAVERAGES workflow.

5 PARALLELIZING SIMULATION RUNS

Variations of simulation runs can quickly increase workflow run time. However, since the individual simulations are independent of each other, the variation process can be parallelized, which can considerably reduce workflow run time.

The standard approaches to parallelization in Kepler (Jianwu, Altintas et al. 2009; Wang, Crawl et al. 2009) are ill suited for our purpose as they are designed to parallelize entire sub-workflows. For the DPTK, however, the single time-consuming task is the simulation execution itself, which is independent of the Kepler workflow. Therefore, we parallelize simulation runs employing two techniques: Data flow parallelization using the Kepler PN director and parallelization of simulation execution with distributed worker components.

Parallelization of simulation runs is demonstrated with the workflow CALCULATEAVERAGES (see Figure 4), designed to extract two specific values from

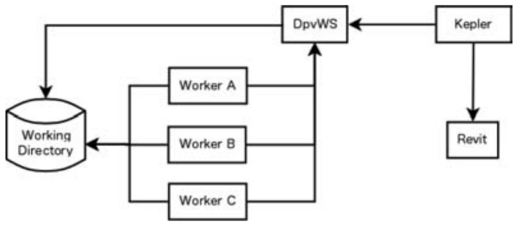

Figure 5. Worker components in the DPTK ecosystem.

the weather files bundled in the DPV legacy code: Average outdoor dry bulb and average direct solar radiation. Knowledge of these values for the list of locations known to the DPV was necessary for the implementation of a commercial frontend to the legacy DPV code. Using the legacy DPV plugin for Autodesk Revit Architecture, this information could be retrieved by repeatedly simulating the same building, manually varying location information after each simulation.

By altering the standard DPV simulation workflow slightly, this task can be automated and due to parallel execution of simulation runs, the entire task can be completed faster.

5.1 *Overview of the CALCULATEAVERAGES workflow*

The Locations.txt actor is a standard Kepler Expression Reader that is set to a file containing the list of locations to simulate formatted as a single Kepler string expression per line. Each time this actor fires, a new location is read from the file and fed into the workflow. The rest of the workflow is basically the same as the standard DPV workflow presented in Section 3.

5.1.1 *Parallelization of workflow execution with the PN director*

The Kepler PN Director is used in this workflow to parallelize the data flow of the workflow. The PN Director fires all actors non-deterministically and in parallel as soon as their input ports contain data. This results in a rapid execution of the preprocessing phase until all locations have been processed and corresponding simulation requests have been sent to the Design Performance Web Service. This leads to a backlog of simulation requests at the DPWS that can then be simulated in parallel.

5.1.2 *Parallelization of simulation execution in the design performance web service*

The DPWS keeps track of simulations and their completion. The actual simulation is performed by worker components as shown in Figure 5.

Worker components share access to a working directory for EnergyPlus input and output files with the Web Service. Each worker waits until a simulation request is available and then runs the simulation, reporting progress periodically to the Web Service. Once a simulation is completed, the worker notifies the Web Service and awaits the next simulation request.

The Design Performance Web Service maintains a timer for each simulation assigned to a worker component and reassigns simulation requests that time out to new worker components. This is necessary, because worker components are distributed over multiple machines and can fail for a variety of reasons unrelated to the workflow itself, e.g. shut-down of the computer running the workflow component or network failure.

The amount of simulations that can concurrently be performed increases linearly with the number of worker components.

5.2 *Results*

The combination of Kepler workflows and the DPWS automates an otherwise manual, labor intensive and time consuming task. The use of data flow parallelization and concurrent simulation execution reduces the execution time linearly by the number of worker components available. These techniques can be used in conjunction with parameter studies such as the VARYTIMESTEP workflow shown in Section 4 to increase the viability of routinely performed large scale parameter studies, what we call continuous building simulation.

6 CONCLUSIONS

We have shown that scientific workflow systems can be used to augment the data available to architects even in the early design phase. The creation of custom workflows helps explore the design space continuously while staying focused on the design activity itself. Such workflows can be reused from project to project as part of the architect's toolbox.

We demonstrated that the combination of the Design Performance Toolkit and Kepler scientific workflows simplifies the simulation of parameter studies.

In addition, the encapsulation and exposure of DPTK functionality in the Design Performance Web Service simplifies access to DPTK routines and provides a convenient device for parallelization of simulation runs using distributed worker components.

Current work focuses on extending both the functionality and usability of customizable continuous building simulation workflows by expanding the DPTK to include interfaces to other simulation engines and data sources, as well as including a navigable history of workflow executions and their results.

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eWork and eBusiness in Architecture, Engineering and Construction – Gudnason & Scherer (Eds)

Validation of simulation results using sensor data to improve building control

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ABSTRACT: In general, current Building Energy Simulation Tools are used for pre-construction design and comparison of designs rather than a full exact varying representation of reality. To provide the best level of detail full CFD analysis for the entire building would be required. However this is currently by far outside the scope of current computing power and labour efforts for a building energy system. Because these simulation tools are designed for comparison of potential designs and because of the difficulty in predicting occupant behaviour, very often the predicted results do not correlate with the real actual performance when buildings are in operation. This paper describes a methodology being developed to combine building energy simulation results with accurate and real sensor & meter data with the purpose of better understanding the relationship between energy simulation and real building operation for better occupant comfort and more efficient operation.

1 INTRODUCTION

As new and retrofitted buildings are developed with more complex monitoring, control and automation systems, more data is being produced. A goal of the scientific and engineering community is to provide a holistic and integrated building information solution which can utilise this information and provide value by reducing building energy consumption. Better use and more integrated use of building energy information can contribute to meeting requirements of both the European EPBD and the European 20-20-20 targets which require the EU to reduce Greenhouse Gas levels by 20%, reduce domestic home energy consumption by 20% and increase Renewable Energy by 20%, all by 2020.

A key part of this holistic energy information solution is the integration of building energy simulation tools. Energy analysis plays an important role in developing an optimal HVAC and Architectural design for new buildings and in determining optimal retrofit and commissioning measures for existing buildings (Liu & Liu, 2011). However a barrier to this integration is that the majority of commercial building simulation tools are developed for design solutions rather than absolute accurate representations of minute by minute building performance. Therefore, pre-construction simulations often do not exactly correlate with operating building performance even though building simulation tools operate with accurate physics algorithms (Clarke J., 2001). The reason for this mismatch is that detailed input information is required to produce the correct output (Kusada, 1981). To calibrate a dynamic building simulation, measured data from buildings can be used. Calibrating computer models to actual metered data is not a new practice (Liu & Liu, 2011). For over 40 years, recommendations were made to calibrate models based on measured data (Ayres & Stamper, 1995). Most calibration procedures require months of measured data (Liu & Liu, 2011). Previous studies have developed a calibration procedure based on developing archetypes whereby patterns of similar buildings which operate alike would be developed and used for future similar buildings. This can be used to calibrate buildings to better predict future similar buildings (Flores Larson, Filippin, Beascochea, & Lesino, 2008).

Comparison of simulated cooling and heating energy simulation against time of day is a very important step in model calibration (Flores Larson, Filippin, Beascochea, & Lesino, 2008). Furthermore short term cooling load forecasting with lead times from 1h to 7 days can play a key role in the economic and energy efficient operation of cooling appliances (Clarke et al, 2004). The study under development presented in this paper is based on calibrating accurate building information models and associated simulation models with real measured sensor data procured from existing buildings.

From previous project experience a deficit has been encountered whereby the correlation between simulation results and measured data is not entirely accurate. This paper discusses a method of validation, which will provide a means of comparing measured data (e.g. sensors and weather data), and simulated data (e.g. near future simulations).

This method for validation of building simulation results initially involves a comparison of data from building simulation and respective measured sensor readings. From this comparison, value is added from correction of simulation results, and/or input to simulation parameters. Further worth can also be provided by gaining knowledge for creation of simulation profiles which are difficult to predict before construction and operation. Additional value can also be derived from identifying conditions of poor results and other relevant input factors which can be corrected. Simulation data and actual data is available from various campus buildings of University College Cork, Ireland. Simulations are undertaken using readily available commercial products and use practical and straightforward data analysis methods so that results and further development can be implemented by building engineers who may not have extensive IT or coding experience.

2 ERI BUILDING DESCRIPTION

This study focuses on UCC's Environmental Research Institute (ERI) which is located on the west of Cork city, Ireland. It is a satellite building of the main university campus and consists of approximately 2600m^2 of laboratory, office and meeting space over three floors. The building is capable of housing approximately ninety researchers. The low energy facility usually consists of a mixture of lab and office facilities. The general construction of the building consists of superstructure of exposed concrete, with a façade of wood-framed windows and high-performance glazing. The building was designed and operates as a demonstration site for renewable energy technology such as solar thermal and geothermal systems.

In addition it is supplied with gas for hot water boilers and electricity from the national grid for lighting and running other electro-mechanical systems.

Other energy efficient building features include:

- Solar Collectors evacuated tube & flat plate for DHW and pre-heat of heat pump aquifer loop
- Geothermal Systems (88 kW Heat Pump with aquifer open loop)
- Cooling and Air Handling (6 heat pumps (2.2 kW) for cold rooms, 4 AHUs for Labs (incl. heat recovery section)
- Back-Up for Renewable Systems (Gas Fired Boiler (163 kW))
- Under floor heating system.
- High frequency lighting with Advanced lighting controls.

The building operates as a "living laboratory" for research into various building energy systems. Therefore a number of concurrent research projects are undertaken focussing on various energy aspects of the building operation. Particular attention is paid to the monitoring and collection of data related to building performance, control and operation.

All information available from the traditional building management system (BMS) consisting of wired sensors along with meters and actuators, with 13 different types of measurements, including indoor environment and outdoor weather conditions is stored and made available for research. The BMS is made up of approximately 180 wired sensors and meters throughout the building. These include air temperature sensors in all rooms and corridors along with CO_2 level, humidity and radiant temperature sensors in four rooms.

Figure 1. Exterior View of ERI Demonstrator Building.

Additionally, a test bed for wireless sensors, meters and actuators has been installed since April 2008 for the ITOBO research project (Information and Communication Technology for Sustainable and Optimised Building Operation). This provides a concentrated wealth of information of building performance in greater detail than typical buildings. The ERI building therefore is an ideal demonstrator to conduct energy simulation study.

3 DEMONSTRATOR BIM MODEL

A detailed BIM model of the ERI building has been developed for study within the authors' research group. This model has been independently verified and checked for accuracy of all dimensions, materials, etc. This same BIM model is utilised for various research projects and experiments to allow for easy comparison and cross checking of all results. A key part of a holistic energy information solution is the integration of building energy simulation tools. Therefore, rather creating a simulation model within the simulation tool, the calibrated and verified BIM model was used. For the research conducted for this paper, the verified BIM model was exported from Autodesk Revit MEP 2012 as gbXML format to be utilised by IES-ve energy simulation software.

The BIM to Simulation Process for this can be summarised as follows:

1. Creation of BIM model with accurate dimensions, geometry, materials, etc.
2. Definition of spaces within model.
3. Definition of type of spaces.
4. Export as gbXML.

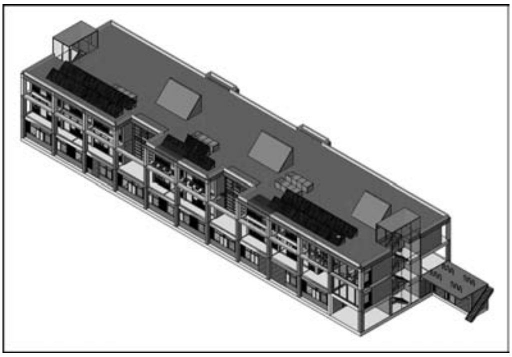

Figure 2. Overview of Detailed BIM Model.

As mentioned previously, it is a goal of the scientific community to have seamless interaction between software processes. And indeed, a dedicated import tool exists this did not turn out to be the case in this instance. However, a number of time consuming problems occurred which had to be corrected before simulation could occur.

These problems included existence of holes between rooms and external spaces. Whilst not in the BIM model a number of holes appeared only in certain rooms. It is not possible to perform simulations with holes between internal and external spaces. The solution involved checking each individual room/space (92 no.) and deleting any external holes which had appeared. Other problems included

- Certain building information properties not imported and had to be specified.
- Unusual spaces resulted from non standard building shapes e.g. roof lights.
- Awkward and unnecessary shaped features within rooms.

Figure 3 illustrates an example of some unnecessarily complex geometry produced when exporting from BIM as gbXML. This geometry was not altered before simulation to minimise the number of time consuming corrective measures to be undertaken however it is likely that these anomalies increased the time taken for simulation process to occur. What is observed in Figure 3 is a wireframe overview of one corner of what should be a simple 90° angle. Instead the walls have overlapped to produce an unnecessary complex arrangement.

Whilst the BIM should provide geometry, it is likely that when the time taken for corrective measures is taken into account it would have been quicker to recreate the building model for simulation from scratch as the building modelled in this instance is composed of relatively straightforward geometry and materials.

A better solution is more careful creation of BIM solely for the aim of export. The downside of this is that the BIM needs to be utilised for other functions and may be less accurate. The BIM should function as the hub for all information for the project. It cannot be altered to optimise simulation if this interferes

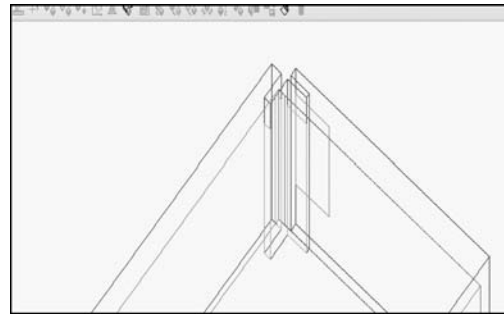

Figure 3. Example of Complex Space Geometry produced.

with other functions such as construction or facilities management. The original or record BIM needs to be entirely accurate. It therefore would be better if the BIM was modified post export before simulation. This would maintain the central BIM hub method whilst still optimising the simulation process.

4 BUILDING SIMULATION

After adjustments were made dynamic building energy simulation was carried out using IES-VE (Integrated Environmental Solutions Virtual Environment). This simulation software was chosen as it is commonly utilised in commercial design in the UK and Ireland. Because it is an aim of this researcher not to be confined to a single software product or suite previous research has been carried out using Vabi Simulation, a popular Dutch dynamic building simulation tool and future comparative studied will be carried out using Energy Plus, the comprehensive U.S. simulation software.

A typical simulation procedure was carried out. For this particular simulation software steps taken include, setting correct weather file, running simulation of sun features for building location (Suncast), and adjusting materials schedules (Building Template Manager). Unlike typical preconstruction building simulations whereby building operation schedules, occupancy and timing schedules are estimated based on proposed building usage, this building has the benefit of known and recorded operation schedules and is closely monitored. Therefore efforts were made to match the simulation inputs as best as possible to reality.

Simulations results were undertaken using two of the methods provided by the IES software, ApachSim (Dynamic Simulation) and the CIBSE loads methodology.

Steady state heat loss is the equivalent of running a 24 hour heated building with no internal heat gains for a long period of weather at a constant outside air temperature and no solar income. This process removes the internal heat gains from a Tas dynamic simulation model, runs the model using a weather file with constant outside air temperature and no sunshine and at the end of a 30 day period the simulated

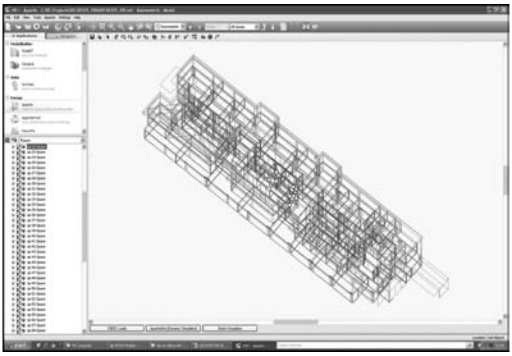

Figure 4. Wireframe View of Simulation Model.

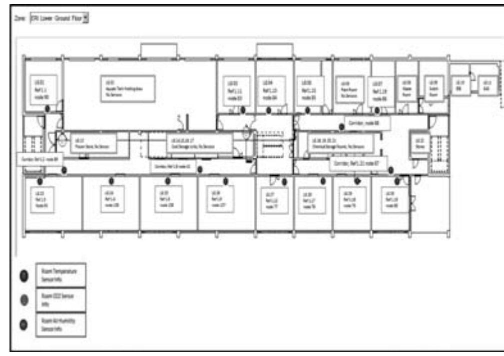

Figure 5. Screenshot of ERI Data Access.

heating load is exactly the same as the steady state heat loss calculation (EDSL, 2012). The steady state method used to design the building analysed is based on the CIBSE admittance method. This method uses idealised (sinusoidal) weather and thermal response factors (admittance, decrement factor and surface factor) that are based on a 24-hour frequency (CIBSE, 2006).

Dynamic Simulation Models can be defined as models which are based on first principles and are capable of replicating dynamic heat transfer in a building, in response to external and internal influences on the time scale of one hour or less (Jankovic, 2012).

From the simulation process a full and detailled set of results was created which are to be used for comparison to real data as described in the following section.

5 BUILDING PERFORMANCE SENSOR AND METER DATA

As mentioned in the Building Description section, a large body of real building sensor and meter readings procured from the ERI building exist for research purposes. These readings are stored on an Oracle data warehouse used for various research purposes within the authors' research group. This data can be accessed using a number of interfaces of varying complexity, from direct data warehouse queries to a web based tool, described below. This web based tool provides intuitive access to data and records from a graphical overview of the ERI building on a floor by floor basis showing where any wired or wireless sensors or meters are located. Overviews of other important areas such as the plantroom are also included in this tool.

Figure 5 shows the view of one floor of the building with the location of all sensors and meters located on that floor. From this view, any of the sensors or meters can be clicked upon to be analysed further. Other floors or areas can be chosen from the drop down menu located on the top left of the screen. When a sensor is chosen, a summary of the previous week is displayed in graphical and tabular form as per Figure 6. Furthermore the option is given to download a set of

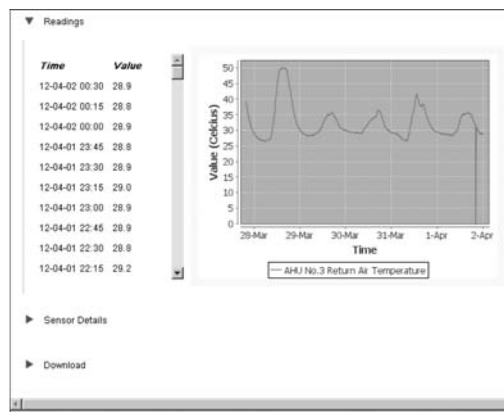

Figure 6. Detail of Temperature Sensor Information interface from ITOBO.

data in excel or csv format. This provides straightforward access to data without knowledge of data warehouse operation.

For more analytical tasks data can be aggregated in the Data Warehouse implementing "Materialised Views". However for the purposes of this research this is not required and the web access tool provides access to all required data.

6 EARLY FINDINGS

Thus far this paper has described a process for providing detailed simulation results from an accurate and verified BIM model and providing access to a considerable body of building sensor and meter records. The next stage of the process to provide value from comparison and aggregation of this simulated and real data. The comparison concentrated on heating because of the building type and cool nature of the Irish climate. The first point of comparison is to determine for which the same simulation results and measured data exists. Next statistically and graphical comparative analysis is conducted.

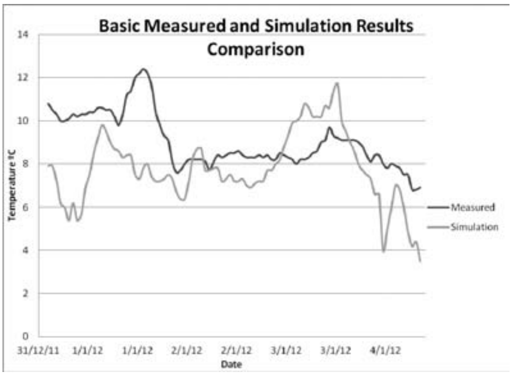

Figure 7. Example of comparison of Measured and Simulation Data.

Figure 7 shows an example of a graphical comparison for measured results from one particular temperature sensor and corresponding simulation result. At the time of writing detailed analysis is still being undertaken. However some general trends have been observed to date.

Reasons for differentiation include many of the typical factors for building simulations not exactly adhering, in particular occupancy, scheduling and weather conditions. Improvement and validation of these is discussed in the Future Research Section.

7 FUTURE RESEARCH & DISCUSSION

The expected result to be derived from this method is to give an indication of quality of simulated data results and provide feedback. If the difference between simulated and real data is too large, steps to improve results will be suggested. In future it is envisioned that automated adjustments may be performed to simulation inputs to correct results.

Live instantaneous simulation can provide benefit from tuning BMS for near future tweaking of BMS/control systems (continuous commissioning), building certification, energy profiles and design performance review.

Possible scenarios which could be implemented include

Design Review and comparison: During design phase, inputs for Design Simulation Models are estimated future building usage, occupancy density, etc. For Operational Simulation Models, inputs can be real functional data, from BMS and observation. Operational Simulation Models can provide a design check on the Design Simulation allowing feedback to designers for future Design Simulation improvements.

Building Benchmarking: Benchmark building energy use as compared to other, similar buildings to identify need for improvement. Will also allow for potential improvements/alterations to BMS setpoints to be simulated to allow for energy savings.

Energy Use Tracking: Track energy use to monitor changes. Continuous simulation can identify deviations from previous trends or simulated “should be” trends to identify damaged equipment (e.g. broken fan/condenser) or altered user conditions (e.g. change of use, from office space to server room). This can aid facilities managers in detailing the work required for repairs of equipment or building operator to change BMS setpoints.

Trend Data Analysis: Trend key system parameters to detect problems early and assess system performance. As above.

Recommissioning or Continuous commissioning: Perform ongoing recommissioning activities to ensure that the building meets its current needs. Identify and correct deviations from “Ideal” initial operating conditions.

Creation of Building Certification: can provide a more efficient method or an automatic Operational phase building simulation

Further worth can also be provided by gaining knowledge for creation of simulation profiles which are difficult to predict before construction & operation. Additional value can also be derived from identifying conditions of poor results and relevant factors which can be corrected.

Aside from near future simulation validation, the tool may be able to provide long term commissioning feedback to detect and alert users to long term degradation of systems and possible maintenance or repair remedies. As a distant research goal, it is envisioned that results can be used to provide automated feedback to the Building Management System and further improve control.

Furthermore an explicit process of Knowledge Management has been undertaken by turning data (simulation results & measured data) into information (basic comparison of key results) and future plans for creating useful knowledge (improve building operation for key results, energy, comfort and CO_2). This will ensure that the process can be clearly documented to allow results to be achieved on other buildings in future.

8 CONCLUSION

Effective building performance simulation can reduce the environmental impact of the built environment, improve indoor quality and productivity, and facilitate future innovation and technological progress in construction. (Hensen & Lamberts, 2011)

The procedure described in this paper describes a clear methodology for creation of dynamic simulation and comparison with real measured results with the goal of providing better understanding of building operation for the ultimate goal of improving building control. Whilst detailed post occupancy simulations comparisons to building simulations are difficult due to the lack of data, the tools and building being discussed in this paper provide a rare opportunity to do so.

Future research to develop this methodology will be undertaken as part of the EU FP7 project Campus21.

ACKNOWLEDGEMENTS

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PassivBIM – a new approach for low energy simulation using BIM

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ABSTRACT: The process of Building Information Modelling (BIM) is slowly replacing traditional design methods. The use of BIM has been documented to produce many benefits, both on- and off-site. BIM authoring tools create the building model, and this can be further analyzed by downstream applications. Currently, one of the main data transfer schemas, the Industry Foundation Classes (IFC), contains a domain describing structural analysis, but lacks one describing energy concepts. This paper proposes a methodology for a software independent energy analysis extension. It will be implemented via a system called PassivBIM, which supports the design of Passive Houses using BIM-based models. This implementation supports the design decision making process at both the initial and later stages without having to use methods such as optimization. It also provides an opportunity to design more robust buildings as alternative building elements and climates can be used without the need for multiple building models.

1 INTRODUCTION

Building Information Modelling (BIM) has been defined by (Eastman et al. 2011) as "*a modelling technology and associated set of processes to produce, communicate and analyze building models*". The concept itself is not new, and dates back to 1975 when it was referred to as a "Building Description System" (Eastman 1975). In recent years BIM technology is replacing traditional 2D CAD, and this trend is further supported by government reports (BIM Industry Working Group 2011; HM Government 2010). A primary difference between BIM authoring and 2D CAD tools is that the former uses a parametric modelling system whilst the latter simply creates independent 2D views of a project. The BIM approach is less error prone, and as a result can be used to produce higher quality documentation (Azhar et al. 2008). Using BIM also has many other benefits, which can apply to different stages of a building's lifecycle. One of the benefits for the whole project is that it can be used to support multi-disciplinary collaboration (Singh et al. 2011). Another benefit which is more relevant to the construction period is that it can increase labour productivity (Kaner et al. 2008).

Once a model is populated by a BIM authoring tool, an indication to its performance can be given by Building Performance Simulation (BPS) tools. A BPS tool is a "*powerful tool which emulates the dynamic interaction of heat, light, mass (air and moisture) and sound within the building to predict its energy and environmental performance as it is exposed to climate, occupants, conditioning systems, and noise sources*" (Crawley 2003). BPS tools can be steady state or dynamic, and are used for a range of purposes from building regulations compliance checking (Keiholz et al. 2009), and addressing decision support systems and optimization (Hopfe 2009), to supporting PassivHaus certification. Simple models are generally used for the early stage design such as MIT Design Advisor (Massachusetts Institute of Technology 2009); more complex dynamic models are used for the detailed design stages, such as IES<VE> (Integrated Environmental Solutions Ltd. 2012). Arguably, the energy performance domain is becoming more important as the UK is legally bound to reducing its emissions by 2050 (DECC 2012). Furthermore, climate change is inevitable and predicting how a building will behave in the future could prevent issues such as overheating (CIBSE 2005).

The task of data exchange between BIM and analysis tools often relies on the Industry Foundation Classes (IFC) (buildingSMART International Ltd. 2012) or the Green Building XML (gbXML) (gbXML.org 2010) schemas. A comparative study of the two, conducted by (Dong et al. 2007), states that the IFC can represent a whole building project whilst gbXML can only be used in the energy simulation domain. The IFC contains domains, some of which have even been translated to Model View Definitions (MVD), one of which is a Structural Analysis View (Liebich 2008). It does not, however, contain an Energy Analysis View or an Energy analysis domain.

Data transfer between BIM and analysis tools is an active research area (Cormier et al. 2011; Bazjanac 2008; Y. J. Kim et al. 2011). However, most solutions to interoperability issues are tool specific, and there is a lack of research which would address the possible extension of the IFC with an energy analysis domain. An exception to this is a study by (O'Donnell et al. 2011), which is compatible with IFC, gbXML, IDD and Open Studio IDD. The main aim of this is to eventually inform a new MVD for data exchange between HVAC design applications and energy analysis applications. Research is also lacking regarding the use of BIM to support accreditation/certification to schemes such as PassivHaus (BRE Ltd. 2011) and LEED. As indicated in a study conducted by (Azhar et al. 2011), BIM could be used to produce documentation necessary to achieve an LEED rating. In order for BIM to support PassivHaus certification, data transfer would have to be more direct between BIM tools and the Passive House Planning Package (PHPP) analysis tool. Currently one of the only ways to transfer data is by importing schedules into PHPP from BIM tools.

This paper therefore proposes a methodology which extends the IFC with an energy analysis domain, closely based on the pre-existing Structural Analysis concepts. The energy concepts will be taken from the PHPP annual heat demand calculation. This calculation closely follows EN 13790, thus the solution aims to be software independent but able to support PassivHaus design through BIM.

The structure of the paper is as follows: Firstly an overview is given to PHPP and the PassivHaus design principles. The methodology is then described in more detail, and a case study is outlined to which the methodology can be applied. Finally, an example user interface is given with some preliminary results.

2 PASSIVHAUS AND PHPP

2.1 *PassivHaus*

If the UK is to meet its GHG reduction targets, and converge upon a harmonised European standard for zero carbon buildings, PassivHaus could be the standard used as a template to deliver significantly increased levels of energy efficiency (McLeod et al. 2012).

Passive Houses are designed to have such a low heat demand that a conventional heating system is unnecessary (Feist et al. 2007). They are highly insulated buildings, which are only heated by warm air supplied by the ventilation system. The space heating demand has to remain below 15 kwh/m^2 per year for this to be successful, which is one of the main constraints for certification. Another constraint is that they have to be highly airtight. Before certification, the building is tested for air leakage, which cannot be greater than 0.6h-1 at a pressure differential of 50 Pa.

In order to achieve such design constraints, some design principles must be followed, such as:

– No thermal bridges are allowed;
– The ventilation system must include high efficiency heat recovery;
– External building elements which have a U-value below 0.15 W/m^{2}K are used.

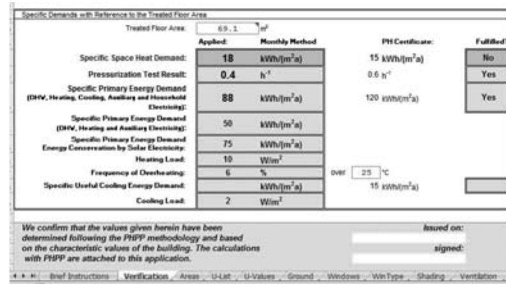

Figure 1. Screenshot of PHPP showing part of the verification tab.

2.2 *Passive House Planning Package*

PHPP is a steady state tool which is used in the design and certification of Passive Houses. It consists of an MsExcel base calculation workbook and a handbook; Figure 1 shows a screenshot of the part used for certification. Its main aim is to replace the use of data intensive dynamic tools, whilst still giving reliable results (Feist 2007). It was developed by simplifying a range of simulation tools (PassivHaus Institut 1998), the main simplifications being:

– The whole building is treated as a single thermal zone;
– Calculations are in monthly or annual time steps.

The main annual energy demand calculation is based on EN 13790, and involves balancing heat gains (internal and solar) to heat losses (ventilation and transmission). The simulation results have been compared to measured data from completed projects, and have been found to show a good correlation (Feist 2007). Examples of data input include the climate, building geometry, building element material values, ventilation, and details of any shading. The tool comes with a range of climates which are ready to be used. There is also the option for user defined data, which can be imported from other tools such as Meteonorm (METEOTEST n.d.).

3 METHODOLOGY

The methodology is divided into two stages. The aim of the first stage is to extend the IFC schema with energy analysis concepts, and implement this using a Java tool. This tool should be able to accept XML data files created from existing PHPP models. The main aim of the second stage is to extend the Java tool so that it can use geometry extracted from an IFC file. A simplified data flow diagram of both stages is given in Figure 2. The overall objective of the methodology is to provide a design tool which supports PassivHaus design from a BIM-based environment. This also alleviates some of the dependency on using PHPP for passive house design. The complete solution, which will include not only the design tool but also all of the

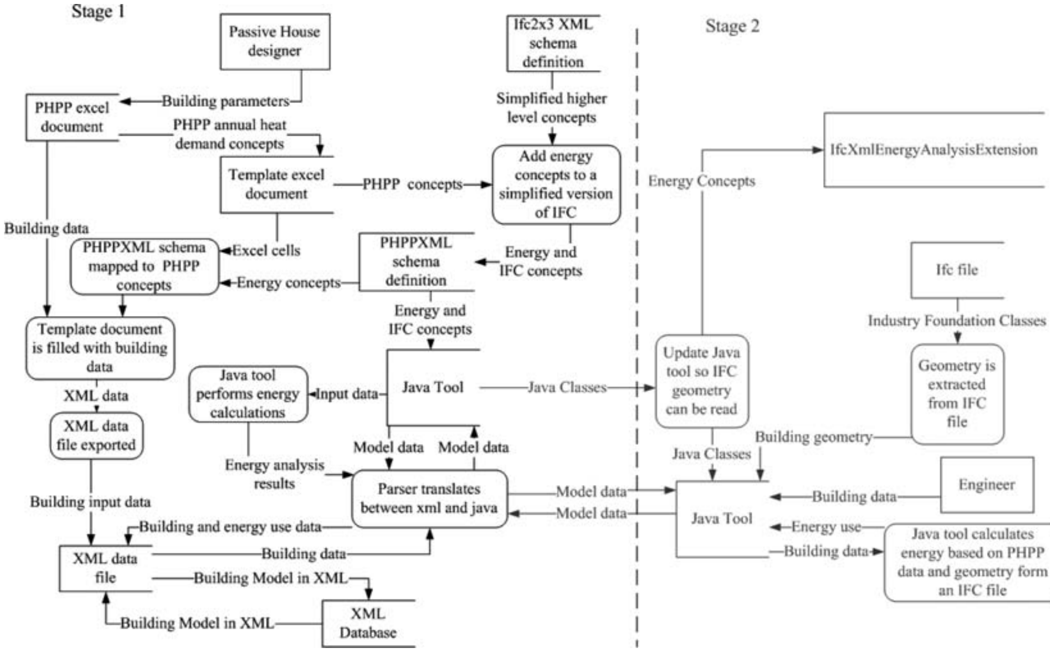

Figure 2. Gane Sarson data flow diagram of the proposed methodology.

documents and processes in the supporting methodology, is called PassivBIM. User interaction with this system is explored in Section 5 below.

3.1 *Stage one*

During the first stage, three main products are developed; an extended IFC schema, a template excel document and a Java tool. Their development is explained in more detail below.

3.1.1 *IfcXmlPhpp*

The IFC2x3 schema is available in both the EXPRESS and XML schema formats. The XML version is called IfcXml, and this is the version used in this methodology as XML schemas can be used to export data from an MsExcel spreadsheet.

The first process is to examine the PHPP annual heat demand structure and extract the main input and output energy concepts. The main structural analysis domain entities of the IFC, such as IfcStructuralItem are then identified. Any overlap between IFC entities and energy concepts is noted to avoid data redundancy. Some existing IFC entities will however be ignored, such as IfcThermalMaterialProperties. This is because they are depreciated in future IFC candidate schemas. Some of these are documented as property sets in current guidance documents e.g. Pset_MaterialThermal, but they are not included in the formalised (EXPRESS and XML) versions of the schema. This is a key limitation to using property sets, as before use their contents have to be agreed upon between individuals exchanging information. These future schemas cannot be used directly for this work as they are currently unavailable in the XML schema format.

Energy analysis equivalents to structural analysis entities in the structural domain, such as IfcEnergy Item, are then defined. The main energy concepts are assigned properties to allow the IFC extension to represent all the necessary PHPP annual heat demand concepts. Table 1 shows some of the main extensions.

The main difference between the hierarchy of the structural domain and the proposed energy analysis is in the IfcGroup entity. In structural analysis calculation forces in a model are balanced and can be grouped into input and resulting groups. For an energy calculation, the input is groups of heat loss and gain activities (described under the IfcPruduct entity) which can be grouped into a total heat loss and heat gain. The main output is the heat demand. Therefore, the main equivalent to the IFC load group entities is IfcThermalLoadGroup. This has its own three subtypes: IfcThermalHeatLoss, IfcThermalHeatGain and IfcAnnualHeatDemandGroup.

It must be noted that a property sets exist in the IFC documentation which includes properties such as heat loss. These include

- Pset_SpaceThermalRequirements, which includes the properties: space temperature max., natural ventilation rate, mechanical ventilation rate, air conditioning,
- Pset_SpaceThermalDesign, which includes the properties: heating design airflow, total sensible heat gain, total heat gain, total heat loss, ventilation airflow rate, exhaust airflow rate.

Table 1. Examples of energy extensions.

IFC supertype entity	IFC Structural analysis subtype entity	IFC energy analysis subtype entity
IfcProduct	IfcStructuralItem	IfcEnergyItem
IfcProduct	IfcStructuralActivity	IfcThermalActivity
IfcSystem	IfcStructuralAnalysis Model	IfcEnergyAnalysisModel
IfcGroup	IfcStructuralLoadGroup	IfcThermalLoadGroup
	IfcStructuralResultGroup	
Entity	IfcStructuralLoadResource	IfcEnergyResource

This highlights that energy concepts have been identified as necessary in the IFC schema in the past, but the author is of the opinion that for consistency and equality they should be part of the formally defined IFC schema in an energy analysis domain, similar to the structural analysis domain.

The energy analysis extension is formalised in an XML schema document, IfcXmlPhpp, which imports the original IfcXml schema. Consequently, IfcMeasureResource entities can be directly referred to. There are some issues with extending other entities directly from the original schema, as IfcXmlPhpp has to be compatible with MsExcel's process of mapping and exporting XML data using an XML schema. The key issues are:

– After importing an XML schema for mapping, MsExcel does not display abstract entities and does not allow their mapping. Inherently, this applies to all their subtypes.
– MsExcel is not able to map an element which is part of a <choice> schema construct (Microsoft Corp. 2012).

As the original IFC schema contains both abstract entities and the <choice> construct, extending key IFC entities directly from the original schema is not possible if the schema is to be used by MsExcel. As a result, simplified versions of various IFC entities are included in IfcXmlPhpp including the schema root element, UOS. However, this element has to be further extended, as an XML schema used in MsExcel for XML data mapping has to have a root entity, which contains all the other entities (or references to them) needed for mapping.

In addition to all the concepts identified from PHPP, one other concept is added to the new schema – an abstract entity called IfcDesignAlternative. This entity can be substituted by either a climate or a building element description. This allows alternative climates and building elements to be assessed without overriding existing information. A similar idea is presented by (O'Donnell et al. 2011).

3.1.2 *MsExcel template document*

The purpose of the MsExcel document is to allow data from PHPP documents to be exported in an XML file, ready for manipulation by the Java tool. In order to achieve this, IfcXmlPhpp is imported into a MsExcel spreadsheet – the 'Template document' – and energy concepts are mapped to specific cells. A macro is then used to open the target file PHPP document and to copy input data into the Template document. Finally, an XML data file can be exported. This whole process is necessary as the mapping of repeating elements, such as IfcEnergyItem, is not compatible with the data structure of PHPP.

3.1.3 *Java tool*

In order to enable use of the exported Java tool, a parser has to be used to read the file and populate java classes with data. Java classes could be created manually, but this would be time intensive and error prone as the IFC schema is very complex. Therefore, Liquid XML Studio 2011 is used instead to generate java classes based on the IfcXmlPhpp file. This tool is then augmented with energy demand calculations and instructions which enable it to read the input data, instantiate classes to hold result data, and export data into an XML file. This resulting XML file is then sent to an XML database called Xindice, which stores collections of XML files. Employing database storage allows several people working on the same project to view the resulting XML file. Xindice is an eminently suitable target database as it has a Java API, and it is schema independent. This means that the Java tool can send XML files directly to the server, and different types of XML files can be stored on the server.

3.2 *Stage two*

The main processes for the second stage involve augmenting the Java tool to enable geometry information extraction from an IFC file generated by Autodesk Revit. In addition, the Java tool is given a user interface which enables it to accept data as user input, or as XML and IFC files.

Open IFC Java Toolbox (Open IFC Tools 2012) can be used to select specific IFC entities from an IFC file. This is an open-source tool which is mainly used to visualise IFC STEP files. However, the source code is available and can be used to iterate through IFC entities such as IfcWall, in order to extract information such as geometry and orientation.

4 CASE STUDY

The Lime House (named after the render material used) is the second Welsh Passive Social Housing prototype designed by Bere Architects (bere:architects

Figure 3. The Lime House (bere:architects 2011b).

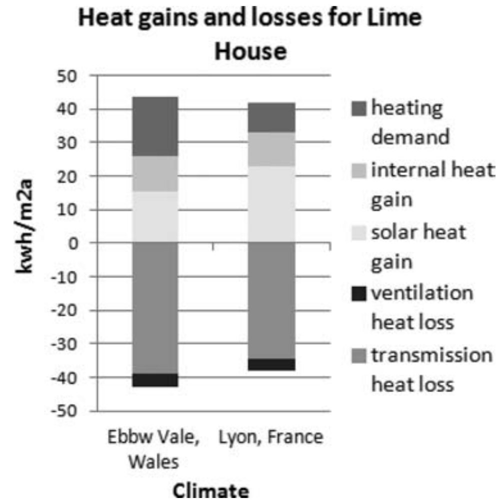

Figure 4. Example of graphical representation of results.

2011b) in order to achieve exemplary energy use. The Lime house is ultra low-cost, and has also achieved code 5 of the Code for Sustainable Homes (bere:architects 2011a). The house is located in an exposed location in Ebbw Vale, South Wales, one of the wettest parts of the UK, where mist and cloud are particular issues. It is a two bedroom house, was built between June 2010 and March 2011, and has a total area of 78 m^2. The Lime House was certified Passivhaus, using extreme 10 year 'worst-case' weather data.

A prototype of the PassivBIM system will be tested using the Lime House. Figure 3 shows the front façade of the constructed building. A model of the Lime House will first be created in Revit, and then building data will be extracted in the format of an IFC document.

Additional data needed for the calculation of annual heat demand will be added from two sources: user input, and data exported from a PHPP model of the building. This aims to demonstrate that either method is viable and that both methods return identical results. The Lime House performance will then be calculated based on current climate data, and data from a location that resembles the potential climate for Ebbw Vale 50 years hence. For the current data, a climate file for Ebbw Vale will be used which has an average ambient temperature of 9.4°C. For the future data, current climate data for Lyon, France will be used which has an average ambient temperature of 11.4°C. The reasoning for this is as follows:

- Due to past emissions, the Earth already faces a 2°C average temperature rise (Hansen et al. 2008)
- There is a time lag of approximately 50 years until the full effects of the change occurs (Wasdell 2006)

The climate data will be exported from PHPP, but could also originate from Meteonorm.

5 REPRESENTATION OF RESULTS

The energy demand results will be stored on the Xindice database and also portrayed in a graphical form to the user. An example graphical portrayal of results based on the case study for current and future climates is shown in Figure 4.

The user will be able to select which data they wish to view based on the building name and any related alternative building elements and climates. This will enable the user to switch between combinations of building elements and test them under future climate scenarios. For this paper, an alternative location was used to simulate a future climate scenario, but research exists which is focused on creating future climate scenarios for PHPP, which will be inherently compatible with PassivBIM.

Further proposed functionality of this system will allow users to be presented with recommended values for building data such as building element u-values. To achieve this, the users will define limits on the main heat loss/gain types and choose which measures they want to change. This functionality will still be based on rearranging existing equations, and will not depend on complex optimization methods.

6 CONCLUSION

A new methodology has been proposed which supports BIM-based Passive House design. It also enables the design team to make informed decisions based on design options without using complex methods such as optimisation algorithms. By doing this we will invent a rapid way of simulating alternative measures without data duplication on two separate levels: (a) geometry data is imported from a BIM model and (b) the same base model can be used to test alternative measures such as building elements.

The implementation of this methodology can enhance the decision making process without restricting the user to specific design stages. It also supports robust design, as the representation of results can be used to:

– Show how a building will perform in future climates and with alternative building elements;
– Present alternative boundary conditions of the building, based on user input limitations.

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Virtual wind laboratory for the aerodynamic analysis of building structures

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ABSTRACT: The design of tall and flexible buildings requires durable building materials of high strength and reduced weight. Such structures have less damping than conventional, and become more vulnerable to excitations induced by the wind. For their accurate dimensioning, it is required a precise calculation of the dynamic response of non-static wind impact. In this paper we present the concept of a model-based and service-oriented computing platform for the numerical aerodynamic simulation and analysis of buildings and the associated numerical methods for aerodynamic analysis of wind flow and Fluid-Structure Interaction analysis. The final software can be used as a "numerical wind tunnel" facilitating detailed studies of various design variants that will enhance the architectural design phase with an extra design criterion. Based on the IFC data model and several data management services for model filtering, transformation and configuration the Virtual Wind Laboratory will ensure interoperability between the involved domain models and thereby enable full integration of the aerodynamic analysis into the overall design process according to the BIM-based work paradigm.

1 INTRODUCTION

In order to design slender and flexible modern tall buildings, efficient structural systems of high-strength materials are used to reduce their weight. These structures exhibit lower damping values than conventional ones, which make them more susceptible to wind-induced excitations, having the potential to reduce their structural safety and cause discomfort to the occupants, adversely affecting the habitability and serviceability of the buildings. As the wind pressures vary spatially over the surface of the structure, there is the potential for the development of regions of high localized pressures, which are of particular concern for the design of cladding systems.

It is evident that wind-induced excitation has to be regarded as an important design criterion for the structural integration (especially in the case of high-rise constructions). However, simple static or quasi-static treatment of the worst case scenario to account for the wind-induced loading according to Eurocode 1 regulations may lead to unacceptably conservative designs in case of very tall buildings. Therefore, the knowledge of the accurate dynamic response of the building to any wind load is needed. In addition, the need to suppress wind-induced excitations and improve the performance of tall buildings has led many investigations related to the testing and development of control techniques, mainly by experimental means. Such techniques either concern aerodynamic modifications of the building geometry related to flow control (to suppress vortex-shedding) or to structural control aiming to improve the structure response to the excitation. In both categories, passive, semi-active or active control techniques are met in the literature (e.g. Kim et al. 2008, Balendra et al. 1999, Ricciardelli et al. 2000).

The proposed method is suggested for the assessment of mechanisms and shape design techniques aiming to control wind-induced vibration and improve the performance of tall buildings to it. Thus, the impact of wind-induced loads to the architectural design, as well as measures to alleviate undesired building responses, can be incorporated in the design stages in the engineer's office. The final software stands for a Virtual Wind Laboratory (VWLab) and provides a numerical procedure for the unsteady coupled aerodynamic-structural calculation of wind loads on civil engineering structures, based on existing Computational Fluid Dynamics (CFD) and Computational Structural Dynamics (CSD) solvers, appropriately modified and combined in an effective and efficient way. The VWLab can be used as a "numerical wind tunnel" that will enable comprehensive studies of various design variants and enhance the architectural design phase with an extra design criterion, essentially shifting the experimental phase towards the final stages of the whole design procedure, a fact that is already routinely used in the aeronautics industry in the last decades.

The VWLab aims also to enable full integration of the aerodynamic analysis, assessment and dimensioning of building structures into the overall building design process according to the BIM-based work paradigm and thereby closing the gap between the architectural, structural and aerodynamic design and analysis data. The IFC project model will be used to provide the baseline data model for the needed information exchange and transformation processes between the involved domains and software tools. Therefore, another main part of our work is the development of methods providing for the (semi-)automatic generation and transformation of the needed CFD- and CSD-domain models, namely the aerodynamic building envelope and the building structure as well as their interlinking with aerodynamic analysis data. The resulting “aeroBIM” data model can be seen as a multi-model (Fuchs et al. 2011) that will provide for a wide range of visualization and evaluation capabilities for better support of domain experts.

2 AERODYNAMIC ANALYSIS IN THE BUILDING DESIGN PROCESS

To account for the wind-induced loads on a structure, Eurocode 1 regulations (EN 1991-1-4) are routinely used by commercial structural analysis software. However, in case of artistic-strange architectural designs involving complex building shapes, the use of EC1 is approximating and goes through the use of rough assumptions, since it mainly refers to applications with simple geometries. In addition, only integrated loads on structures can be obtained, but not load distributions. Whenever accurate and detailed calculations are needed for the wind-induced loads to the structure, for example in the last stages of a design, experimental studies in wind tunnels have to be performed. Such an approach implies significant costs, especially if used in the context of the design procedure where successive modifications and corresponding constructions of the structure model are needed, as well as the repetition of the experiments after each modification. Also, the model of the structure is often constructed totally rigid, thus not allowing for the measurements of local deformations/displacements. If a control decision is to be made, a remarkable number of models, with various sets of parameters, have to be tested. In the light of the above, it is obvious that experimental studies cannot be trivially used. What happens for routine design is that the structure is often over-dimensioned by means of qualitative and/or heuristic use of EC1 guidelines. However, in the case of elastic structures, over-dimensioning against static loading does not guarantee their safety against extreme, dynamically varying real wind loads. While, commercial software, for mechanical engineering applications concerning fluid structure interaction, exists in the market, such software, oriented towards civil engineering applications seems to be missing. Often, commercial flow analysis software (e.g. COMSOL, PamFLOW) is used to study environmental flows or to demonstrate flow structure interaction, but in no case the dimensioning of the structure is achieved in the context of an automated procedure as a feature of the software.

However, the application of the VWLab is supposed to change the traditional aerodynamic analysis process by enabling seamless information exchange between the involved actors and their tools as well as by providing numerical methods for the estimation of wind effects in consideration of the fluid structure interaction phenomena. The envisaged design process is characterized by

- significantly reduced manual rework due to direct information exchange between architect, structural engineer and aerodynamic analysis,
- reduced number of needed experimental wind tunnel studies,
- allowing for efficient aerodynamic analysis and evaluation of multiple design variants, parameter configurations and control mechanisms,
- harmonized and user friendly treatment of aerodynamic design studies
- a more holistic view on the aerodynamic analysis with respect to different constraints and interdependencies related to the design work in other domains and
- enabling advanced aerodynamic analysis for a wide range of building types in an economically justifiable way.

3 AEROELASTIC SIMULATION FOR THE ESTIMATION OF WIND EFFECTS ON BUILDING STRUCTURES

3.1 *Aerodynamic analysis of wind flow around building structures*

The flow field around building structures consists of a very complicated three-dimensional turbulent vortex structures, which is characterized by stagnation, separation, circulation and unsteadiness.

The flow field around building structures can be modeled by incompressible, turbulent Navier-Stokes equations.

The incompressible Navier-Stokes equations for unsteady turbulent 3D flows are solved numerically by a finite volume method based on the concept of pseudocompressibility on a hybrid numerical grid. Efficient calculation of flow fluxes is implemented in an edge-wise fashion and upwind schemes of up to third order of accuracy for inviscid fluxes.

The incompressible Narier-Stokes equations for mean flow in integral form, taking into account the Boussinesq approximation for Reynolds stresses and after the addition of pseudocompressibility terms, can be expressed as:

$$R\frac{\partial}{\partial\tau}\iiint_V Q\cdot dV + E\frac{\partial}{\partial t}\iiint_V Q\cdot dV = \oint_{\partial V}\vec{F}_{vis}\cdot\vec{n}dS - \oint_{\partial V}\vec{F}_{inv}\cdot\vec{n}dS \tag{1}$$

where:

$$R = diag(1/\beta, 1, 1, 1),\ \ E = diag(0, 1, 1, 1) \tag{2}$$

$\vec{Q} = (p, u, v, w)^T$ is the flow variables vector

$$\vec{F}_{inv} \cdot \hat{n} = \begin{pmatrix} u \cdot \hat{n}_x + v \cdot \hat{n}_y + w \cdot \hat{n}_z \\ \left(u^2 + p\right) \cdot \hat{n}_x + vu \cdot \hat{n}_y + wu \cdot \hat{n}_z \\ uv \cdot \hat{n}_x + \left(v^2 + p\right) \cdot \hat{n}_y + wv \cdot \hat{n}_z \\ uw \cdot \hat{n}_x + vw \cdot \hat{n}_y + \left(w^2 + p\right) \cdot \hat{n}_z \end{pmatrix}, \qquad (3)$$

the inviscid flux vector

$$\vec{F}_{vis} \cdot \hat{n} = \begin{pmatrix} 0 \\ \tau_{xx} \cdot \hat{n}_x + \tau_{xy} \cdot \hat{n}_y + \tau_{xz} \cdot \hat{n}_z \\ \tau_{yx} \cdot \hat{n}_x + \tau_{yy} \cdot \hat{n}_y + \tau_{yz} \cdot \hat{n}_z \\ \tau_{zx} \cdot \hat{n}_x + \tau_{zy} \cdot \hat{n}_y + \tau_{zz} \cdot \hat{n}_z \end{pmatrix} \qquad (3)$$

the viscous flux vector.

p is the effective pressure and the shear stress tensor for turbulent flows, taking into account the Boussinesq approximation is obtained by the relations:

$$\tau_{ij} = \frac{1 + a_t}{\mathrm{Re}} \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \qquad (4)$$

$a_t \equiv \frac{v_t}{v_m}$ is the dimensionless viscosity factor and the turbulent viscosity v_t is computed by the solution of turbulence model equations that are weakly coupled with the mean flow equations.

The Reynolds number is defined as $Re = U_{ref} \cdot L_{ref} \cdot \rho/\mu$, where "$\rho$", "$\mu$" are the fluid density and dynamic viscosity respectively.

A dual-time-stepping scheme is used for temporal discretization of the time accurate artificial compressibility method (Vrahliotis et al., 2012). An implicit second order backward difference scheme is used to advance the flow field solution in physical time. An implicit first order backward Euler scheme is used to achieve fast steady-state convergence in pseudo-time. For the computation of the inviscid fluxes the Roe's upwind scheme is adopted. The left and right states of Roe's scheme are reconstructed with a third order accurate interpolation scheme. The gradients for the reconstruction of left and right states of Roe's scheme are computed either with the least-squares method or the Green-Gauss method. The viscous fluxes are computed with a second order accurate central scheme. For the computation of the viscous fluxes, the gradients at the middle of an edge are computed by combining in an efficient way the methods of Haselbacher et al. (1999) and Kallinderis et al. (2005). The resulting non-linear algebraic system of equations is solved with Newton's method. The resulting linear system from Newton's method is solved with Jacobi method.

Various Eddy Viscosity turbulence Models (EVMs) and their variants have been implemented to capture correct flow physics. Some representative turbulence models are standard k-ε, k-ω, k-ε MMK, k-ω TNT, k-ω SST, k-ω SST-SAS.

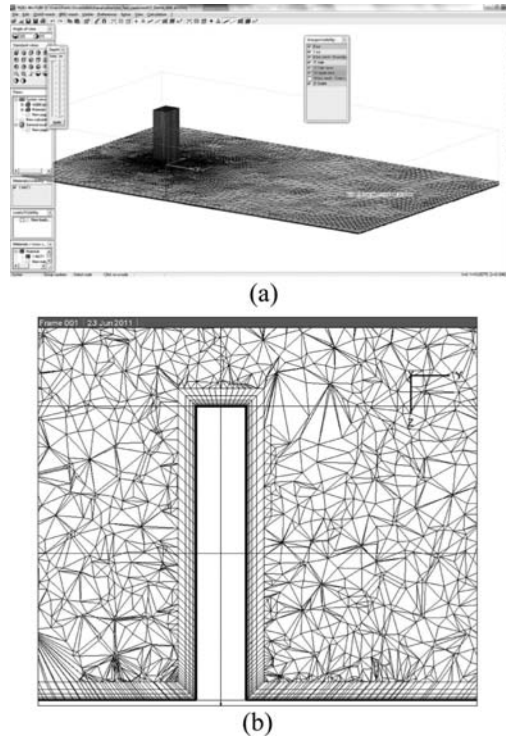


Figure 1. Hybrid numerical grid over the CAARC building.

k-ω SST-SAS turbulence is prevailed in our simulations due to the characteristics of k-ω SST for blending k-ε and k-ω and combining the advantages of the two models. k-ω SST-SAS behaves as a RANS model in stable regions of the flow and provides LES capabilities/behaviour in unsteady flow regions. The turbulent length scale is adapted according to the local resolved turbulent structures. It gives physically more realistic results compared with standard URANS formulations. It is less expensive than LES. The k-ω SST model is easily converted to SAS mode with the addition of a source term at the ω equation which contains the second derivatives of velocity.

The above numerical method was used for the calculation of the flow field over the CAARC (Commonwealth Advisory Aeronautical Council) standard tall building model (Huang et al. 2007 and Braun et al. 2009).

The hybrid numerical mesh is composed by 287.434 nodes 1.034.367 prismatic and tetrahedral elements. The boundary layer region is discretised by a prismatic mesh resulted from the "parallel" inflation of the boundary mesh (building and ground) according to user's specified growth rate and boundary layer zone thickness (figure 1).

k-ω SST and k-ω SST-SAS turbulence models were used emphasizing on the correlation of the results with the corresponding of LES model.

The predicted flow field is strongly unsteady with induction of alternating vortex shedding from the side

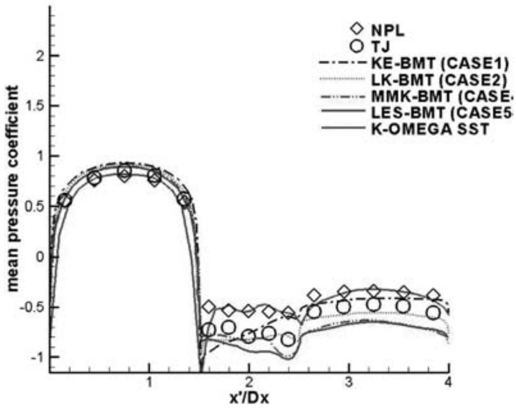


Figure 2. Pressure coefficient distribution along building faces at 2H/3.

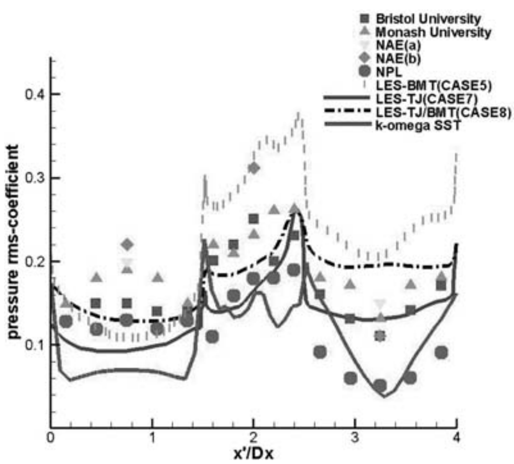


Figure 3. Distribution of mean pressure coefficient rms along building faces at height 2H/3.

walls of the building with dimensionless frequency about 0.9 as in the relevant literature.

The numerical results of the mean pressure coefficients, Cp, on the front, back and side faces of the building at 2/3H are compared with corresponding ones from the literature, as shown in figure 2. The numerical results fall in the range of other numerical results and the experimental data in general, but substantial discrepancies exist among them.

The rms of pressure coefficient on the faces of the building at 2H/3 is depicted in figure 3. The results of the present study are compared with corresponding numerical results and experimental measurements from literature. Our predictions seem to have acceptable deviations from the compared distributions.

The main reason for the noticed discrepancies may be the uncertainties for the incoming turbulence intensity profile.

Mean values and rms for lift and drag coefficients from the present study and the literature are arrayed in Table 1.

Table 1. Mean values and rms for lift and drag coefficients around CAARC building.

	CD_{mean}	CD_{rms}	CD_{mean}	CL_{rms}
Present study (SST)	1.86	0.05	−0.008	0.168
k-εLK [Hua07]	1.71	0.0127	0	0.2816
k-εMMK [Hua07]	1.89	0.071	−0.01	0.297
Dynamic LES SGS	1.90	0.118	0.004	0.3118
Exp. [Oba92]	1.79	0.277	0	0.3

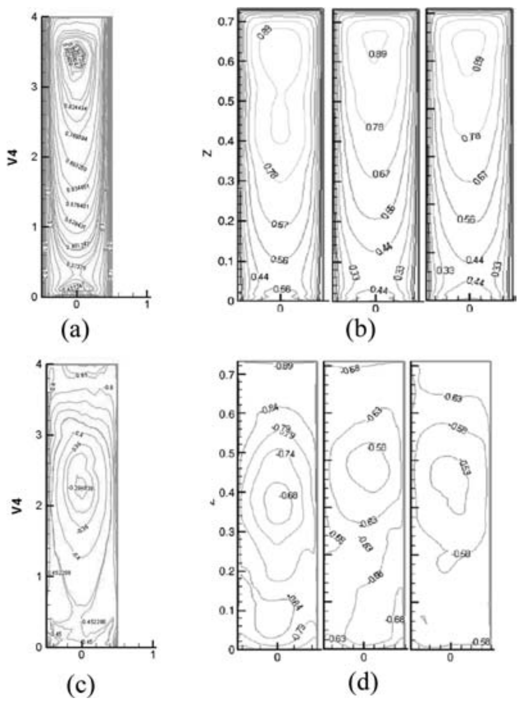


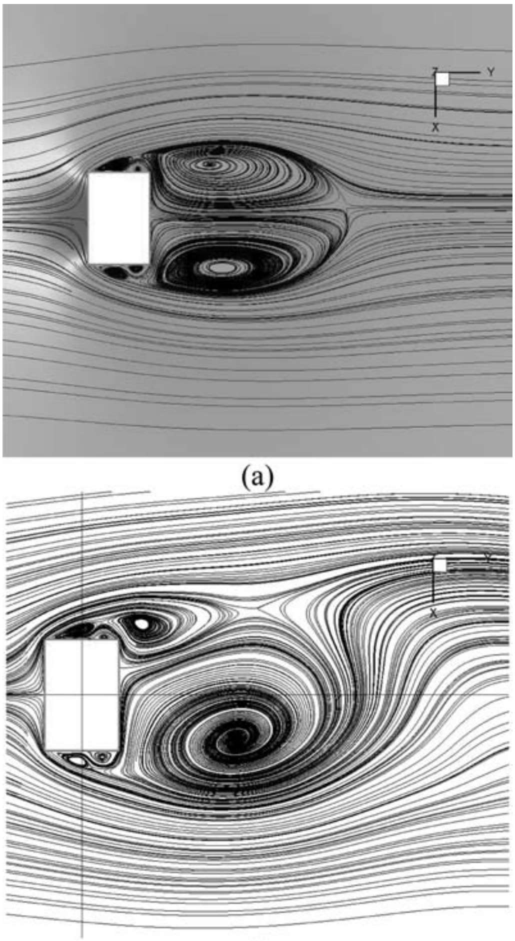
Figure 4. Pressure coefficient distribution on windward (a) and leeward faces (c) and corresponding results from literature (b), (d) (LES-SGS, Huang 2007).

Mean pressure coefficient distribution on windward and leeward building faces and corresponding results from literature are represented in figure 4.

The symmetric mean and some instance of the unsteady flow field on a horizontal level at height 2H/3 can be seen in figure 5.

3.2 *Coupled Fluid-Structure Interaction analysis for building structures*

The dynamic response and the consequence dimensioning of building structures subject to time varying wind loads require the coupling of Fluid-Structure analyses tools to a unified computational procedure with a user defined level for the coupling between the two types of analysis. The coupling of fluid-structure analyses causes deformations of the structure and consequence deformation of the flow field and the computational mesh as well. The



(a)

(b)

Figure 5. Mean (a) and instant (b) flow field on a horizontal level at 2H/3.

deformation/movement of the mesh for CFD analysis introduces additional mesh velocity terms into the flow equations (mass and momentum conservation) due to the deformation/movement of each control volume. The mesh velocities should be calculated in a way that the geometric conservation law (GCL) for moving grids will be respected:

$$\frac{d}{dt}\int_{V(t)} dV = \oint_{S(t)} V_g \cdot \hat{n} dS$$

An Arbitrary Lagrangian-Eulerian (ALE) method for taking into account the movement/deformation of hybrid computational meshes has been developed. The GCL arises naturally in the context of ALE formulations for solving problems on deforming domains.

The coupling algorithm between the ALE CFD and CSD (Computational Structural Dynamics) solvers requires to set appropriate convergence criteria and to efficiently integrate the two corresponding partial software tools into a combined one.

The main tasks for the formulation of the fluid structure interaction procedure are:

– To translate aerodynamic loads as pressure and shear stress loads to structural model for structural analysis.
– To apply an equilibrium equation on the fluid-structure interface in order to equalize the stress tensor acting to the solid surface with the resulted fluid stress tensor from CFD analysis and to equalize the solid wall movement velocity with the fluid velocity on the same grid points.

Considering a viscous fluid, the equilibrium and compatibility conditions may be expressed by:

$$\vec{\sigma}^s \cdot \vec{n} = -p\vec{n} + \vec{\tau}^f \cdot \vec{n} \quad \text{on } \Gamma^{fs} \text{ fluid-structure interface}$$
$$\vec{u}^s = \vec{u}^f$$

where $\vec{n}$ is the unit normal vector at a point of the boundary Γ^{fs}, $\overleftrightarrow{\sigma}^s$, $\overleftrightarrow{\tau}^f$ are the structure stress tensor and the fluid viscous stress tensor, respectively, p is the fluid pressure and $\vec{u}^s, \vec{u}^f$ are vectors representing the structure displacement field and the ALE displacement field of the fluid domain, respectively.

– To satisfy the continuity conditions for mesh motion in relation to fluid particles motion:

$$\left.\begin{array}{l} \vec{x} = \vec{u}^s \\ \dfrac{\partial \vec{x}}{\partial t} = \dfrac{\partial \vec{u}^s}{\partial t} \end{array}\right. \text{ on } \Gamma^{fs}$$

where $\vec{x}$ denotes positions or displacements of mesh nodes corresponding to the fluid domain.
– To continuously exchange data between structural and aerodynamic models.
– The synchronization of the two analyses due to the severe differences of required time steps.
– The formulation of an iterative procedure for the weak coupling of CFD and CSD analysis and implementation of suitable interfaces for exchange of boundary conditions.
– The formulation of convergence criteria for the evolution of the coupling procedure.

For the elastic dynamic response of the structure, the SOFiSTiK Commercial Software System has been used. The body has been discretised by 4-noded tetrahedral elements.

The aeroelastic behavior of the CAARC building model is investigated in this work, by analyzing its structural response under various different wind speed levels, corresponding to specific values of reduced velocities (VH/nW). The building was taken as solid body with mechanical properties from corresponding analysis from the literature. Some of our first results, in the form of buildings' deformation on T/4, T/2, and 3T/4 time levels, for reduced velocities equal to 4 (7a) and 10 (7b), are demonstrated in figure 6.

Extensive examination of aeroelastic phenomena for the CAARC building and detailed comparison with literature reviews is a promising work for the future.

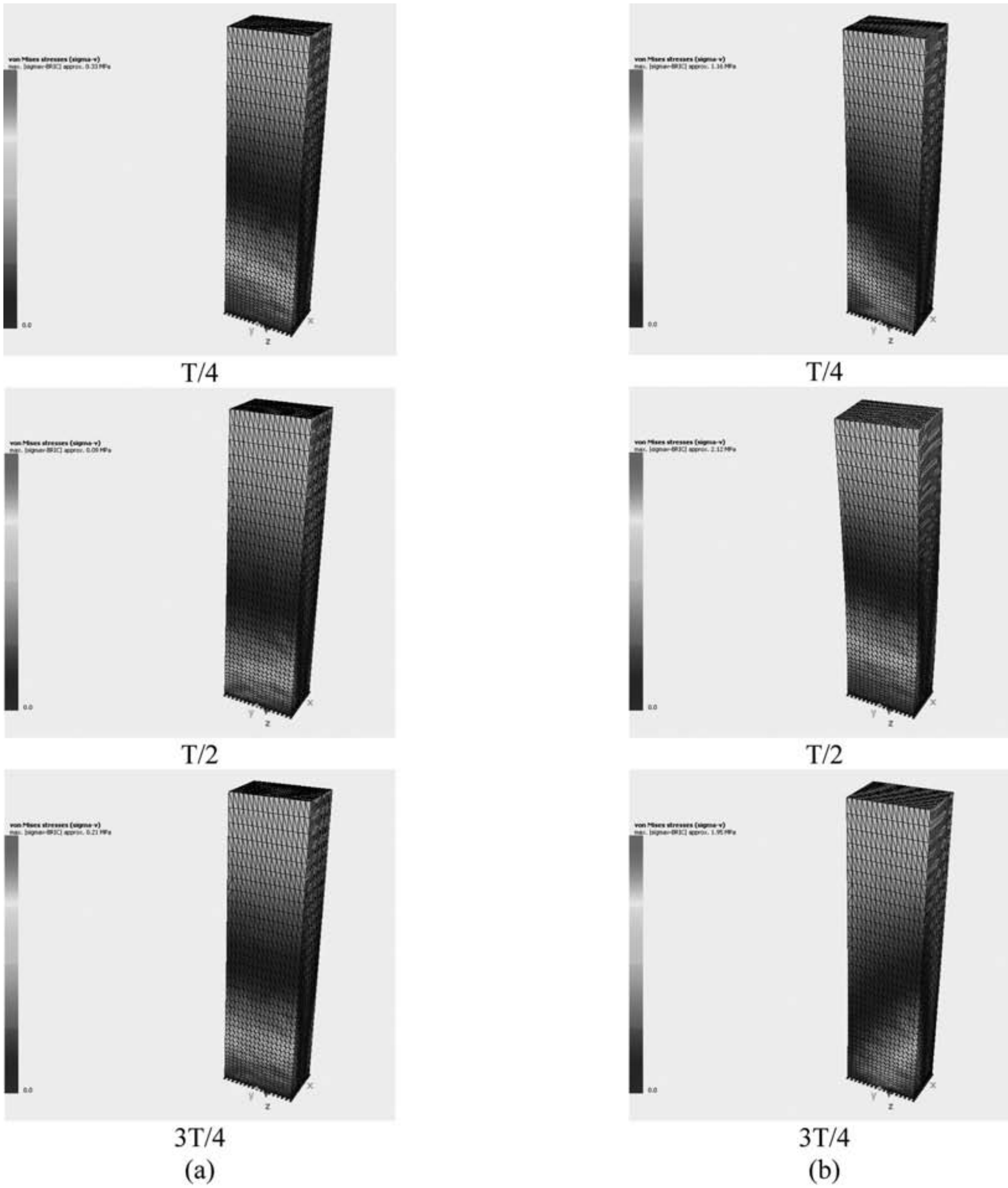


Figure 6. Deformed structure for reduced velocities equal to 4 (a) and 10 (b).

4 DATA INTEROPERABILITY

In addition to the requirements for the numerical simulation, the integration of different information resources places particular challenges to the design and methods of the integrated VWLab software platform. These challenges mainly result from:

– Diversity of the necessary information such as geometry, material, shape and surface texture of the building, geographic and topographic conditions of the surrounding site, structure and shape of surrounding buildings and wind climate data.
– The heterogeneous and distributed nature of this information,
– The diverse and heterogeneous data models and data structures for the formal description of the various information and

These problems will be tackled by using the IFC project model (ISO 16739) as common data model providing for interoperability between the different data models of the involved domains and additional methods for model filtering, manipulation and transformation. Thereby the most important issue is the (semi-)automatic generation and configuration of the fluid and the structural domain models required for CFD and CSD analysis. Given the architectural BIM as starting point the building envelope as well as the building structure will be derived by the application of a system oriented approach. This approach uses formal description of engineering systems based upon the IFC project model to define the building envelope system and the building structure system rather than an envelope or structural model. Based on the formal definition of the both engineering systems filter and configuration operations are defined to identify, extract and configure the building elements that are (potentially) part of these systems in/from a given architectural BIM. The filter and configuration operations are based on a generic filter framework defining a set of modular filter functions as well as operations and rules for their flexible combination to complex filter operations. The filter framework provides for deriving implicit model information and transformation that is a major task in order to enable the use of system-related topological, functional, geometrical and physical information for the derivation of the envisaged engineering systems. This process utilizes the GMSD-approach (Weise et al. 2003) combined with additional filter methods for filtering on class and object level (Katranuschkov et al. 2010). For example the identification of external walls that is the first step in the derivation of the building envelope has to be applied by involving physical and topological constraints defined on object level. These constraints will be defined in terms of specific filter functions that provide for mapping the constraints to the related concepts of the IFC project model thereby establishing the needed criterions for object selection.

However, the aerodynamic analysis process needs additional information that is not in the scope of the IFC project model. This encompasses e.g. information about the surface properties of the building envelope elements and the wind climate data. This information has to be linked to the actual IFC project model and the derived domain models respectively. On the other hand the analysis results have to be linked to the related elements in the actual IFC project model in order to enable the evaluation of the calculated wind loads and aerodynamic behaviour in the context of the overall building design. This will be realized by the adoption of the multi-model approach that provides for logical and semantically linking between model data contained in different data models (Fuchs et al. 2011). The resulting data model can be seen as an “aeroBIM” that contains the information needed for BIM-based aerodynamic analysis and evaluation.

5 THE VIRTUAL WIND LABORATORY

The Virtual Wind Laboratory (VWLab) defines an integrated software platform that is based on the principles of the common concept of a Virtual Engineering Lab. This concept was introduced in the frames of the ISTforCE project (Katranuschkov et al. 2001) and further developed within the HESMOS project (HESMOS 2010) with respect to the life cycle building energy management (Baumgärtel et al. 2011, Scherer et al. 2011). In the next sections the software architecture and the components of the VWLab, representing a specialized type of a Virtual Engineering Lab, are presented in detail.

5.1 *VWLab platform architecture*

The development of the VWLab in terms of an integrated software platform follows an UML-based approach with respect to the specific problems related to the numerical aerodynamic analysis representing an integrated part of the BIM-based design process. According to the proposed architecture of the IVEL (Baumgärtel et al. 2011) the resultant VWLab architecture applies a model-oriented approach focusing on the interoperability of the different domain models and a flexible application of the required numerical simulations as well as their integration into a distributed design environment. In order to ensure efficient collaboration between the involved actors and a flexible integration of the numerical simulation the development of the VWLab software platform utilizes the Service-oriented Architecture (SOA) concept and consequently applies a modular approach.

The VWLab architecture encompasses several services and applications, bound together by the VWLab core module. The core module acts as middleware that provides for interoperability of the needed data and the functionality deployed by the different services and modules respectively. The several modules of the VWLab are related to the identified actor roles according to the envisaged use case scenarios. The following modules were defined:

- Design module: The design module primarily comprises a CAD-system and related design tools. Primary use of the module is building and structural design. Main users are the architect and the structural engineer.
- Public access module: This module provides for a general purpose user interface. It is dedicated to support the accomplishment of aerodynamic studies of different design variants on various levels of detail via a VWLab GUI. Main users are the structural engineer and the expert for aerodynamic analysis. Other users may be subcontractors (e.g. façade manufacturer) and inspection engineers.
- CFD/CSD-computing module: This module contains the analysis and simulation tools for computational fluid and structural dynamics as well as their coupling for fluid-structure interaction computation. Main users are the (specialized) structural engineer and the aerodynamic analysis domain expert respectively.
- Reporting module: The reporting module serves for the generation of different reports and protocols for assessment and evaluation of analysis and simulation results used for decision support of the domain experts.

Each of these modules is principally exchangeable due to the application of standardized data models,

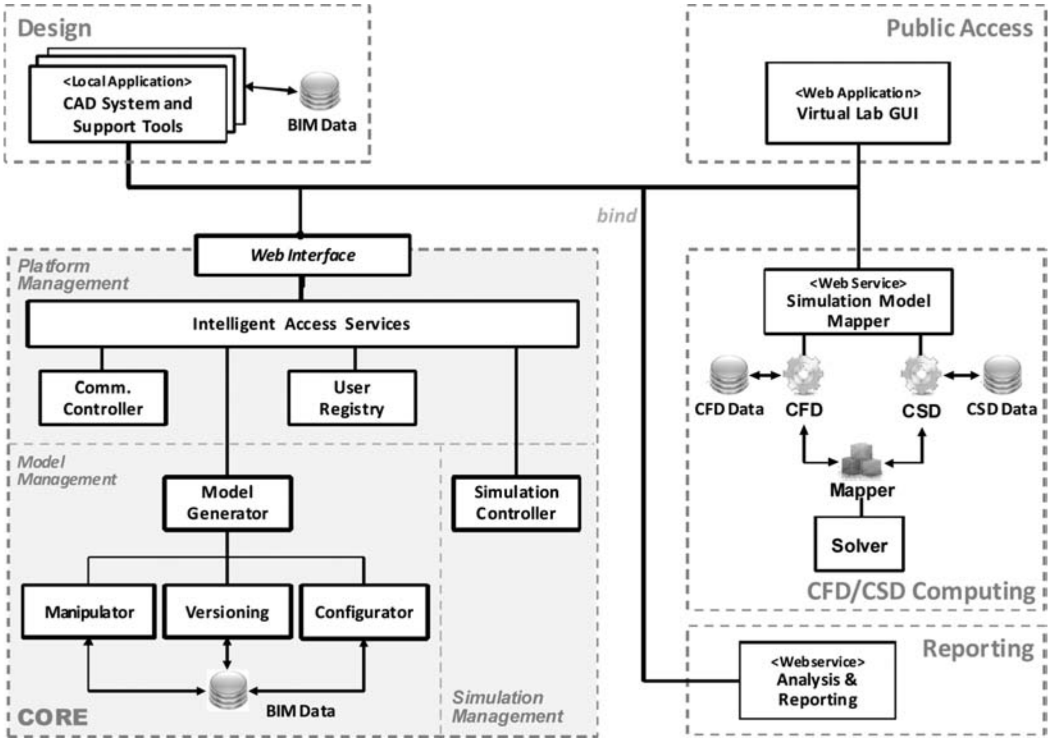


Figure 7. Software architecture of the VWLab.

specified information exchange requirements and programming interfaces (APIs). With exception for the core module each module has its own specialized user interface (GUI) that serves for the specific requirements and tasks of the different actors. The VWLab core is strictly service-oriented and accessed via WSDL-based interfaces. It controls the binding of all external modules and contains services for workflow control as well as data management (e.g. transformation of data models, model filtering and configuration, versioning etc.). The connectivity between the external services and the core module is enabled by the web-interface which establishes a homogenous interface based on the SOAP technology. The following types of software tools have to be considered with respect to the connection of the external modules to the VWLab core:

- Local applications: Typically, stand-alone software applications offering user access via their own GUI. In order to connect this type of applications to the VWLab they have to be extended by a VWLab connector component (on plug-in basis).
- Web applications: Typically stand-alone software applications that are connected directly to the VWLab core module and offering user access via a web-based GUI. The Virtual Lab GUI in the public access module represents an application of such type.
- Batch applications: this application type mainly refers to the software components dedicated to the numerical analysis and simulation (e.g. components for mesh/grid generation of the fluid and structure domain, numerical solvers for CFD, CSD and the domain coupling problem). These components offer either their own GUI or they are connected to an external user interface. In the context of the first prototypical implementation of the VWLab a file-oriented data input is designated that allows for easy application of plug-in based connection to the VWLab core.
- Web services: The web service application type encompasses software tools which are defined as services based on WSDL. All components of the VWLab core are web services.

Figure 7 illustrates the principle software architecture of the VWLab and its modules, components and software tools.

5.2 *Components of the VWLab core*

The VWLab core provides for different middleware functionality that is required for user management, data management and workflow and simulation control. The data management components comprise several functions for model mapping, data transformation, model linking, model filtering and versioning tasks. The workflow management integrates the data management functionality into the business processes that allows for (semi-) automatically execution of user specific workflows. The components of the VWLab core are assigned to three levels: a) platform management, b) simulation management and c) model management.

The access to the VWLab is established by the web interface and the Intelligent Access Services (IAS). The web interface integrates the external service and tools and is accessible via a web application. It is service provider and service requester at the same time. The IAS provides for interpretation of user requests regarding the associated data models and offers support to the web interface.

The User Registry component is dedicated to the storage and management of the user data with respect to specific user roles and access rights assigned to it. Each user role defines a certain user-oriented view on the software platform and is additionally related to the actual workflow.

The Communication Controller provides for communication management between the several software tools and the web services. It routes the service requests to the addressed web services and monitors the status of the requested web services. If a requested service is not available the Communication Controller offers a directory of services that are applicable alternatively.

The Simulation Controller manages the superior simulation workflows including pre- and post-processing tasks. It checks for integrity of the input data and launches service requests for generation of the right data format that is appropriate for the envisaged simulation process. Additionally, the Simulation Controller provides for coordination of multiple simulation processes computed in parallel.

The model manipulator provides primarily for model checking and model filtering functionality. It checks model conformance related to the minimal requirements that have to be fulfilled for the generation of the different domain models. For example it will check the completeness of the spatial structure of a certain building model or whether it contains 2nd level space boundaries. According to the level of model quality the appropriate method for the generation of the building envelope system will be selected. This task is strongly related to the model filtering capabilities of the Model Manipulator component. It encompasses filtering on schema, class and object level that is an essential prerequisite for the generation of domain, ad-hoc and multi-model views (Katranuschkov et al. 2010).

The Model Configurator accounts for the generation and configuration of the domain models and their preparation for the numerical simulation. This encompasses the transformation of the architectural BIM into the domain systems, namely the building envelope system and the structural system as well as their transformation into the domain models. Additionally the Model Configurator offers functionality for the enrichment of the domain model with information that is missed in the (actual) IFC project model, e.g. information regarding the topographical properties of the surrounding area, wind climate data or specific physical and mechanical properties of the façade and structural elements.

The Versioning component allows for linked storage of model and simulation data related to different users and provides for various comparison and evaluation functionality. It will enable the evaluation of different versions of the same building model and their contextual assessment in order to optimize the aerodynamic behavior of the building structure with respect to architectural and structural design constraints.

6 CONCLUSIONS

The proposed approach aims to enhance the traditional aerodynamic analysis process of building structures in consideration of the BIM-based work paradigm as well as aeroelastic and fluid-structure interaction phenomena. It comprises numerical methods allowing for complete computational treatment of the fluid and structure parts of the aerodynamic analysis and their coupling as well as an integrated software platform that provides for comprehensive aerodynamic design studies and full integration of the aerodynamic analysis process into the overall BIM-based design process. The integrated software platform is designed in terms of a virtual engineering lab by applying the service-oriented architecture concept in order to provide for flexible integration of the different software tools needed for design, aerodynamic simulation, data and user management based on a consistent communication provided by the XML-based SOAP protocol. The prerequisite data interoperability will be achieved by the application of several model filter, manipulation and transformation methods as well as additional functionality for model linking. The proposed aeroBIM data model integrates the involved data models on logical and semantical levels and serves for the numerical procedure as well as for sophisticated evaluation capabilities in the context of the overall building design.

The VWLab is supposed to reduce the number of expensive experimental studies, to enable computational treatment of several aerodynamic control mechanisms by enabling comprehensive design studies of multiple design variants and to close the gap between aerodynamic analysis and architectural design.

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Practical application of a newly developed automated building energy-analysis software module prototype

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ABSTRACT: One key challenge when it comes to developing industrial building concepts for the housing industry is improving the energy performance of buildings, while at the same time ensuring that the end product remains affordable and attractive to customers. This paper summarises the findings from the application of a newly developed prototype for an automated energy-analysis software module in a real-life project. The prototype is used for the energy analysis of the low-energy, multi-family residential P303 concept developed by NCC Construction Sverige AB – a leading construction and development company in the Nordic region. A building concept is based on continuity and repetitions of most of the building components. Most of its characteristics are known and defined beforehand and only a few parameters vary due to the adaptation of the concept, for example, the configuration or site location. In energy performance calculations, the proposed energy-analysis software module prototype processes the known parameters as constants and only varies the unknown parameters. The energy calculations are then carried out by the calculation kernel from the dynamic building simulation software module, VIP Energy, and the result is exported to an Excel spreadsheet where it is presented in a table. This makes it possible, in a practical manner, to execute a larger number of performance analyses in a shorter time, investigating different design alternatives and configurations and thereby facilitating optimisation towards the best possible design solution. The case study presented in this paper simulated energy losses through the building envelope of a real P303 building. The parameters that were varied are the location and orientation of the building and various energy characteristics of windows/glazing.

1 INTRODUCTION

1.1 *Industrialised concept buildings*

Construction companies manage user requirements first and foremost through their business philosophy, which focuses on certain customer segments. As things stand, there is a well-established construction process and an approach involving the developer, the constructor and the authorities. Through this process, a project slowly develops and a number of compromises, negotiations and agreements must be completed by everyone involved before this project can be realised. This process is in no way compatible with an industrial concept construction and it is the reason why new and untested solutions are tested time and again in real-life construction projects. In an industrial concept construction, the client should not tell the constructor what to build. Instead, the constructor should tell the client what his/her product has to offer. From a strict industrialisation perspective, the optimal solution is a concept based on mass production. However, as the construction industry traditionally works almost exclusively with one-off products, it is necessary for these two principles to meet by developing concepts that can be adapted to the site in question. Depending on the amount that can be specified in advance before the client places an order, different types of industrial concept can be identified, see Figure 1.

In the traditional construction process in Sweden, the starting point is normally standards and norms such as the construction regulations, BBR, issued by the Swedish National Board of Housing, Building and Planning. The development of what are known as technical platforms, such as NCC Bostäder (NCC Homes), based on methods and solutions designed in advance which are integrated and adapted to projects in a traditional planning process, is often based on templates. Even if the actual planning process is not influenced to any real degree, the use of platforms is based on the owner of the concept (the construction company)

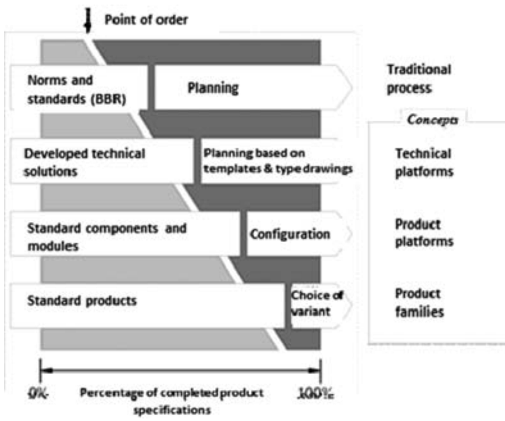

Figure 1. Concept categorised according to the location of the order point in relation to the percentage of completed product specifications, adapted according to Hvam et al. (2008).

acting as the total contractor and thereby being able to ensure that the design of the project falls within the framework of the technical platform.

Configurable concepts or product platforms are more flexible than product families, but they also have more limitations compared with technical platforms. A business-strategy tool also defines the conditions with which a construction project needs to comply. The planning is replaced by a configuration process in which the production of performance documentation and building documents can be more or less automated. Examples of configurable concepts are the Sweden company Lindbäcks Bygg's volume construction system and PartAB's bathroom furnishings and fittings. NCC Komplett, which no longer exists, was an example of an element-based configurable concept.

In principle, a product family consists of finished buildings with few variables within the framework of a concept. These variables can include the number of floors, number of staircase entry blocks, balcony positions, entrance positions, foundation type, colour schemes and other cosmetic features. The planning process is largely replaced by a sales process in which performance documentation and building documents are generally produced in advance. Examples of the concepts that are produced in the product family category are NCC's P303, Skanska's and IKEA's BoKlok (Live Smart) and SKANSKA ModernaHus (Modern Buildings). BoKlok produces "small buildings" in the form of detached houses, terraced houses and apartment blocks. Its largest product by far is a multi-family residential building with six apartments on two storeys. SKANSKA ModernaHus produces apartment blocks, three- to eight-storey staircase entry blocks or tower blocks.

In so-called product platforms and product families, where the potential for customer adaptation is reduced, it may be important to be involved in the developer's/ customer's process at an early stage in order to offer suitable alternatives. Sometimes detailed plans,

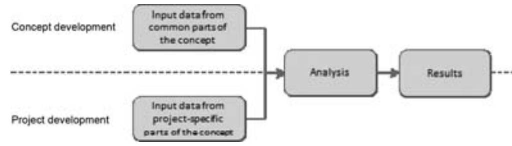

Figure 2. Performance analyses of industrial concepts in con-cept development and project development.

illustration plans and drafts can include requirements that make the use of a concept impossible. Instructions relating to building measurements, heights, setback apartments, roof designs and so on can be very difficult if not impossible to comply with if they are too detailed.

1.2 *Energy analyses in concept development and project development*

Every kind of concept has an organisation for management, the handling of further development, purchasing and follow-up. This organisation is also responsible for producing and following up the performance of the tendered product. Energy consumption is part of the performance of the tendered product and enables the developer to compare it with the functional requirements the client organisation has drawn up.

Unlike the traditional construction process, an industrial concept construction process is made up of two separate processes; a concept development process (cf. product development process) and a project development process (cf. sales process) when the concept is customer adapted to needs and location.

In some ways, concept development resembles a standard planning process in that performance analyses of the concept must comply with the functional requirements that are set. The difference is that the requirements do not come from a specific customer but instead represent a market segment. The market analysis also determines the type of concept that is going to be developed and the number of variants that are going to be offered. Performance analyses, such as energy analyses, are conducted in the same way as standard planning in order to develop concepts with attractive characteristics.

In project development, i.e. when the concept needs to be adapted to customer and location, performance analyses can significantly simplify matters. A large part of the concept characteristics or input data will be the same and will be known in advance; in other words, only the characteristics that vary (influenced by customer adaptation) need to be defined, Figure 2. As a large part of the time in an energy analysis in a traditional planning process, for example, is spent on defining the necessary input data, the time needed to conduct performance analyses of industrial concepts and product variants can be significantly reduced (Racz et al., 2010).

Additional streamlining, and automation, can be achieved by integrating different performance analyses and choices of product configuration in so-called

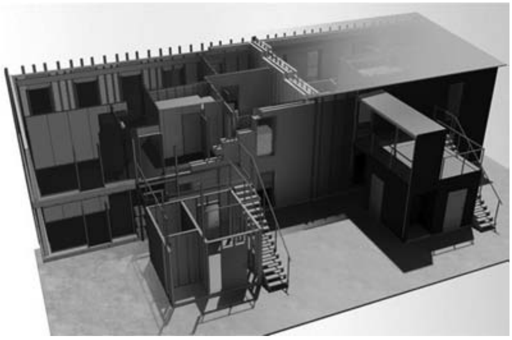

Figure 3. NCC's P303 concept, two–storey detached or terraced houses, source: www.ncc.se

configuration systems. An example of the automation of energy analyses of NCC's P303 concept is given in the next section.

2 PRACTICAL APPLICATION OF A NEWLY DEVELOPED AUTOMATED BUILDING ENERGY-ANALYSIS SOFTWARE MODULE PROTOTYPE

2.1 *NCC P303 concept*

This section illustrates the opportunities offered by automatic energy planning and the configuration of the P303 concept. P303 (Byggsystem (building system) – a new way of building homes – NCC, see http://www.ncc.se/sv/Projekt-och-koncept/Byggsystem-och-produkter/boende-hyresratter), is a concept comprising a multi-family residential building with two storeys that can be configured as detached or terraced houses, Figure 3. The energy consumption should be low, maximum approximately 60 kWh per square metre and year. The buildings are delivered ready to occupy at a fixed price (from SEK 11,995 SEK per square metre) and have a construction time of around four months.

The buildings can be delivered with different apartment configurations, see Figure 4:

- $2 \times 54\,m^2$ BOA (living area), two-room apartments (E22),
- $2 \times 67\,m^2$ BOA, three-room apartments (E33),
- $2 \times 82.8\,m^2$ BOA, four-room apartments (E44).

2.2 *Developed prototype for energy planning and configuration of P303*

During project development, when the concept has to be adapted to suit customer and location, performance analyses of energy consumption and costs, for example, can be significantly simplified. A large part of the concept characteristics or input data will be the same and will be known in advance for all the product variants, i.e. only the characteristics that vary (influenced by customer adaptation) need to be defined.

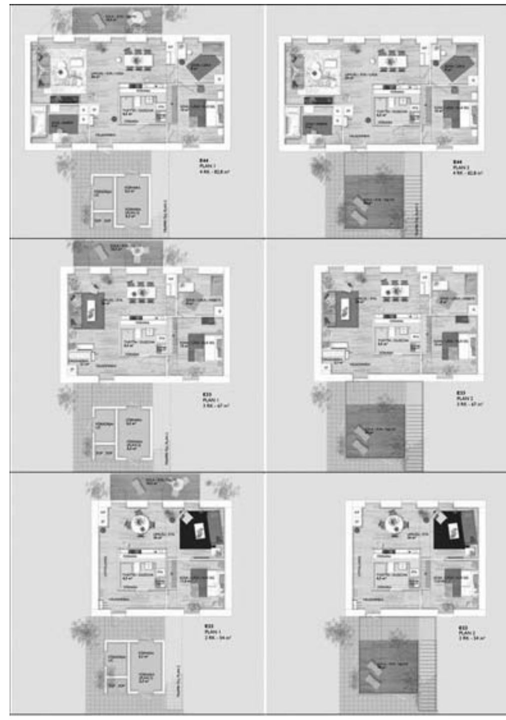

Figure 4. P303 three module configurations, E44 – 4 rooms and a kitchen, E33 – three rooms and a kitchen and E22 – two rooms and a kitchen.

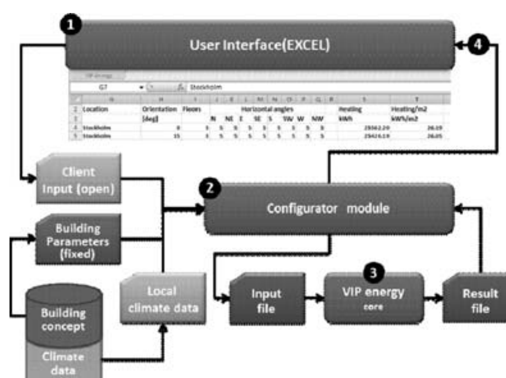

Figure 5. Demonstration prototype developed for configuration and performance analysis of P303.

Different performance analyses and choices of product configuration can then be integrated in so-called configuration systems.

This demonstration of the configuration and calculation of energy performance only includes transmission losses, i.e. the factor that is primarily influenced by climate characteristics.

Figure 5 shows a flow chart of the developed configuration prototype (see also Racz et al., 2010).

Excel (1) has been used as the user interface for open parameters and the presentation of results and as a tool for supplementary calculations and presentations. The configurator (2) scans the open parameters from Excel and the locked parameters and climate data from a database to generate input data to the VIP calculation kernel. When the energy calculation is complete (3), the configurator scans the result from the output data file, calculates the production costs and collates the information in Excel (4).

The configurator can be used in the manual mode or the optimisation mode. In the manual mode, the result is calculated from open parameters that are given in rows. The open parameters that are varied in this demonstration are location, building orientation in relation to north, configuration (i.e. the modules that are used and connected, see Figure 4), window characteristics (U value and solar energy transmission %), as well as solar radiation angles in different directions. These solar radiation angles are connected to the choice of location.

The result of the calculation is the transmission loss by the configuration, expressed as kWh per year and kWh/m2 BOA and year, together with a simplified cost estimation including cost of land (including the developer's costs) and building construction cost.

According to the BBR regulations, the energy performance per m2 of the heated area, Atemp, is presented. The reason why the energy consumption in this demonstration is shown per m2 of BOA is that the investment costs are calculated as SEK/m2 of BOA. The result for the energy performance per m2 of BOA can easily be re-scaled to m2 Atemp in a real-life case.

To evaluate the different alternatives, a decision-making support module based on the Smart DMF decision-making framework (Schreyer et al., 2010; Schade et al., 2011) has been implemented in the configuration program. The Smart module combines Key Performance Indicators (KPIs) calculated using utility functions reflecting user preferences and the criteria comparison and ranking method of Saaty's Analytical Hierarchy Process (Saaty, 1980).

The evaluation is based on five criteria, three of which are subjective and two objective. The subjective criteria are location, building orientation in relation to north and the selected configurations. The objective criteria are based on the investment costs and the energy consumption for heating (in this case only the transmission losses) per m2 of BOA. The combined result is presented in the form of a rating where 100% is the highest rating that can be given symbolising the fact that the alternative complies with all the developer's requirements for all criteria.

In the optimisation mode, the open parameters that are going to be varied are specified. The configuration program automatically calculates the number of alternatives that are going to be analysed and it then performs the analysis and presents the alternatives that produce the highest rating. If, for example, three locations, with four orientations at each location and five configurations with two window types for each configuration are going to be analysed, this means that the configurator is going to analyse $3 \times 4 \times 5 \times 2 = 120$ variants, where the variant that produces the highest combined rating will be presented.

Table 1. Open parameters in the manual mode. One set of parameters per row.

Location	Orientation [deg]	Configuration	Window		Incident angle of solar radiation							
			U value	transmission	N	NE	E	SE	S	SW	W	NW
Malmö	90	E22+E33+E33+E44	0,80	60	5	5	10	15	15	10	5	5
Malmö	90	E33+E33+E44+E44	0,80	60	5	5	10	15	15	10	5	5
Göteborg	60	E22+E33+E33+E44	0,80	60	10	15	10	20	20	10	30	30
Göteborg	60	E33+E33+E44+E44	0,80	60	10	15	10	20	20	10	30	30
Stockholm	0	E22+E33+E33+E44	0,80	60	30	25	20	25	15	15	10	10
Stockholm	0	E33+E33+E44+E44	0,80	60	30	25	20	25	15	15	10	10
Luleå	45	E22+E33+E33+E44	0,80	60	25	15	10	5	5	10	5	5
Luleå	45	E33+E33+E44+E44	0,80	60	25	15	10	5	5	10	5	5

Table 2. Results of different configuration alternatives.

Location	Configuration	Area	Transmission loss		Cost	Rating
		m2	kWh	kWh/m2	Kr/m2	%
Malmö	E22+E33+E33+E44	542	7946	14,7	18422	83
Malmö	E33+E33+E44+E44	599	8986	15,0	17820	85
Göteborg	E22+E33+E33+E44	542	8570	15,8	18422	88
Göteborg	E33+E33+E44+E44	599	9749	16,3	17820	90
Stockholm	E22+E33+E33+E44	542	10374	19,1	21589	72
Stockholm	E33+E33+E44+E44	599	11798	19,7	20684	73
Luleå	E22+E33+E33+E44	542	13481	24,9	15255	83
Luleå	E33+E33+E44+E44	599	15245	25,4	14957	83

2.3 *Configuring P303 in the manual mode*

Table 1 shows P303 variants that are going to be analysed in the manual mode; two configurations (E22 + E33 + E33 + E44 represents two two-room apartments, four three-room apartments and two four-room apartments) in four different cities in Sweden. The other open parameters are kept constant. Please note that the solar radiation angles are linked to the choice of location.

The next table, Table 2, shows the result of the configuration:

- Living area (BOA) for different alternatives
- Total transmission losses (kWh) per square metre of BOA (kWh/m2 BOA) and year
- Cost (kr/m2 BOA) of contracting costs including estimated land and developer's costs
- Combined rating for decision criteria: location, orientation, configuration, energy consumption (transmission loss) and investment costs.

The rating is dependent on the values and criteria that are regarded as important for the investment decision.

In the above examples, one of the configurations (four three-room apartments and four four-room apartments) emerges as the most optimal with a location in Gothenburg. In the following sections, we are going to optimise the orientation and choice of sealed double-glazed windows.

2.4 *Configuration of P303 in the optimisation mode*

To optimise the orientation and choice of sealed double-glazed windows, the window types and orientations that are going to be investigated must be

Table 3. Configuration in the optimisation mode.

Location	Orientation [deg]	Configuration	Window		Incident angle of solar radiation							
			U value	transmission	N	NE	E	SE	S	SW	W	NW
Göteborg	0	E33+E33+E44+E44	0,80	50	10	15	10	20	20	10	30	30
	45		1,00	60								
	90		1,20	70								
	135											
	180											

Table 4. Results in the optimization mode.

	Orientation	Window		Area	Transmission loss		Cost	Rating
	[deg]	U value	transmission	m2	kWh	kWh/m2	EUR/m2	%
Progress	180,00	0,80	50	599	9593	16	17820	82
Optimal	0,00	0,80	50	599	9749	16	17820	90

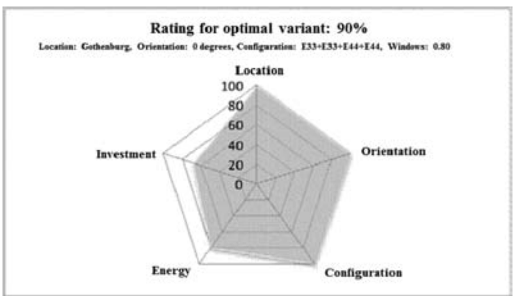

Figure 6. The rating for the optimal variant for the different decision criteria. Ratings are given from 0–100%, where 100% indicates that the decision criteria have been fully complied with.

determined. The location and configurations are kept constant, see Table 3.

The number of variants is $1 \times 5 \times 1 \times 3 = 15$. The result of the analysis, which takes a few seconds, is presented in an Excel table in which the Progress row shows the result of the latest analysis, while the Optimal row shows the alternative which obtains the highest rating, see Table 4.

Instead of the combined rating, it is possible to study the ratings the selected alternative obtains for the different decision criteria, Figure 6.

3 CONCLUSIONS

An "energy configurator" has been developed to make the product and project development of so-called concept construction more efficient (Racz et al., 2010). Its use has been demonstrated on NCC's P303 concept where the configuration in product and project development has been optimised on the basis of both subjective and objective criteria which are thought to resemble a specific customer segment. Hundreds of alternative designs can be evaluated in just a few minutes, compared with days and weeks, if the same analyses were made manually using energy calculation software with manual data input. This also opens the door to the more straightforward inclusion of clients and other skills in order to develop the decision-making process towards an improved end product.

This is the first time NCC has tested this prototype with a view to automating the energy-analysis process in a real-life project. We feel that this working method is effective and has enormous potential when it comes to creating benefits in projects involving concept construction. We can also confirm its user friendliness and reliability in terms of energy calculations. We suggest that the further development of the prototype should include the storage and handling of input data, the preparation of sets of input parameters, relating to areas such as installations, user characteristics and climate, and that the "visual interaction" in the Excel-based user interface should be developed to support improved interaction and decision-making and to connect it to external sources and software.

It would also be interesting to use a system set-up other than VIPCore calculation engine as the calculation engine. Is this possible and how would a system of this kind differ in terms of applications and use?

The next step for NCC when it comes to automated energy analyses is to continue using the proposed prototype in additional and more comprehensive tests, including all the necessary parameters, to calculate the energy performance of a building (not just the energy shell) and to analyse project-related organisational and implementation aspects and how [using the proposed working method] decision-making can be further streamlined at an early stage.

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eWork and eBusiness in Architecture, Engineering and Construction – Gudnason & Scherer (Eds)

Building information modeling supporting facilities management

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ABSTRACT: The advancements in building information technologies are leading to new approaches and methodologies to work in more collaborative environment. HESMOS is a European FP industry project which goal is to provide a holistic approach for sustainable optimization of energy performance and emission (CO_2) through integrated design and simulation, while balancing investment, maintenance and reinvestment costs. The product of HESMOS is an Integrated Virtual Energy Laboratory (IVEL) for energy and emission studies of buildings. The IVEL integrates different tools for design and lifecycle management. This paper describes the integration between the building automation systems (BAS) with the energy-enhanced BIM (eeBIM) using an ontology along with the integration of the facilities management tools of the IVEL platform utilizing web services.

1 INTRODUCTION

The last decade the building industry has experienced major changes with the use of building information technologies. Building Information Modeling (BIM) has been a dynamically growing topic in the industry due to the extensive documented benefits during design and construction; yet, the Facilities Management (FM) phase has lacked the same level of successful BIM implementation. A growing number of stakeholders, especially owners and operators, are now focusing in implementing BIM to support the FM and operations phase with an emphasis in improving energy efficiency of their facilities.

Energy efficiency and reduction of greenhouse emissions are major concerns in the building industry. In Europe, buildings account for 41% of primary energy consumption of which 85% is used for heating and cooling and 15% for electrical energy. Overall, buildings account for 35% percent of the primary energy use to achieve comfortable indoor conditions and 6% per electrical energy (Siemens, 2011). In addition, CO_2 emissions are continuously increasing with the consumption of fossil fuels. Currently, energy generation and consumption cause approximately 94% of CO_2 emissions. Considering these significant figures the European Union has been working in different strategies committing to reduce energy consumption and greenhouse gases by at least 20% compared with 1990 levels in 2020 (EC 2011). For instance, the European Commission through the 7*th Framework Programme for Research and Technical Development* (FP7) is co-funding research projects which one of their objectives is to strengthen the scientific and technological base of European industry.

1.1 *European FP7 project – HESMOS*

HESMOS is an European FP7 industry driven project whose goal is to provide a holistic approach for sustainable optimization of energy performance and emission (CO_2) through integrated design and simulation, while balancing investment, maintenance and reinvestment costs. The project is targeted particularly to the demand of Public Private Partnership (PPP) and Building Operate Transfer (BOT) providers for an integrative view on energy efficiency and cost balance over the building lifecycle. HESMOS main objective is to integrate different existing CAD, Building Automation Systems, eeTools (energy efficient) and Facilities Management tools by building up a virtual energy laboratory. The purpose is that different stakeholders can work in a collaborative environment enabling them to have information concerning energy efficiency and lifecycle costs in order to improve the decision making process (Katranuschkov, et al., 2011). The product of HESMOS is an Integrated Virtual Energy Laboratory (IVEL) for energy and emission studies of buildings (Figure 1). The IVEL is an ICT design and lifecycle management platform that will be used during design, operation and refurbishment/retrofit for building solutions upon existing software tools for building design, energy analysis, simulation, BAS and

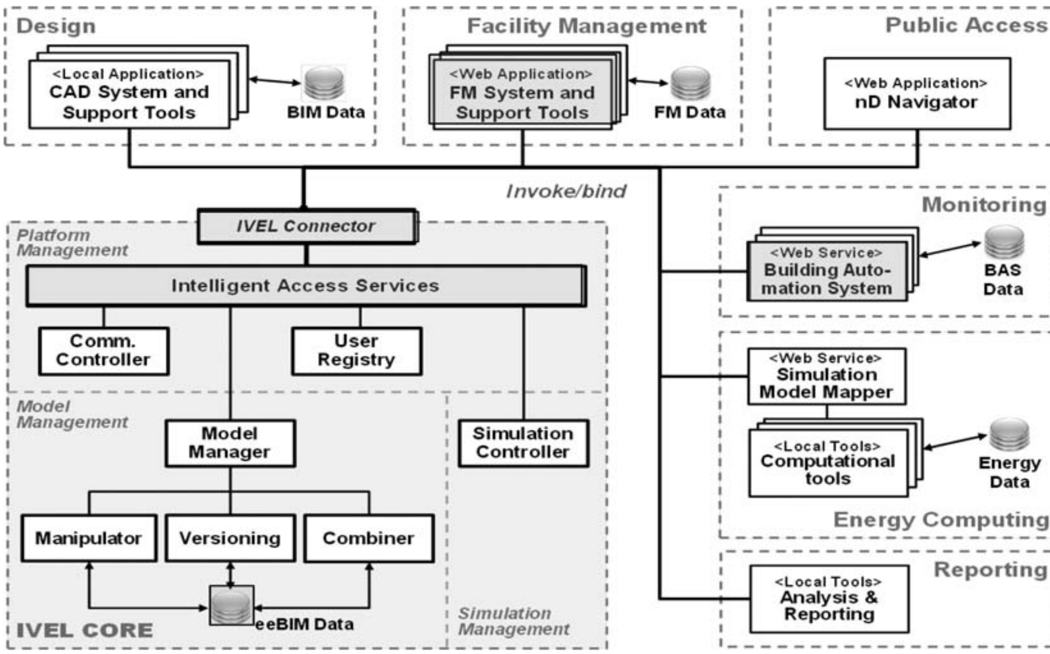

Figure 1. Architecture of the IVEL and the key components supporting FM in green color.

cost calculation making them interoperable via common energy extended information structure and a set of related infrastructure services. There are different applications modules in the IVEL core. Some of them are responsible for the BIM data creation; other tools are responsible for the enrichment of the existing data. The eeBIM is the central component of the IVEL core which is an extended version of BIM that contains the whole information and data to provide the necessary input for every IVEL application. The eeBIM is defined as a collection of well-structured files and databases in different application formats with the pecularity that they are related to each other via a common link model (Siroky, et.al.,2011).

In this paper the focus is on one of the HESMOS goals to integrate the eeBIM with the Facilities Management tools and the BAS systems utilizing web services for operations and maintenance. Specifically, the aim to provide energy-related tools and web services for the intelligent lifecycle management of public use facilities that are capable to resolve operating problems, improve comfort, optimize energy use, identify retrofits and provide related cost estimates, all of these being very important for monitoring and energy efficiency management.

2 BIM AND BAS INTEGRATION

2.1 *Building automation systems*

For existing and new buildings an important focus has been in the use and update of building automation systems (BAS). BAS have proven to better monitor and control energy consumption thus improving the quality performance of the building and improving energy efficiency. The European Standard EN 15232 ("Energy performance of buildings – Impact of Building Automation, Controls and Building Management") was created to describe the methods for evaluating the influence of building automation and technical building management on the energy consumption of buildings. According to EN 15232, the overall energy consumption can be reduced by 12% by using building automation systems and making a significant contribution to EU savings targets of 20% reduction by 2020. However, BAS systems usually contain isolated information and their full benefits have not been exploited yet. The raw measured data delivered resides in the BAS system has not been accurately integrated with other applications like building information modeling or facilities management tools that can do better use of this information by reporting and linking this information in a more efficient way.

2.2 *BIM – BAS Ontology*

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

The ontology is used to link BIM and BAS together. The link between the BIM ontology and the BAS

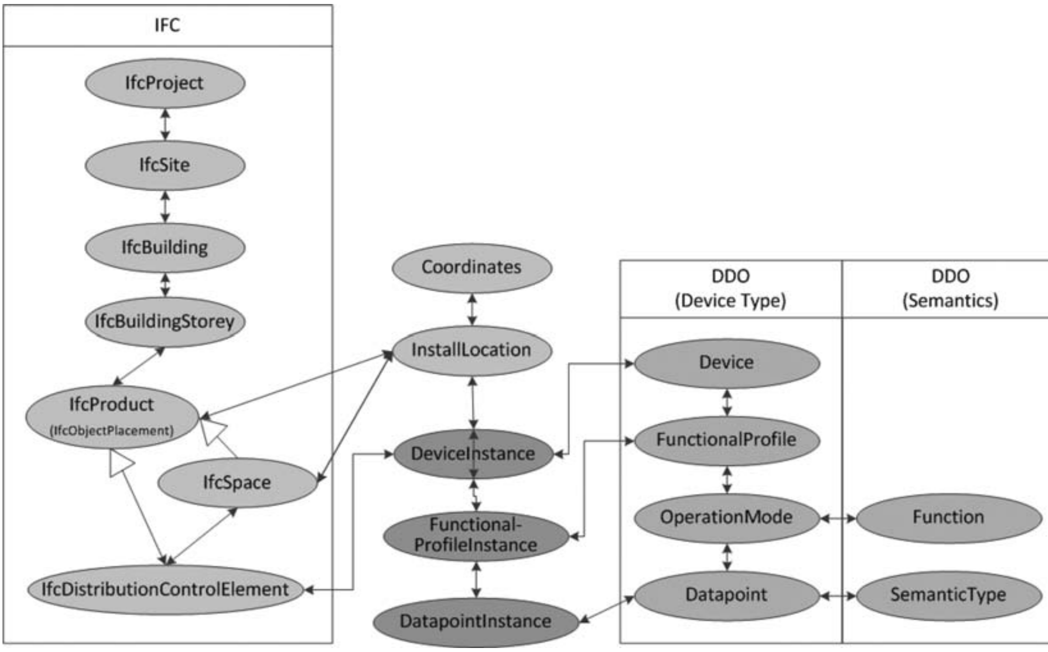

Figure 2. Simplified overview of the ontology combining eeBIM and BAS.

ontology is done by mapping a physical device to a room (IfcSpace) or to a building element like a wall (IfcBuildingElement or more general, ifcProduct) See Figure 2. The reason is that there are two types of sensors: Sensors measuring quantities of spaces like room temperature, room humidity, room air quality etc., and sensors measuring quantities of walls between spaces, e.g. heat flow sensors, heat transfer coefficient sensors etc. Also coordinate information (location) can be added for sensors where this is important. E.g. it is important for exact energy evaluation whether the temperature is measured near a window or near a heat source. The third target for mapping BAS devices is an IFC BAS device (IfcDistributionControlElement, including the new entities IfcSensor and IfcActuator of IFC2x4), what is rare in current IFC files.

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

There is also a simple view on the mapping ontology which is intended to be used by building operators which are not familiar with BAS technologies, only with the “application layer” of their own BAS system. That means that these persons usually know an ID and the location of each measurement point but not details about the used technology.

For better comprehension, a (simplified) part of an example building modelled using the simple ontology version is given in Figure 3.

More details about this ontology can be found in (Ploennigs, 2012).

3 BAS AND FM TOOLS INTEGRATION

Additionally to the BIM-BAS integrations, this paper presents the development of the web service and data interface client for energy related facilities management. Web services are utilized to integrate sensor data collected by building automation systems (BAS) with the tools of the Facilities Management IVEL module.

3.1 *Web services*

In HESMOS, web services are utilized as the method to transfer measured sensor data collected from the BAS systems into energy-related performance management and energy-related requirements management. This method enables better integration of BAS data with energy related management systems. The purpose of using web services is that allows working with services independent of the platforms and programming languages in which they are written.The key component of web services is the internet protocol XML (eXtensible Markup Language). XML is the universal format for structured documents and data on the web. It represents content in a textual format that is platform and language neutral. XML can separate the user interfaces from structured data making possible to integrate the data which comes from different sources.

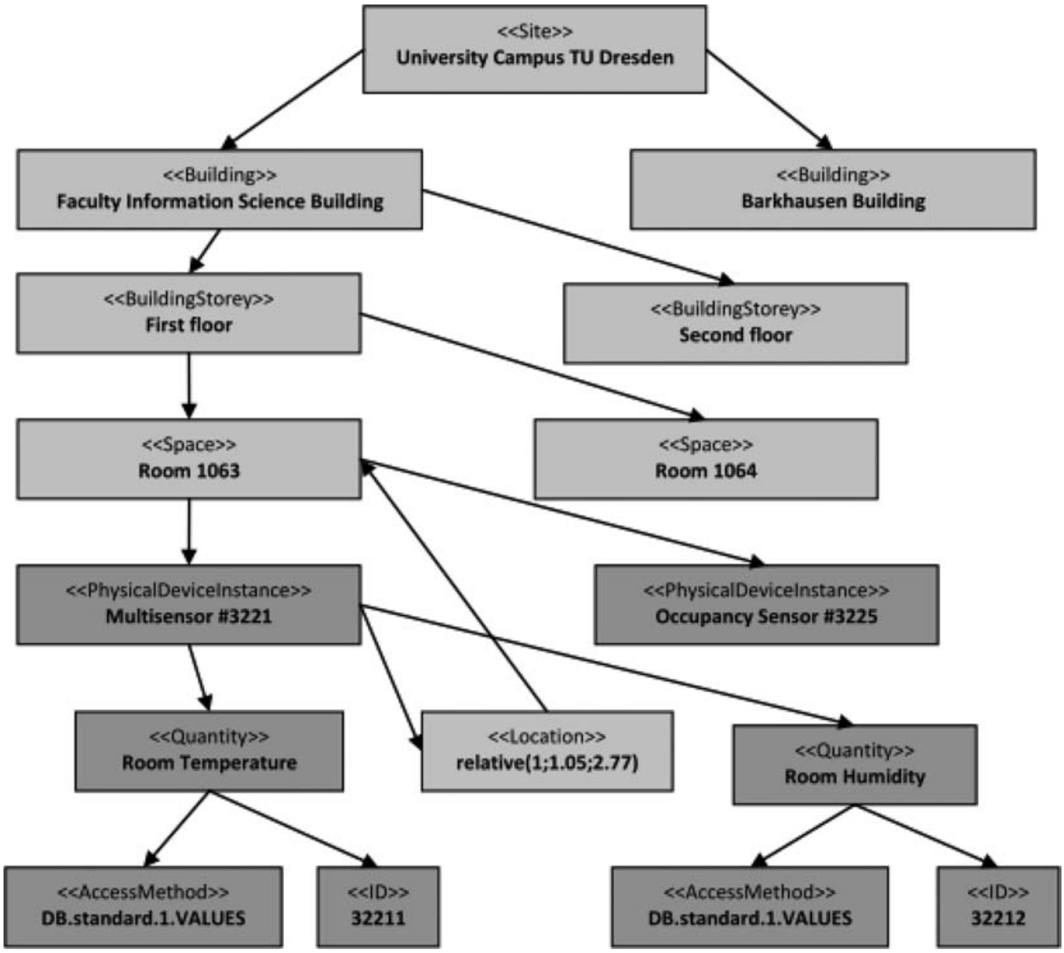

Figure 3. Example building modelled using the simple view on the ontology.

Many buildings use different levels of BAS systems. In many cases the information is not transferred in XML format but it can be delivered in other formats such as xls, csv or txt. For that reason an XML converter will be developed in HESMOS to convert the information into an XML-file format. An example of that file is shown in Figure 4.

The measured data is placed in the section named <CONDITIONFILE>. The basic idea is to send data values for selected data points (<LogPoint>) in a time tag section named <LogResult>. The time tag is defined with special fields for each time concept (year/month/day/hour/minute/second). The type-attribute contains information about type of data and the unit for the data. In addition to temperature measurements other XML files will contain information about room humidity, CO_2 levels and concrete core temperatures.

3.2 *Use case scenarios*

In order to cover applications for new and existing building that utilize BAS systems, two case scenarios are presented that integrate sensor data with FM tools.

1. The first case is typically used in new buildings with higher level, web-based BAS systems.
2. The second case is used for existing buildings with different levels of BAS systems.

3.2.1 *Use case 1*

Use case scenario 1 focuses on a new or existing buildings with higher level web based BAS systems. The information delivered will be related to energy spatial thermal conditions. The requirements management systems ROOMEX already provides as-required and as-analyzed thermal conditions. In HESMOS as-measured sensor data for specific times will also be provided in order to have more information to perform comparisons regarding actual measured thermal conditions in a building. In this case scenario a user will log in to the IVEL connector providing a username and password. The IVEL connector is the portal application where web services can be chosen and connected

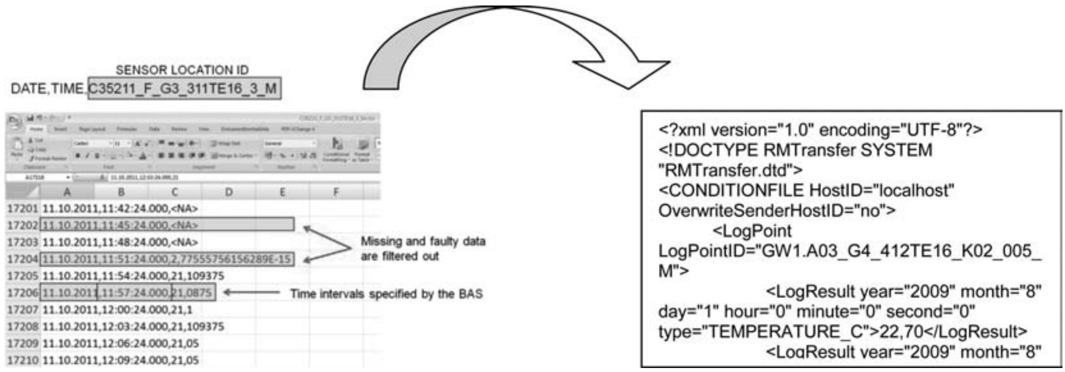

Figure 4. XML-Convertion from csv to XML.

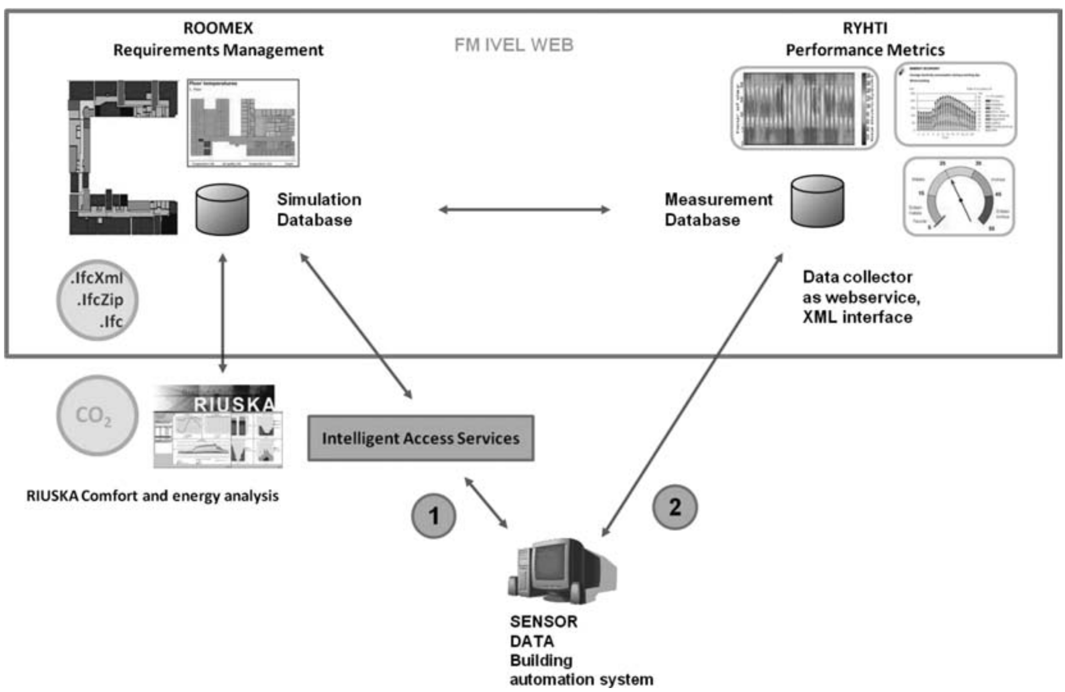

Figure 5. Description of data transfer of the two use case scenarios.

to each other. The Intelligent Access Service (IAS) of the IVEL get the information from the IVEL connector and the user can access to other applications such as the building automation sytems. Sensor data can be accessed through the IAS by a specifying filter, for instance, room temperature for a specific period of time can be selected from the interface. The basic connections are shown in Figure 6.

The user can request data of actual measured values and times from ROOMEX through webservices. For that purpose a list of Ifcspace "names" and Attribute Keys (temperatures, humidity, CO_2 levels, etc) of the measurements values that are requested for specific starting and ending time (StartDataTime and EndDateTime) has to be provided. The web service response will deliver the measured values of the IfcSpace "names" and Attribute Keys within the time interval requested. The requested values will not be stored in the ROOMEX database. In addition to actual measured data, average, minimum and maximum values can be requested through the IAS to make comparisons with designed values stored in ROOMEX database.

3.2.2 *Use case 2*

Use case scenario 2 focuses in existing buildings that utilize different level building automations systems. Measured sensor data obtained from building automation systems (BAS) will be transferred into energy related performance management RYHTI Metrics. The purpose is to obtain actual measured data to improve energy performance of the heating, ventilation and air conditioning (HVAC). This aims to reduce energy

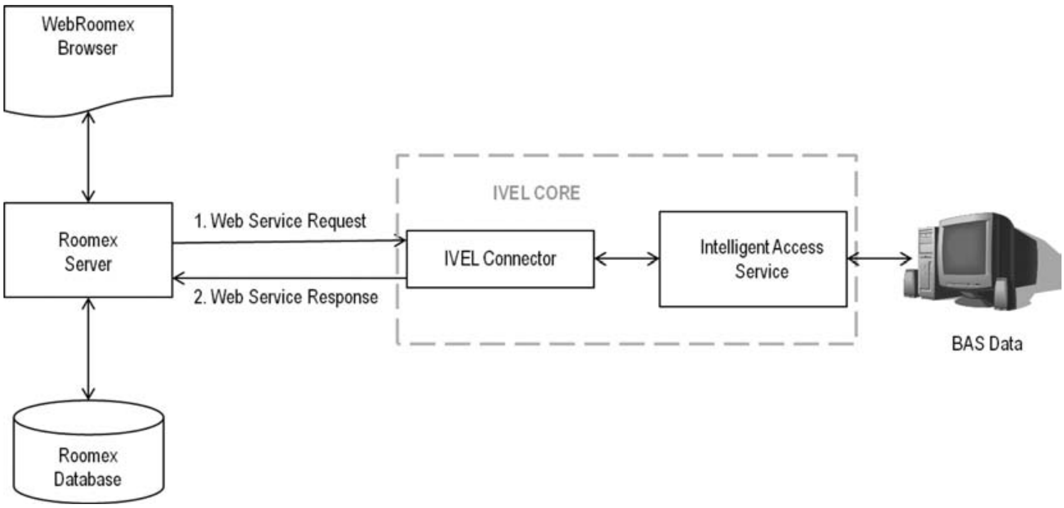

Figure 6. Description of data transfer from BAS into ROOMEX.

consumption and improve indoor environmental conditions by continuously tracking and monitoring issues related to HVAC equipment. Current uses of building automation systems have been successful in collecting and transmitting data of HVAC systems thus facilitating management and control. However, still BAS systems are not prepared for the analysis of performance and for exchanging measured data in an efficient and standardized way. The integration of BAS data with performance management system such as RYHTI will allow reporting and visualizing information of the measured conditions in a more comprehensive way.

Figure 6 shows a common data transfer procedure for measured sensor data of BAS system into energy related management system. The procedure starts by obtaining measurements of different parameters such as temperature, humidity, CO_2 levels etc. from technical systems in various location points in a building. Afterwards, the sensor data is stored into the BAS server and later transferred for validation. In many cases, data is exported with file extensions such as xls., csv or txt. After the data is processed and validated it is stored in a central database. The results are later reproduced in a performance management system for monitoring and reporting purposes.

Thus, an XML-converter has been developed to convert the measured data exported in file formats other than XML. In addition, three different BAS data transfer mechanism have been developed utilizing web services taking into account the wide range variations in BAS systems. Figure 7 illustrates the first concept specification and the different components of the data transfer mechanism.

The procedure starts with BAS systems being configured to scheduledly save sensor measured data to defined folders in the BAS server. In this case, the BAS server is directly connected to the BAS systems. The XML-converter runs a scheduled service and reads many file formats, later it converts and transfers the information in XML format into the webservice input folder. An example of the "Data Transfer XML" is presented and described in Figure 4. The data collector client requests scheduledly measured information through web service. The Data Collector web service receives the request from the data collector client program and reads the information in XML format and sends the information back the Data Collector Client. Data Collector Client saves the information (raw data) to the database in the IVEL FM Server.

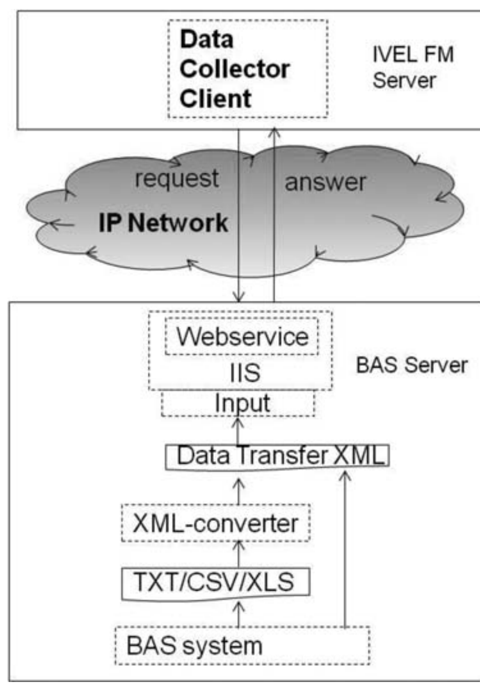

Figure 7. BAS data transfer concept specification.

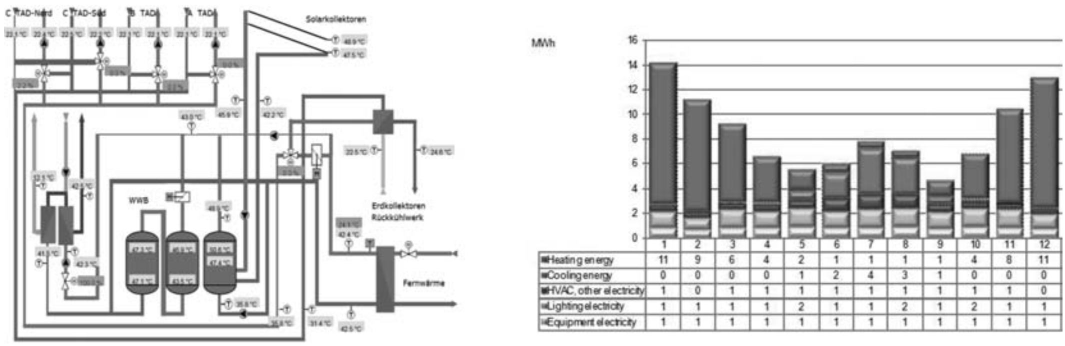

Figure 8. Visualization and Reporting of Systems Performance.

4 MONITORING AND REPORTING

The linkage between BAS, BIM and Facilities Management tool will be pilot tested in two different projects. The goal is to integrate different tools but most importantly have access to that information that can be easy monitored and reported. Figure 8 illustrates an example of visualization of the building automation systems complemented by a monthly reporting graph of the system performance.

5 CONCLUSION

This paper discusses one of the objectives of the HESMOS project that integrates building automation systems, eeBIM and facilities management tools of the IVEL module. Firstly, an eeBIM ontology is developed to link the BAS with the eeBIM. Secondly, it presents the development of the web service and data interface client for energy related management. Considering the advantages of utilizing web services as the method to integrate data from different sources, building automation system data will be integrated into energy related performance management RYHTI and energy related requirement management ROOMEX. We present the development of data transfer of two use case scenarios in order to cover the use of BAS data for existing building that utilize different levels of BAS systems and also modern or new buildings that utilize web-based BAS systems. This integration will close the gap between BIM, BAS and Facilities Management tools providing accessible data for reporting and monitoring, essential for supporting energy efficiency management.

ACKNOWLEDGEMENTS

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

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ICT for energy efficiency in buildings

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eWork and eBusiness in Architecture, Engineering and Construction – Gudnason & Scherer (Eds)

Energy efficiency in European social housing – Three pilots across Europe demonstrating the enabling factor of ICTs to sustainable growth

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ABSTRACT: The objective of E3SoHo project is to implement and demonstrate in social housing pilots an integrated and replicable ICT-based solution which aims to bring about a significant reduction of 25% of energy consumption in European social housing. The E3SoHo service is demonstrated within three social housing pilot buildings in Zaragoza – Spain, Genova – Italy and Warsaw – Poland.

1 BACKGROUND

The E3SoHo project is part of the CECODHAS Housing Europe strategy which promotes the right to decent and affordable housing for all in Europe. With the residential sector accounting for 27% of EU energy consumption (Cecodhas), the potential reduction in CO_2 emissions that energy efficient housing would provide cannot be underestimated.

CECODHAS HOUSING EUROPE members provide more than 21 million homes across Europe, meaning that they have a potential to make a real difference in the ongoing campaign to make Europe's homes more energy efficient. Moreover social housing providers have proved to be innovators in the use of energy efficient technology and renewable energy sources.

2 THE E3SOHO APPROACH

2.1 *Project objective*

The objective of E3SoHo project is to implement and demonstrate in social housing pilots an integrated and replicable ICT-based solution which aims to bring about a significant reduction of 25% of energy consumption in European social housing.

The E3SoHo services will:

- provide tenants with feedback on consumption and behaviour patterns of energy use;
- reduce overall energy consumption and encourage the use of RES (Renewable Energy Sources) by informing tenants, owners, and managers about energy efficiency cost, comfort, and environmental impact;
- provide stakeholders with the best possible information upon which to make energy management decisions (e.g. retrofit, maintenance, incentives, etc.).

2.2 *Stakeholders*

E3SoHo empowers inhabitants, owners, and managers through access to energy data in the following ways:

- End-User (or renter): By providing an intuitive and user-friendly interface which allows the user to monitor and make decisions to adjust their building's environmental parameters;
- Owner or Social Housing managers: Through access to accurate energy consumption data in real time, thus having a support tool to take decisions about the need of refurbishments or installing new systems;

– Energy Services Companies: By connecting each dwelling to a networking platform that allows the monitoring of energy consumption, device performance, and social behaviour patterns of each group.

2.3 *Technology*

The E3SoHo technological solution consists of the following ICT enablers:

– A common service platform: The base for developing the different sub-services to be developed within the project;
– Power consumption measurement devices: Different sensor options for sub-metering and smart metering the parameters affecting energy efficiency at different levels (e.g. building, floor, dwelling, room, system, appliance);
– Power generation measurement for RES devices;
– Water consumption measurement devices;
– Comfort sensing: Temperature, light, humidity, and air quality;
– Control: Manual, programmable, and automatic options to regulate lighting, heating, and cooling;
– User interface: Offering feedback to the different stakeholders by mean of appropriate interfaces; display console for instant access; web-based application for remote access; database server.

3 PILOTS

The E3SoHo service is demonstrated within three social housing pilot buildings in Zaragoza – Spain, Genova – Italy and Warsaw – Poland.

3.1 *Methodology for implementation*

The success of ICT enabled energy efficient solutions is in part directly related to the activities surrounding their implementation. Through the deployment activities within the 3 pilot sites, the project has collected best practices, insights, and lessons learned related to:

– Managing the period between design and implementation
– Planning installation activities
– Executing installation activities
– Supporting end users through awareness and training

These activities are critical as glitches in these areas (unplanned or unforeseen events, technical problems, etc.) likely result in delays, frustration, extra costs, and/or wasted resources. In the event of poor awareness and training, the end result is likely a system that is not put to its best use or one that is forgotten or dormant soon after its installation because it is never well accepted by the end user.

In contrast, successful implementation activities likely excite the end user, encourage self learning and result in referrals for future business activities. It should be noted that implementation is not only the first impression but potentially the most important impression because it is when the system becomes personal to the end user. It is the first time they interact with the system and make their decision whether or not it brings value and change to their life and behaviours.

The following sections summarize the findings from those implementation activities for each demo site.

3.2 *Zaragoza, Spain*

3.2.1 *Pilot description*

The Zaragoza pilot site is an 8-floor social housing building of 43 dwellings located in Goya District, built in 2002. The building has a central gas heating system with individual thermostats within each dwelling to regulate the temperature. There are solar panels installed in the roof to produce domestic hot water. This system is aided by the gas boilers whenever the contribution of the solar panels is not enough.

The building is owned by Zaragoza Vivienda, which is a municipal society for urban regeneration and building development. Zaragoza Vivienda is therefore the building manager, and is interested in improving the energy efficiency of its social housing stock. ACCIONA Infraestructuras is a Spanish construction company responsible for the design, installation and monitoring of the ICT solution in the pilot, in close collaboration with ISA, which is a Portuguese provider of telemetry and remote management solutions.

3.2.2 *Pilot installation and deployment*

The ICT solution deployed in Zaragoza consists of the following blocks:

– Electric consumptions monitoring of both general electric consumption of the selected dwellings and detailed consumption of partial circuits within the dwellings.
– Monitoring of gas and hot/cold water consumptions of the selected dwellings.
– Monitoring of comfort/weather/behavioral parameters: temperature and humidity within the dwellings and in the common areas, weather parameters through weather station and monitoring of opening/closing of windows.
– Communications network for data transmission to a remote server for data storage and processing.
– User interfaces for the tenants (tablets) to let them visualize their consumptions and get advices for achieving energy savings.

The smart sensors and meters are provided by ISA, and they make use as much as possible of wireless communications in order to minimize the impact of the installation in the dwellings.

3.2.3 *Lessons learnt*

Among the main lessons learnt during the installation of the ICT system, we can highlight the need to carefully plan the interaction among all the stakeholders implied in the pilot, e.g. getting permissions from the different utility companies for installation of the smart meters, or communication with the maintenance staff of the building for coordination of the different steps of the installation. The interaction with the tenants from the very start of the installation process is essential in order to get their involvement in the project, a follow-up after the installation is necessary in order to solve any technical problems that might have been originated during the process. A detailed check of all the legacy equipment already installed in the dwelling is necessary in order to ensure the interoperability with the new devices that are going to be deployed, e.g. it is very frequent that part of the counters of the dwelling have been changed by new ones, so it is necessary to check all of them one by one.

3.3 *Genova, Italy*

3.3.1 *Pilot description*

The pilot site of Genova is a social housing cluster developed during 1980–1990. The pilot is located on the west part of the city in the so called San Pietro quartier on Pegli's hills.

The site consists of around 350 social housing dwellings. It is divided in four main blocks and each of them is composed by three parts: a high block, a lower block, and a centre clock of apartments that span a large change in elevation called "the steps." The complex is diverse in ownership (some public some private), energy infrastructure (some renovated some not), and population (some private, some public, young, and old). The complex has a small shopping centre on site, one common area, ample parking, and is served by a public bus line.

The following pre-existing HVAC and lighting technical installations are encountered in the pilot:

- Heating System: there are two typologies of heating system:
  - Dwellings with a centralized system (within the part "high block"). The system is composed by a central thermal power plant for heating with a Lower Heating Value L.H.V. of 8550 Kcal/kg (this covers 160 dwellings). Residents can turn off radiators by closing valves.
  - Dwellings with radiators and a dedicated apartment level heating system (result of refurbishment). Temperature can be regulated through a digital Siemens thermostat.
- Ventilation System: Natural ventilation only through opening/closing of apartment windows.
- Air Conditioning: Dwellings of one or two individual unit air conditioners.
- Domestic Hot Water: Unit level gas water heaters.
- Lighting: Traditional incandescent. Bulb types vary.

3.3.2 *Pilot installation and deployment*

The ICT solution deployed in Genova consists of the following blocks applied within 16 dwellings:

- Electric consumptions monitoring: general electric consumption of the selected dwellings.
- Monitoring of comfort/weather/behavioral parameters: temperature and humidity within the dwellings, weather parameters through weather station and monitoring of opening/closing of windows.
- Communications network for data transmission to a remote server for data storage and processing.
- User interfaces for the tenants (tablets) to let them visualize their consumptions and get advices for achieving energy savings.

The smart sensors and meters are provided by ISA, and they make use as much as possible of wireless communications in order to minimize the impact of the installation in the dwellings.

Moreover, it has been noticed that the historical data available for the detection of electricity savings in Genova were not enough.

Indeed only few tenants were able to provide their electricity bills for the development of historical profile needed for the baseline period.

For this reason, it has been agreed to develop a control group composed by 16 dwellings similar to the ones already involved in the project.

The dwellings have been equipped with all the necessary sensors to monitor the indoor comfort and the electricity consumption, similarly to the ones belonging to the first group.

3.3.3 *Lessons learnt*

The main issue encountered and lessons learnt from the technical visits are listed below:

- Choice and locations of dwelling in pilot activities is fundamental, since closer dwellings allow avoiding communications and cable deployment problems.
- Cabling deployment across the dwelling and the collection point areas was difficult mainly due to the complexity of the buildings; wherever possible, it should be better to avoid cables and to set up wireless solutions.
- Communication with tenants is essential. Awareness and training activities are key elements that need to be set up to make aware, inspire, excite, and motivate the tenants towards the understanding of energy efficacy measures and the adoption of energy efficiency behaviors.
- Conduct as many technical visits as required since the presence of project people on the pilot ensures to smooth activities and to solve unexpected and unplanned problems which always arise in field testing.
- Interaction during installation activities is fundamental. Tenants are curious. When they see people from the project staff at the pilot, they ask questions, and want to learn about what is happening (and offer their suggestions). Such occasions need to be treated as opportunities and increase awareness of the sensors installation and, in case of new dwellings needed, to stimulate people to become part of the project.

- Make sure than any action carried on the pilot do not affect the tenants activities and their comfort. In case that electricity needs to be cut-off ensure that tenants have been previously informed.
- Make sure that all the permissions have been obtained in advance to the pilot technical visit. Plan any installation activity in advance in order to be prepared to any change that needs to be adopted.
- Ensure to control any installation previously to the next activity phase to be deployed. This may allow pre-identifying possible further needs and requirements.
- Make sure to identify risks associated to any pilot activity (sensors installation, communication issues, data transmission, internet network, etc.) and deploy in parallel a proper contingency plan to ensure the fulfillment of the activities.
- Internet connection is a relevant issue, for both sending the data to a remote server and enabling internet access to the tablets. One cannot rely on any individual tenant internet connection. There is the need of designing and implementing an ad hoc internet solution which is completely independent on the dwellings/tenants and on the availability of internet connection previously to the pilot activities implementation. Two independent internet networks might be needed to be set up for remote data communication and for dashboard use. A 3G HSPA data communication system represents a feasible solution to ensure data communication from data loggers to the remote server. A Wi-Fi 3G communication can be set up to provide internet access to the any individual dashboard.
- Cost and contract analyses need to be carried on to identify the most effective and sustainable solutions to deploy the internet communication network.
- Training of the tenants on the dashboard (tablet) use. It can be expected that end users might be unfamiliar with this new technology. Because it is a powerful (and likely new) technology, pre and post training on the tablet is likely required. Clear materials need to be developed to support the tablet. Moreover, the chosen is needed to be the simpler, intuitive, and easier to use.

3.4 *Warsaw, Poland*

3.4.1 *Pilot description*

The building is located in the suburbs of Warsaw, with a south-west orientation. The building is a recent construction (2007), with five levels occupied by offices at ground floor level and dwellings in the other levels. The building has a capacity of 9444.40 m^3 and floor area of 1639.13 m^3, was constructed with supporting structure made of reinforced concrete, curtain wall and longitudinal hall walls made of aerated concrete, external load-bearing wall insulated with expanded polystyrene, and window woodwork of PVC, with traditional incandescent lighting. The building has two staircases, five above-ground storeys and has 48 apartments inhabited by 111 persons. Almost half of the apartments are inhabited by families with children. Dwellings are of two types: one room (approximately 20 to 30 m^2) and two rooms (approximately 40 to 45 m^2). Dwellings are mono oriented (to the north-west or to the south-east) and fully equipped with appliances. The electrical table box includes four fuses for various plugs and lightings. Cooking is realized with gas. There is an office of ZGN with an area of 255.60 m^2 in the building, and a common room, in which meetings with residents may be held.

The building is alimented with gas and electricity, common counters being located at floor level. The terrace is fully accessible and a possible place for installing a weather station. The building is heated through a collective gas boiler (recent system) and hot water, for heating and for DHW separately, is distributed to the dwellings individually. For each dwelling, pipes are equipped with individual energy counters measuring separately heat consumption and DWH consumption. Hot water is distributed into the dwellings through radiators equipped with manual thermostat. Common areas, in the dwellings, are composed of corridors (one in each floor). Energy consumption in these areas is limited to lighting. Electrical counters for common areas are located downstairs.

3.4.2 *Pilot installation and deployment*

The ICT solution deployed in Warsaw consists of the following blocks:

- Electric consumptions monitoring of both general electric consumption and lighting.
- Monitoring of hot water and heating consumptions of the selected dwellings.
- Monitoring of comfort parameters (temperature, sun exposure) and presence sensor within the dwellings.
- Weather parameters through weather station and monitoring of opening/closing of windows.
- Communications network for data transmission to a remote server for data storage and processing.
- User interfaces for the tenants (tablets) to let them visualize their consumptions and get advices for achieving energy savings.

The smart sensors and meters are provided by SABUR, a Polish technology provider.

3.4.3 *Lessons learnt*

For the Polish pilot, the following lessons learnt have been listed hereafter:

- It was necessary to check 3G connection and permeability of radio waves. In case of poor signal penetration, the installation of repeaters must be planned beforehand.
- It was necessary to check all the meters to ensure that they had output pulses (M-Bus compatible). If they don’t have any output pulse, they have to be replaced or adapted.

– An additional Internet connection had to be installed, in order to preserve the existing bandwidth of the existing connection dedicated to the office area.
– It was necessary in advance to inform and prepare tenants for the installation process.
– The installation process should be carefully monitored by building owner – in this case City of Warsaw.
– It was helpful to prepare a special table with the basic data for the installers (number of rooms, number of people, surface).
– It was needed to think how to protect sensors and counters from potential damage and/or theft, and limit access to them.
– It is rather useful to limit the functionality of the tablet, so that it can be used only for the display data from the system.

4 CONSUMPTION ANALYSIS

The pre-deployment monitoring process (Salmon 2011) aimed first at defining the baseline for further comparison of energy consumption profiles in order to define the energy performance of the actions undertaken in the E3soHo project. In that objective, sufficient data has been collected for the three pilot sites, either through bills collection and through measurements realized on-site.

Bills give a long term perspective for consumption of heating, hot water and electricity, whereas detailed consumption analysis showed the profiles of consumption for specific periods. Both long term analysis and short period's assessment will allow comparing the dwellings before and after implementing the E3soHo solution and understanding the impact of specific actions. Furthermore, a complete analysis has been produced on the collected data to clarify what are the consumption patterns today in the pilot sites and prepare the way to their optimization. The main observations as for the observed consumption profiles and the resulting savings' potential are presented hereafter.

First, consumption patterns are very heterogeneous.

It applies for the three sites, for heating consumption as well as for electricity consumption. An example is shown in Figure 1 which presents the total energy consumption per square meter of dwelling and per tenant for each monitored dwelling in the site of Zaragoza. We can observe the large discrepancies in consumptions for the same site. It indicates that the potential for savings exist and it might be interesting to use the lower consumers as examples for the higher consumers.

High energy consumers have been identified in the three sites and for each type of consumption (heat and electricity). High consumption profiles for heating and for electricity correspond in most of the case to the same tenants.

Very little relationship has been established between consumption and typical building characteristics like living area, floor level and number of tenants.

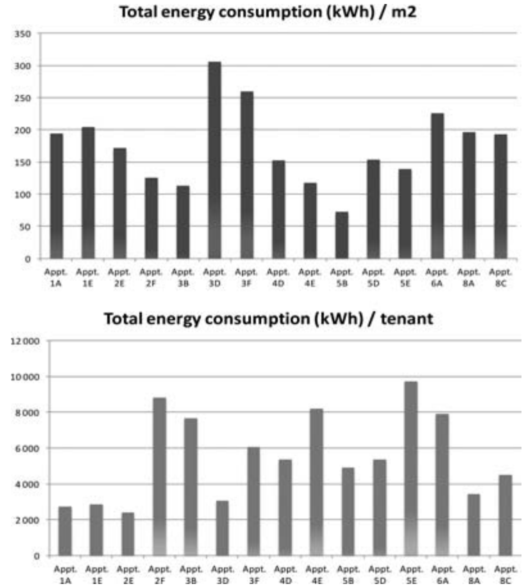

Figure 1. Total energy consumption by m^2 and by tenant in the Zaragoza pilot site.

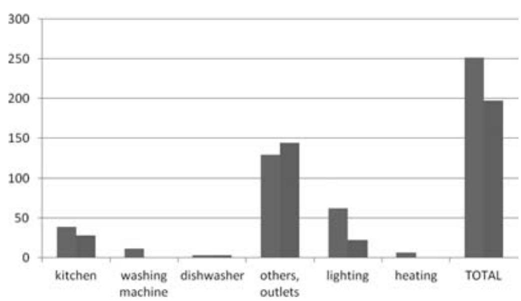

Figure 2. Electricity consumption for two particular dwellings in the Warsaw pilot site.

Here also we can conclude that there is good potential for savings using in a better way energy optimization techniques in the most favored situation (south exposure, mid-level floor, etc.). Exposition can be a key for energy savings (improvement of lighting, heating and comfort); it was observed that it is used in a proper way by some tenants but this could be generalized to all of them.

Most especially in the site of Warsaw, light and appliances are the first targets for electricity reduction in warm and intermediate season. This was concluded from the electricity consumption patterns as shown in Figure 2 for two typical dwellings (consumption in kWh during one week).

Some dwellings (but not those with non working people as it is the case for retired people in Genoa) present a consumption peak at mid-day and at night. It might be interesting to work on peak load shaving in these apartments.

Summer comfort was also analyzed during this monitoring period. Figure 3 shows the comfort

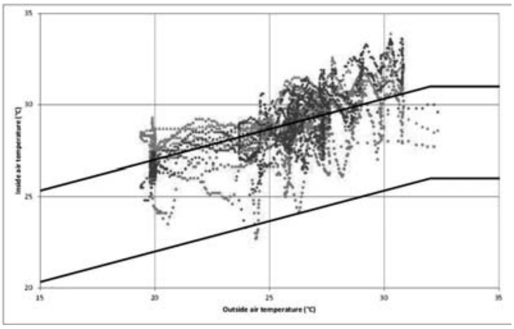

Figure 3. Summer comfort analysis with several dwellings from the Zaragoza pilot site.

analysis realized in several dwellings in the site of Zaragoza during summer (Outdoor air mean temperature over 24 h (x axis) versus indoor air temperature; Brager's comfort zone (De Dear & Brager, 1998)). It shows that for this site thermal comfort is an important issue. It is of primary importance to solve it in order to avoid further use of air conditioning systems. It might be also the case in Genoa but for this analysis we missed indoor temperature data.

Finally the analysis of indoor air temperature with the behavior of the tenants in warm period (use of windows solar protections and openings strategies) showed that summer comfort can be largely optimized with a smart use of windows; this will be integrated in the training and awareness program of the E3soHo project.

5 CONCLUSION

This paper has presented the E3SoHo concept which aims at using ICTs as an enabler for improving energy efficiency of European social housings.

At this stage, the technology deployment over three pilot sites in Spain, Poland and Italy is now completed, and a number of useful lessons learnt have been drawn up. Some of those initial conclusions can appear fairly trivial at first sight; although they are of primary importance considering that the installation phase is the moment when a first contact is established with the tenants.

Meanwhile, the pre-monitoring period has helped in identifying energy conservation opportunities within each pilot site, providing promising expectations for the next phase of the project.

During the next phase, the tablets for energy visualization and advices will be activated in the dwellings, and their impact will be evaluated over a one year experimentation period. Advices have been adapted to the specific configuration of each pilot. They all contribute to a more sustainable use of resources within the dwelling, while not impacting the tenant's comfort.

E3SoHo being a demonstration project, the project team will ensure that those results will be further exploited by other European social housing to replicate or even improve the E3SoHo approach.

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eWork and eBusiness in Architecture, Engineering and Construction – Gudnason & Scherer (Eds)

Decision making for an optimized renovation process

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ABSTRACT: Refurbishment of existing buildings is a major challenge to reach the French objective to divide by 4 the greenhouse gas emissions by 2050. Methods and tools for decision support are needed, to convince householders, through estimated potential energy savings, to undertake retrofit operations, and mainly, to give professionals the keys to identify potential impacts linked to the implementation of specific refurbishment solutions. To meet these requirements, a seven steps approach is engaged. This approach concerns: (i) users requirements collection and analysis, (ii) typological studies of existing buildings, (iii) database to characterize the holistic performance of renovation solutions, (iv) toolbox to be used for a global building's diagnosis, (v) knowledge base to gather expertise on solutions impacts (expert system), (vi) analysis method for multicriteria decision support, (vii) and tool creation. A state-of-the-art has been carried out on all these steps.

1 INTRODUCTION

In France, the energy rehabilitation concerns more than 30 million houses with 20 million, built before the first national thermal regulation in 1974. They are mainly very inefficient in terms of energy consumption and greenhouse gas emissions. Thus the rehabilitation of existing buildings, and especially housing, is undoubtedly the largest potential in energy saving and greenhouse gas emission reduction compare to the ambitious goals of the French "Grenelle de l'Environnement", the EPBD directives and more generally to respect Kyoto agreements.

In case this process of rehabilitation is not properly driven (i.e. with a holistic approach), performance gains might be lower compared to expectations and thus increase the duration of the ROI, but moreover, this can lead to degradation of the building's intrinsic qualities in terms of comfort (thermal, acoustic), safety, health...

Knowledge uncertainties and imperfections are present all along rehabilitation process, because of lack of information on buildings (data), on calculations models used (simulation hypothesis), on measurements, or expert judgements (in qualitative assessment) (Douguet 2006). Even more concerning renovation of existing buildings, in comparison with new ones, where some characteristics are not known (e.g. external walls are made of bricks but we don't know of how many layers) or have been deteriorated with aging (e.g. insulation panel settling). In many situations, intrusive probing techniques are not possible. Practising uncertainty analyses on characterisation of initial situation and on decision support methods should help decision maker to select more reliable renovation solutions.

Our study focus on residential buildings (individual dwelling) built in France between 1945 and 1974 (i.e. between the end of Second World War and the first French thermal regulation). This target represents a high potential for energy savings. This paper aims to present a decision support methodology, dedicated to facilitate dialogue between building professionals and decision-makers on rehabilitation issues. The method will be implemented as online software, adapted to multicriteria approach. Therefore, a low CPU computational time, a reasonable number of input parameters, easily findable, are mandatory.

The paper is composed of three parts. The first one starts by a state-of-the-art on several existing methods and tools potentially useable for our approach. The second one try to define the end-user requirements: what do they actually expect from a decision support methodology, how end-user proceeds to lead a rehabilitation study on a dwelling, from the diagnosis of initial situation to the decision making. The third one is dedicated to selected components to feed our decision making method. However, since this work is just starting, few points are not yet defined and the conclusion describes the work we intend to do in the future.

2 STATE OF THE ART

A lots of research works, methods and tools, have been dedicated to buildings rehabilitation since the

2000s (Caccavelli et al. 2000, CSTB & POUGET_ Consultants 2011, Flory-Celini 2008). This is an answer of the growing demand to predict and build robust and efficient selection of renovation solutions to improve building energy performances in a sustainable way. The state-of-the-art is engaged in five axes: typological studies of existing buildings, renovation solutions database, toolbox for buildings diagnosis, knowledge base to gather expertise on solutions impacts, and analysis method for multicriteria decision making. The step dedicated to users requirements analysis, has its own chapter (part 3). The state-of-the-art part concludes with the relevance to practice sensibility analysis on typological studies and decision process.

2.1 *Typological studies*

During last decades, several typological studies have been carried out on French residential buildings from the period 1945–1974 (CSTB & POUGET_ Consultants 2011, Flory-Celini 2008, Graulière 2005). These relate to the identification of different construction techniques (bricks, stone, steel, and concrete) and energy equipments (boilers, ventilation systems…) the most representative of this period. The advantages of using generic knowledge on existing buildings are multiple. This allows identifying input parameters useful to run energetic simulations, but also obtaining mean values for these parameters. These works, in a second time, allow simplifying model by reduction of input parameters with sensibility analyses. Typological studies are also used as knowledge's source when intrusive probing techniques are not possible during initial diagnosis (however this approach leads to increase uncertainty).

2.2 *Renovation solutions database*

In order to build a database capable of assess the performance of renovation solutions in an overall approach, state-of-the-art focuses on existing standards and methods, but also on characterization scales.

2.2.1 *Standards and methods helping multicriteria assessment of overall performance*

Performance assessment criteria are often limited to cost-benefit analysis for design and rehabilitation processes. The assessment of other themes like comfort, environmental impact, or health performance for buildings and rehabilitation solutions should be based on existing standards.

In order to assess environmental performances, the French standard NF P01-010 is used at construction product scale. The CSTB tool, called ELODIE, uses a database of construction products (CSTB 2005), through registration forms of health and environmental impacts (FDES), to transpose these indicators at building scale. At buildings scale, High Quality Environmental standard (HQE) assesses the environmental performance and user comfort (the French experimental standard XP P01-020-3 also).

The evaluation of economic performance for retrofit solutions should rely on the international standard ISO 15686-5 which defines global cost principle. To assess characteristics related to internal comfort quality (IAQ, operative temperatures, noises…) the standard EN 15251 defines assessment protocol with quantitative and qualitative approaches.

Concerning aging and deterioration assessment of existing buildings, EPIQR calculation method (ESTIA 2004) proposes user survey questionnaires and audits to identify and prioritize maintenance needs.

2.2.2 *Characterization scales*

As seen previously, characterization of renovation solutions is done from different assessment scales, with qualitative or quantitative indicators. Some characteristics are related to construction products (e.g. grey energy of insulated panels or thermal performance of windows). This common information is generally extracted from products databases (literature, manufacturers' catalogs). In opposition, at buildings scale, performance characteristics (e.g. indoor air quality, thermal or acoustic comfort) are unique from each building and are defined by measurements, by calculation models, and by expert judgments. The impact of renovation solutions is calculated by the difference between initial state, and the final state simulated with the solution tested.

2.2.3 *Quantitative and qualitative assessment of renovation solutions*

Performance assessment of renovation solutions relies on quantitative characteristics (objective results from measurements or calculation models) when it is possible and qualitative characteristics (often subjective and defined by expert or user judgments) when models are too complex or not relevant. Both types are used to assess a rehabilitation process (solutions characterization and buildings diagnosis).

2.3 *Energy calculation models*

No model seems to manage simultaneously the full assessment of targeted areas (comfort, health, environment, economics, security, applicability, use). A common approach in a decision making process consists of aggregate qualitative and quantitative data derived from different sources: calculation models, survey questionnaires dedicated to building users, literature. Among involved models, thermal performance, global cost, and environmental assessment are commonly used.

Many energy calculation models exist. The European directives EPBD 2002 and 2006 (EPBD 2002) advocating the use of standards EN 832 and EN 17390, dedicated to thermal consumption assessment, have been adapted at national level. In France, conventional calculation methods such as Th-C-E and T-h-C-E ex (Etat 2008) (used in national thermal regulation) are an adaptation of these directives. They allow the calculation of annual energy consumption needs taking into account the following points: heating, air conditioning, warm water, lighting, and ventilation (in hourly time step). An indicator of thermal comfort in summer (TIC) is also calculated. Other methods or dynamic simulation tools (EnergyPlus, TRNSYS, Pléiades-COMFIE…) enable to obtain comfort assessment criteria and are able to model energetic behavior of simulated building more accurately but with a higher CPU cost. Finally, the French method DPE-3CL, is a simplified adaptation of European standard EN 832, which uses annual unified degree days (DJU) to assess very quickly the energy consumption of a building and its emissions of greenhouse effect gas.

2.4 *Knowledge base*

The elaboration of combination of renovation solutions (e.g. replacement windows or walls thermal insulation) requires expert knowledge to formalize what is a good combination, from what is not. Decision trees and experts systems allow obtaining selections of solutions from initial diagnosis, users requirements and experts knowledge (CSTB & POUGET_Consultants 2011).

Expert systems are composed of three layers: facts base, rules base, and inference engine (algorithmic process). They can handle initial information in order to create new knowledge by deduction. The advantages of using expert system, is the possibility of adding or modifying expert knowledge easily.

2.5 *Multicriteria decision making support*

Decision making requires two essential parts: scenarios of selected solutions (called alternatives) and assessment criteria at buildings scale.

Alternatives are proposed from knowledge base and its rules base. Assessment criteria are built from a characteristic or a combination of several characteristics of each alternative, aggregated by expert judgments (logical functions or weighting methods).

Once alternatives and their assessment criteria are defined, multicriteria decision making methods help user to analyze which alternative fits the best to his requirements.

Roy describes three type of multicriteria decision making techniques in function of user requirements (Roy 1985, Ben Mena 2000): (P_α) choice problem, in order to find the best alternative; (P_β) classification problem, in order to classify alternatives in type boxes (e.g. good, medium, bad); (P_γ) ranking problem, in order to rank alternatives from the best to the worst.

In renovation process, when several strategies are available (i.e. compatible with user requirements), decision approach correspond to ranking problem (P_γ). The ELECTRE II method, described by Roy (Roy 1985) allows resolving this type of problem by comparing solutions by couple (over-ranking methods).

Table 1. Decision problem classification by Roy.

Symbol	Problem type	Methods
P_α	Choice problem	ELETRE I
P_β	Classification problem	ELECTRE TRI
P_γ	Ranking problem	ELECTRE II

Every multicriteria decision making method is based on weighting criteria. The mathematic laws defining weightings are sensitive to thresholds values, therefore a robustness analysis is required (by sensibility analysis) to assess their reliability.

2.6 *Uncertainty integration in decision process*

A data alone is not significant since we do not know its accuracy, its origin and how it is obtained. Data are often tainted with various flaws (inaccuracy, incompleteness, imprecision) that can ultimately influence for good or wrong on a decision. Generally associated with measurement error, the impact areas of uncertainty are much larger. According to Douguet (Douguet 2006), uncertainty can cover four dimensions: technical (inaccuracy), methodological (unreliability) and epistemological (ignorance), and social (social robustness).

Sensibility analyses are used to assess the influence of input parameters on model outputs (Tian et al. 2011, Jacques 2011, Morris 2006). Three type of methods exist: screening methods, methods of local sensibility analysis (by using sensibility index), and global sensibility analysis (by studying simultaneous variation of all input parameters over their entire range of variation (e.g. Monte-Carlo analysis).

These techniques allow estimating the influence of epistemic and technical uncertainties on calculation models entries, but also to assess the robustness of decision making methods.

3 USERS REQUIREMENTS

After the state-of-the-art and before presenting a part of our decision making methodology for renovation process, the problem of why and how rehabilitation process is perceived by end-users is very important. That is why we want to adapt the approach to their requirements.

3.1 *What does the user want?*

In order to convince householders to start their rehabilitation project, their motivations should be taken into account. A French study from ADEME shows that rehabilitation is motivated by four principal axis (Vergne 2012): solve a specific problem (pathology, equipment dysfunctions), increase indoor comfort (thermal or acoustic aspects), reduce annual energy bill, and increase gross living area (GLA). In a same time, decision is generally function of investment cost (Buhé et al. 2007).

The motivations presented above should lead to ask precise questions to the householder in order to properly define his needs and requirements. The suggested methodology should match with technical level of user (i.e. building professional) to assist him in the rehabilitation process. To reach this aim, a knowledge base on rehabilitation solutions and scenarios of solutions should help user to understand complex interactions between solutions and the building to renovate. Alerts and recommendations should be automatically sent when a risk or an opportunity is presented.

When the professional doesn't know precisely a point for the diagnosis, the method should give him a way to quantify this uncertainty on knowledge or find the solution by inference from other data (e.g. use of generic knowledge from typological studies).

Also, only combination of solutions that match initial requirements should be presented to the decision making support. Finally, the decision support should help user to compare and select the bunch of renovation solutions which provides the best answers to the defined objectives.

3.2 *Assessing of results reliability*

Uncertainties about a result can be presented to public with various shapes. Among them, we notice: reliability indicators, range of uncertainty, security coefficient, or expression of an alternative.

The integration of reliability in decision support to assess the result precision is considered for a specific reason. The uncertainty on a result can affect the user decision, when it is perceived as a risk. St Petersburg paradox, raised by Nicolas and Daniel Bernoulli in 1738, explains this phenomenon: a man will prefer a low gain with a high reliability than a higher gain with low reliability (i.e. with high uncertainties).

A global reliability indicator or the expression of reliability range for each assessment criterion is a part of the solution, but it does not exactly fit with user requirements. User wants to know which solution adopt among the available ones. If all solutions tested show the same amount of uncertainty, what are we supposed to do? The proposed methodology, described below, doesn't answer to this question, but future studies will try to propose a solution.

4 BASES OF PROPOSED METHODOLOGY

This state-of-the-art has enabled us to specify a part of technical steps of the rehabilitation process methodology we want to develop in the frame of our research project (Réhascope).

This methodology should consist in three theoretical parts (initial diagnosis, proposals for renovation solutions, and decision making support) and five steps (Table 2) described in this chapter. The methodology should be implemented in a tool dedicated to professionals that want to integrate a holistic approach in a rehabilitation process.

Table 2. Steps of Réhascope methodology.

N°	Name
1	Typological studies
2	Database of existing and renovation solutions
3	Needs identification and diagnosis of the building
4	Knowledge base (expert rules)
5	Decision support technology

4.1 *Typological studies*

The objective here is to gather typological studies already conducted on residential buildings in France for the period 1945–1974 (part 2.1.1). Information collected from building structure and energetic equipments can help the professional to describe buildings during diagnosis phase. Also, representative houses from typological family (generic buildings) can be used to perform sensibility analyses. These analyses allow identifying influent input parameters on thermal behavior of a building with specific model calculation. At last, sensibility analysis used in this context, should permit to:

– Make shorter data entry, simplify thermal calculation models and thus perform faster simulations.
– Assess knowledge uncertainty on input data collected during diagnosis step

Two levels of sensitivity analysis should be used: screening (Morris 2006) in order to identify influent input parameters, and local sensibility analysis (Jacques 2011) to quantify this influence.

4.2 *Database of existing and renovation solutions*

Data collected on existing buildings from typological studies and characterization of rehabilitation solutions selected in our method (table 3) should be gathered and stored in a dynamic information base (frequent updates might be possible). This "database" should integrate requirements to implement a rehabilitation solution, but also performance characteristics associated to product and system scales (thermal or acoustic properties, investment cost, grey energy…) in opposition with characteristics from buildings scale (coming from calculation models, survey questionnaires and expert judgments) (Figure 1).

The performance assessment of rehabilitation strategies should rely on a holistic approach. The characteristics described in table 4 should be the entry vector of the following decision criteria: health, comfort, environmental impact, security, use, and applicability.

Some performance characteristics of renovation solutions are described at product and system scale. The definitions of these characteristics are essentially coming from the French standard NF P01-010 and

Table 3. List of selected renovation solutions.

N°	Name
1	Thermal insulation of external walls
2	Thermal insulation of floors
3	Thermal insulation of ceilings
4	Windows replacement
5	Air inlets and rolling shutter casings replacement
6	Loggias closing
7	Reducing parasitic air leakages
8	Ventilation systems replacement
9	Boilers replacement (gas, fuel oil, …)
10	thermodynamic water heaters installation
11	Heat pump installation (air-air, air-water, ground-water)
12	Thermal insulation of warm water pipes
13	Installation of solar heating panels
14	Heaters replacement (low temperature, radiant panels)
15	installation of thermostatic valves on existing heaters
16	Installation of photovoltaic solar panels

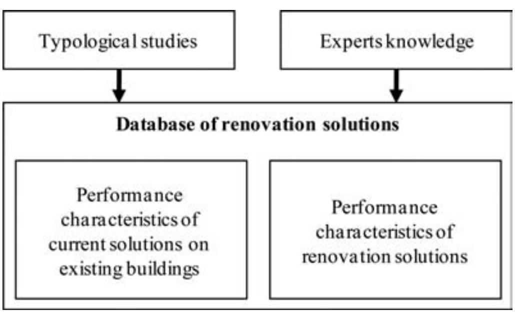

Figure 1. Database of renovation solutions.

Table 4. List of assessment characteristics.

N°	Criteria	Scale
1	Fresh air ratio	B
2	Grey energy	P
3	Climatic impact	B
4	Durability	P
5	Maintenance constraints indicator	S
6	Technical maturity (in France)	S
7	Workings disturbances	S
8	Weighted sound reduction index R_w (C; C_{tr})	P
9	Airborne sound insulation index	B
10	Summer overheating indicator	B
11	Annual final energy consumption	B
12	Annual energy consumption cost	B
13	Payback time	B
14	Global cost	B

B: building, S: system, P: product

expert judgments. The others are defined at buildings scale (table 4).

Annual final energy consumption and summer overheating indicator are directly calculated from selected thermal calculation method *Th-C-E ex* (described in diagnosis part). From this one, climatic impact and annual energy consumption costs coming from energy consumption are calculated.

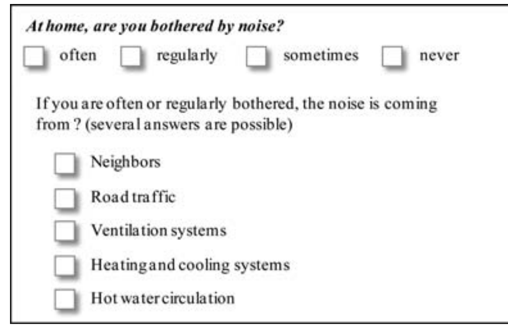

Figure 2. Example of acoustic comfort assessment.

Global cost calculation relies on the international standard ISO 15686-5. In this methodology, we should limit global cost by investment costs (material costs, labor costs), subsidies, loans, energy consumption costs, and maintenance costs. Because of high variations in investment costs, this value should be expressed by price range for each type of operation. Payback period correspond to a function of: the investment plus the maintenance cost, over the difference of annual energy consumptions between the initial situation and the final situation (i.e. with renovation solutions implemented).

The fresh air ratio and airborne sound insulation index should be determined by expert knowledge regarding initial building configuration (from logic functions of initial diagnosis, user survey questionnaires, and selected renovation solutions).

Finally, thermal diagnosis describes in following subsection, helps to define characteristics linked with surface areas (square meter of insulation, and consequently material costs and grey energy).

4.3 *Needs identification and diagnosis of the building*

This step should allow, in a first time, expressing decision makers' needs, then in a second time, guiding professionals toward an effective and overall rehabilitation.

This step should start by the identification of householder needs. (Part 3.1) If a specific need must be addressed (e.g. humidity pathologies, noise reduction…), user questionnaires should help to detect the origin of the problem (example for acoustic discomfort in figure 2).

Once needs identification is done, diagnosis should help to fill in information required to assess building initial performance (finding closest generic building to simplify information entry part, estimate building volumes and surfaces, define energy equipments, and obtain required data to define performance assessment characteristics).

The selected energy calculation model is the French method *Th-C-E ex* dedicated to existing buildings. This choice results from a clever compromise between calculation times (CPU time requirements) and level of precision expected (in adequacy with the input data knowledge). A variant of this method is adapted to adjust user scenarios (heating temperatures, internal load managements…). The outputs of this model are mentioned in the state-of-the-art part (2.1.2).

The same tool should be used to assess the energetic performance after integration of selected rehabilitation solutions.

Other assessment characteristics are treated from structure and equipment information defined during the energy assessment of initial diagnosis as mentioned in 4.2 part.

4.4 *Knowledge base (expert rules)*

After initial diagnosis and needs identification, the professional is confronted to the selection of renovation solutions in order to build an adapted rehabilitation set. The proposed renovation solutions – described in table 3 – require specific configuration of existing building to be implemented without side effects. These “rules” determine the potential impacts of a solution on the building tested, on the needs expressed in diagnosis part, and on the interaction with other selected renovation solutions.

4.4.1 *Principles*

The use of an expert system should help to model this knowledge which relies on a knowledge base (expert judgments on solution combinations and their potential impacts on assessment criteria), fact base (information extracted from diagnosis), and inference engine (algorithmic process in order to appeal expert rules).

In our study, knowledge base should help the professional to identify incompatible solutions through alert messages in order to explain risks and their origins (pedagogic approach). The second interest is to identify opportune solutions through recommendation alerts, or solution selection propositions (in adequacy with decision maker needs). The last interest is to use knowledge base to automatically ask additional questions to the professional, to reduce specific risk associated with the implementation of a solution in particular context (e.g. water vapor diffusion behavior in wall) by reducing uncertainties.

4.4.2 *Expert rules*

The rules base should collect expert knowledge gathered from interviews with buildings experts in different areas (environment, acoustic, thermal, humidity transfers…) and should be expressed in natural language. The added value of expert system is to use independent and short rules. This process allows adding, modifying, or deleting rules easily from a computational system. Rules are ranked from the more restrictive to the less restrictive to be able to deduce knowledge and appeal new rules. Even if the objective of this paper is not to describe this specific point, two examples of expert rules are presented in natural language below (they can be controversial, but the aim here is to provide an illustration of the possible content for the rules base).

First example – pathology risk: for a building not or few thermally insulated and equipped with natural ventilation (i.e. without any mechanical ventilation system), undertake thermal insulation and replacement of old windows without adding an active ventilation system may lead to humidity pathologies (appearance of mold, fungus, bad odor).

Second example – opportunity situation: take advantage of a facelift to provide an external thermal insulation of walls. Here labor costs (scaffolding rental cost) are shared for both operations. In addition, present situation is perfect to treat windows thermal bridges.

Both examples show simple rules which allow helping professionals to lead an efficient renovation process. At the very end, more than one selection of renovation solutions should be retained. Here, decision process is needed.

4.5 *Decision making support*

Once professionals have identified potentially suitable solutions for a rehabilitation project, two approaches should be possible: (i) pre-programmed solution set are presented to reach user requirements (combination of several renovation solutions), (ii) professional designs his own solution set by selecting solutions from the list (table 3).

In both cases, the selected selections of renovation solutions are characterized with assessment criteria to visualize the global performance of each alternative at buildings scale.

4.5.1 *Multicriteria performance assessment*

Our approach is motivated by systemic assessment of performance. Multicriteria analysis allows assessing rehabilitation strategy with overall view. To be used, multicriteria methods need assessment criteria and alternatives (i.e. selections of renovation solutions in our context).

The overall assessment will be accepted by people if it is based on a limited quantity of macroscopic criteria, easy to handle. One solution is to formalize assessment criteria of building performance (comfort, health, environment, economy, use, applicability, security) from characteristics identified in table 4. However, keeping a trace of these characteristics should be useful if users are interested in a particular aspect (ROI time, acoustic comfort…). The transition from characteristics to assessment criteria is done by aggregation methods (logical functions or weighting methods).

At our current research level, relevant methods are not yet identified. We need a method able to handle quantitative and qualitative characteristics, but also able to integrate uncertainties from values or

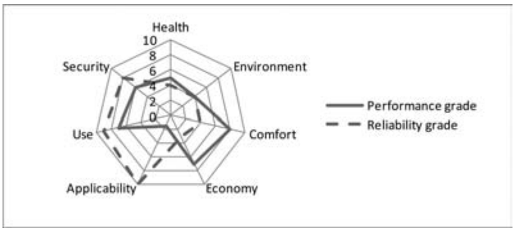

Figure 3. Example of radar diagram to show systemic evaluation of renovation alternatives.

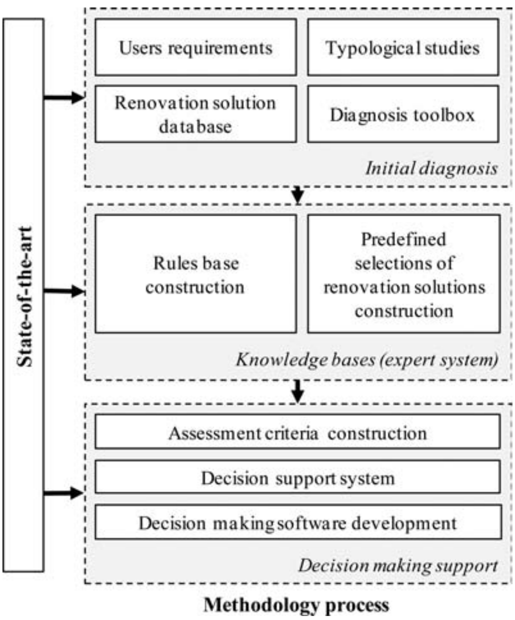

Figure 4. Methodology synthesis scheme.

imprecision from expert judgments. Fuzzy methods and possibility theories are currently investigated.

4.5.2 *Results presentation*

To assess the overall performance of renovation alternatives, assessment criteria could be presented on radar diagram (figure 3).

One possible but insufficient representation of uncertainties might be adding reliability indicators for each decision criterion on the same diagram to estimate the confidence interval on results.

4.6 *Methodology synthesis scheme*

The Réhascope methodology process is summarized in the figure 4.

5 DEBATES

People may ask why we avoid dynamic thermal simulation tool in our study. The main reason is that computation time due to these tools is generally not compatible with decision making tools. Quality of information available during design stage of renovation process is also a source of problem. Frequently, users don't know precisely technical characteristics of the buildings to be renovated, and intrusive probing techniques are generally not possible. Globally, current tools do not have a macroscopic view of the systemic rehabilitation process.

Absence or poor assessment of uncertainties associated with data, models, measures, used in decision making, can lead to undesired results. For example: the non compliance with buildings regulations, the apparition of pathologies and discomfort, or excessive consumption of energy. In order to cope with these problematic, next researches will focus on the integration of knowledge uncertainties in decision process.

6 CONCLUSION

This paper is a state-of-the-art on the theme of rehabilitation design, overall approach, use of assessment criteria, and decision making support. It presents the works that will be carried out by CSTB teams in the frame of overall approach of rehabilitation process with Réhascope project. The principal objective is to give tools to the professionals in order to lead a rehabilitation process with a holistic approach. No results are expected before the end of 2012. The paper aims to make a brief presentation of future works, to present the approach described, and make the scientific community react about the relevance of our approach.

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Tools for building energy efficiency and retrofitting in southwest Europe. E4R project

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ABSTRACT: It is estimated that buildings constructed during the 20th century consume more energy (between 1.6 and 2.4 times) than current buildings which are under more stringent regulations. While in the north-central Europe there is a culture for retrofitting, with 50% of actions on the building mass, southwest Europe (SUDOE) only 20% is reached. E4R project aims to develop a set of actions to promote the retrofitting culture into the SUDOE Space and used to re-launch the construction sector of the current crisis.

1 INTRODUCTION

Potential energy savings in existing buildings in SUDOE Space with the growing awareness of responsible energy consumption have caused than retrofitting has been postulated as a pillar of public policies in economic and energy, as well as a business opportunity for companies in the sector.

Currently, however, these policies are not being applied properly, since in many cases solutions which are chosen are not appropriate for the building, either because they are energy inefficient or because the cost of the investment does not meet expectations energy savings.

This shows the lack of accurate and well structured, to be used by the stakeholders involved in the sector, as well as for the public administration in order to be able to establish a set of objective criteria to support retrofitting measures.

Note than homeowners ignore their real potential of saving money and energy if the appropriate solutions are implemented.

Although some software tools are currently used in order to evaluate energy consumption of existing buildings. However, these tools are difficult to use and are feasible only for expert users and not allowing the homeowner can check the benefits of retrofitting, taking account he must be conscious of these benefits before deciding to retrofit.

2 E4R PROJECT. OBJECTIVES

From the starting point described above, some organizations from Spain, France and Portugal (Research Centers, Universities and Public Administrations), have joined efforts and resources through the European E4R project with the goal of encouraging and promoting energy efficient retrofitting of existing buildings in SUDOE Space.

So, E4R project aims to provide a common environment to all the stakeholders: Public Administration, designers, product manufacturers, builders, facility managers and homeowners.

This common environment consists of:

- A Website that gathers all the stakeholders involved in retrofitting offering news, technical content, policies, etc. Website will also contain a list of specific measurements and strategies for retrofitting in SUDOE Space. Moreover, experiences and successful cases will be exchanged among the stakeholders.
- An Energy Assessment Web Tool capable to quantify, quickly and easily, the energy consumption of existing buildings, suggesting and prioritizing the different energy saving strategies.

3 SUDOE SPACE ANALYSIS

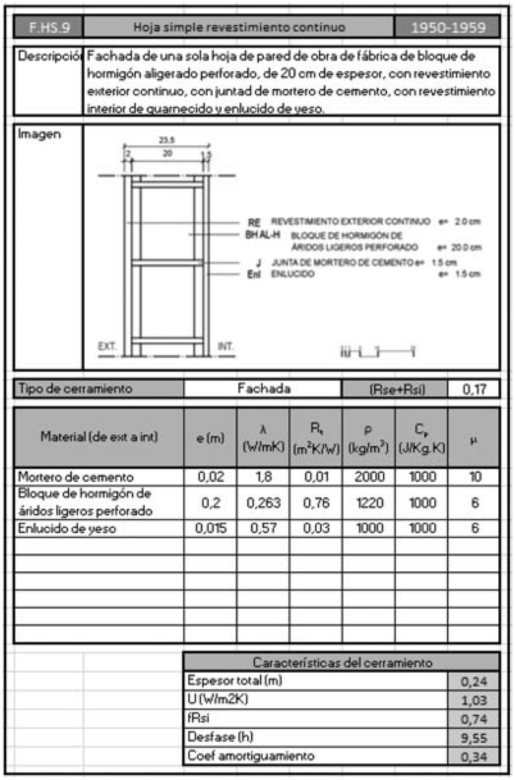
Despite the similarities in SUDOE Space, the first task of E4R Project is to analyze and standardize this space from three points of view: existing buildings, retrofitting strategies and climate zones.

3.1 *Existing buildings analysis*

Buildings are considered as a mechanism for environmental and thermal control where the user feels safe, secure and under acceptable psychological and physical effects.

Buildings have been classified according to a set of parameters related to the building energy performance:

- Activity influences over the occupancy rate, energy demand and comfort needs. Use typologies established are Residential (Apartment Building or House) and Services (Hotels, Educational, Commercial, Offices).



F.HS.9	Hoja simple revestimiento continuo	1950-1959
Descripción	Fachada de una sola hoja de pared de obra de fábrica de bloque de hormigón aligerado perforado, de 20 cm de espesor, con revestimiento exterior continuo, con juntad de mortero de cemento, con revestimiento interior de guarnecido y enlucido de yeso.	
Imagen		

Tipo de cerramiento	Fachada	(Rse+Rsi)	0,17

Material (de ext a int)	e (m)	λ (W/mK)	R_t (m^2K/W)	ρ (kg/m^3)	C_p (J/Kg.K)	μ
Mortero de cemento	0,02	1,8	0,01	2000	1000	10
Bloque de hormigón de áridos ligeros perforado	0,2	0,263	0,76	1220	1000	6
Enlucido de yeso	0,015	0,57	0,03	1000	1000	6

Características del cerramiento	
Espesor total (m)	0,24
U (W/m2K)	1,03
fRsi	0,74
Desfase (h)	9,55
Coef amortiguamiento	0,34

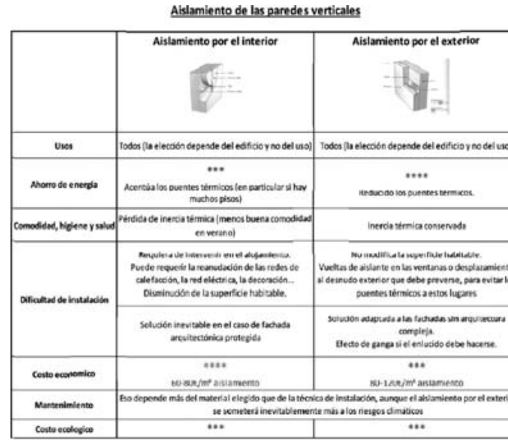
Figure 1. Detail of façade.

– Building Form Factor is the ratio between two items: building surface and building volume. Building surface is related to energy gain or loss and building volume is related to stored energy.
– Envelope constructive solutions are directly related to energy demand. Most common have been classified in façades, roofs and windows, and taking account the building's age. Each constructive solution has been characterized by: thickness, density, thermal parameters (transmittance, conductivity, water vapor resistance), developing a database.
– Thermal and lighting facilities. When passive strategies are not enough to achieve comfort conditions inside buildings, facilities are required to convert energy into heat, cool, light, ventilation, etc. The quality and performance of facilities and systems have evolved considerably in the last years, so a change of the old equipment with another one more modern and appropriate will save energy. In this way, the most common facilities in the SUDOE Space have been cataloged according their characteristics.

3.2 *Retrofitting strategies analysis*

The more appropriate retrofitting strategies have been analyzed and selected depending on:

– Passive strategies. Are applied on the thermal building envelope and are available to reduce energy demand. Some examples are façade insolation (inner and outer), sunscreens, low emissivity glass, etc.
– Active strategies. Are applied on the building facilities, changing for other more appropriate and higher performance or introducing renewable energies.
– Dynamic strategies. ICT systems which optimize and combine passive and active strategies.



Aislamiento de las paredes verticales

	Aislamiento por el interior	Aislamiento por el exterior
Usos	Todos (la elección depende del edificio y no del uso)	Todos (la elección depende del edificio y no del uso)
Ahorro de energía	*** Acentúa los puentes térmicos (en particular si hay muchos pisos)	**** Reducido los puentes térmicos.
Comodidad, higiene y salud	Pérdida de inercia térmica (menos buena comodidad en verano)	Inercia térmica conservada
Dificultad de instalación	Requiere de intervenir en el alojamiento. Puede requerir la reanudación de las redes de calefacción, la red eléctrica, la decoración... Disminución de la superficie habitable.	No modifica la superficie habitable. Vueltas de aislante en las ventanas o desplazamiento al desnudo exterior que debe preverse, para evitar los puentes térmicos a estos lugares
	Solución inevitable en el caso de fachada arquitectónica protegida	Solución adaptada a las fachadas sin arquitectura compleja. Efecto de ganga si el enlucido debe hacerse.
Costo economico	**** 60-80€/m² aislamiento	*** 80-120€/m² aislamiento
Mantenimiento	Eso depende más del material elegido que de la técnica de instalación, aunque el aislamiento por el exterior se someterá inevitablemente más a los riesgos climáticos	
Costo ecologico	***	***

Figure 2. Detail of retrofitting strategies.

Figure 3. Temperature, Humidity and Radiation Maps in SUDOE Space.

A retrofitting strategies database has been developed defining energy savings, economic cost and maintenance tasks.

3.3 *Climate zone analysis*

To know the climate parameters that affect each building is essential in order to determinate their potential energy savings. After analyzed these parameters through energy simulations, some have been chosen as the most representative and influential: Temperature, Relative Humidity and Solar Radiation; discarding others as wind, rainfall or insolation.

Taking as reference the national weather maps in each country (Spain, France and Portugal), some transnational maps have been developed for each one of these parameters: Monthly maps in case of Temperature and seasonal maps in case of Humidity and Radiation. These transnational maps have been developed through gvSIG software tool. It's a free GIS tool developed as open source project, which allows image geoposition, to draw the polygons that define each climate zone. Each map is exported to a .GML file, composing the transnational climate maps database.

So, from the building location can be established the climate zone in each map, obtaining the building weather conditions along the whole year.

4 DESIGN AND DEVELOPMENT OF AN ENERGY EFFICIENCY ASSESSMENT WEB TOOL. E4RSIM

Most homeowners are unaware of their potential energy savings and the retrofitting strategies economic cost in order to calculate the amortization period.

So, one of the main objectives of the E4R project is to design and development an Energy Assessment Web Tool, called E4RSim, accessible by users without technical knowledge and capable to suggest the most appropriate retrofitting strategy in each case.

E4RSim success will be based in usability and results reliability. On the one hand, previous SUDOE analysis will minimize the input data encouraging the usability. On the other hand, after analyzing several calculation engines, Energy Plus has been chosen due to its international credibility, software development environment, fast simulation and its possibility of execution on a web server.

4.1 *Technologies*

To meet the E4RSim goals, several emerging information technologies have been used.

4.1.1 *Rich Internet Applications. RIA*

Rich Internet Applications (RIA) are web applications that have the most features of traditional desktop applications. These applications use a standard web browser to run and supplements or a virtual machine to add additional features. The RIA combines the advantages of Web and desktop applications seeking to improve the user experience (Fig. 4).

Usually, in web applications, webpages are loading each time user clicks on a link. This produces a high traffic between client (web browser) and server. In RIA environments, however, there are no page reloads, because the whole application is loaded from the beginning, and only communication with the server occurs when external data are needed, from a database or from a Web Service.

RIA features are:

- Installation and maintenance are not need. Updates are automatic.
- Offline: can be used without an Internet connection, retaining the status on the client machine.
- Efficiency can be improved depending on the application and network characteristics balancing the process between client and server.
- Richness: adding features that are not native web browsers such as video.

4.1.2 *Cloud computing*

Cloud computing is based on the technological concept of ubiquity. This means having all the resources in the cloud, in servers, available anytime and anywhere,

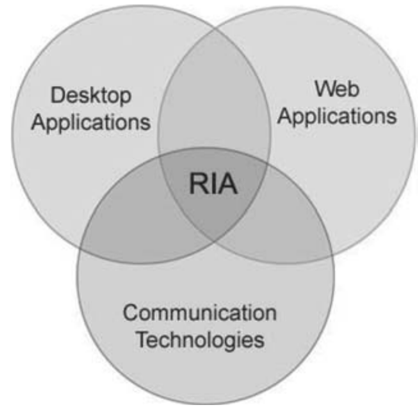


Figure 4. Rich Internet Applications.

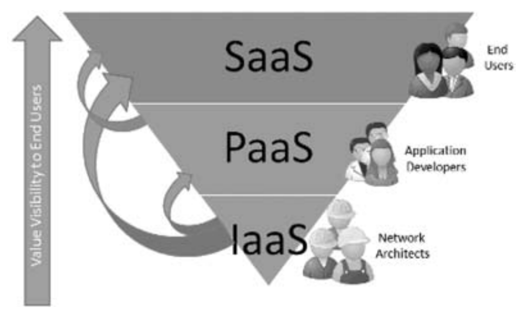


Figure 5. Cloud Computing Architecture.

being cached temporarily on clients. Cloud Computing can be summarized as "Everything as Service".

Client no longer need to worry about installing applications maintenance, updating, storage, etc. Processing and storage are moved to the Cloud, replacing the physical infrastructure.

There are three cloud-based services categories:

- Infrastructure as a Service (IaaS): Servers, virtual machines, storage, firewalls, load balancers, networks, etc.
- Platform as a Service (PaaS). Set of services that give capabilities to developers to build and publish applications and Web Services: database, authentication, authorization, etc.
- Software as a Service (SaaS). It represents de end-user service: email, communication, CRM, etc.

4.2 *Implementation*

E4RSim has been built following the classic three-layer client-server architecture (presentation layer, business logic layer and data storage layer) combined with Web Services provided from the Cloud (Fig. 6).

4.2.1 *Presentation layer*

It's the user interface where the information is shown, communicated and captured. E4RSim, presentation layer is shown through a web browser which handles web pages encoded in SWF and HTML.

4.2.2 *Business logic layer*

The business logic layer is based on the Apache Tomcat web server running on Windows platform. Requests are handled by scripts written by using Java programming language, interacting with relational database and Web Services. Moreover, EnergyPlus calculation Engine is integrated in this layer and requested by MS-DOS commands.

4.2.3 *Data storage layer*

All the information collected along the E4R project (constructive solutions, facilities, retrofitting strategies, weather maps) and user data are stored in a MySQL relational database.

4.3 *Methodology*

E4RSim is a web tool where data from user, database and web services are combined (see figure) in order to assess energy efficiency of existing buildings using EnergyPlus calculation engine. EnergyPlus receives building data through two files. On the one hand, .IDF file contains information about the building: geometry, materials, facilities, etc. On the other hand, .EPW file contains hourly weather information. Both files are created in E4RSim transparently to the user.

4.3.1 *Generation of building files .IDF*

The .IDF file contains information, organized into blocks, about the specs of the building: geometry, materials, location, facilities, building activity, etc.

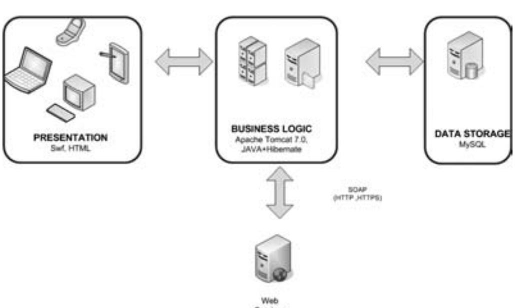


Figure 6. E4RSim Architecture.

Figure 7. E4RSim drawing screen.

E4RSim generates the .IDF file blocks using information from different sites:

- Data provided by the user through the E4RSim Interface. User may provide building location (which will be used to generate the weather file .EPW) and building geometry. To define the geometry, user must draw the building envelope indicating each wall type: façade, dividing or patio. To facilitate this, some layers are shown while user is drawing. On the one hand, a satellite image of the building provided by Bing Maps. On the other hand, a layer with cadastral mapping information provided by Dirección “General de Catastro” in Spain and “Institute national de l’information geographique et forestiere” in France (In Portugal there is no cadastral public service which offers this kind of information).

  Once the user has drawn the building envelope, the geometry .IDF block is generated taking into account that:
  - Plant height is 4 meters in case of the ground floor and 3 meters in case of the other plants.
  - A window is integrated in each façade. The window size is determined according the building construction year.
  - A shading coefficient is assigned to each façade as function of the surrounding buildings.
  - The Internal Mass percent is assigned to each plant, based on its area, to take account the interior walls.
- Data provided by E4R databases. As mentioned above, existing buildings in SUDOE Space have been characterized depending on their location and construction year. So, constructive solutions and facilities are assigned automatically by E4RSim from the databases developed. These values are taken as starting point but can be replaced by the user. Thus, materials and facilities .IDF blocks are generated.
- Data provided by Web Services. E4RSim uses several Web Services (if possible) to obtain useful building information:
  - In Spain, the Cadastre Electronic Office, from the building address, can be obtained the geographical coordinates, building activity, floors number, area, and construction year. So, Location and schedules .IDF blocks are generated.
  - In France and Portugal, geographical coordinates are obtained with Google Maps.

4.3.2 *Generation of weather files .EPW*

As mentioned before, EnergyPlus needs hourly weather information to simulate the building. This information is contained in an .EPW text file. EnergyPlus owns an .EPW files database from some locations (done with information collected from weather stations), but not all, so E4R project has developed a methodology which allows to generate an .EPW file for each one of the cities that make up the SUDOE

Space. It aims to improve other methods, as the used in Spain, where the climate zone of each location depends on the state capital corrected by an altitude factor, which fails on some cases.

This methodology consists of, from the monthly and seasonal weather maps (temperature, humidity and radiation), all the cities in each zone are selected, calculating the hourly average value. For example, in Spain, the 6th Zone temperature during May is calculated as the average temperature in Zaragoza, Madrid, Barcelona among other cities (Fig. 8 and Table 1).

Figure 8. May Temperature Map.

Table 1. 6th Zone Hourly May Temperature Average.

Day	Hour	ZGZ	BCN	MAD	T_Average
1	1	19.4	16.1	16.4	14.9
1	2	11.7	8.3	10.6	10
1	3	11.1	8.9	10	9.9
1	4	11.1	9.4	8.9	9.7
1	5	10.6	10	8.3	9.6
1	6	10.6	10.6	7.2	9.5

This process is done for temperature, humidity and radiation parameters. Once climate parameters schedules have been obtained for each zone, any city weather can be characterized through the dynamic .EPW file generation, as next figure shows.

To complete the .EPW file in each city (rainfall, wind, etc.), is taken as reference the .EPW file of the nearest city contained in the EnergyPlus database.

4.3.3 *Building energy quantification*

Once the .IDF and .EPW files have been created, EnergyPlus runs on the server in order to quantify building energy consumption. Simulation results are displayed: sensible heating energy and sensible cooling energy, both the monthly values as the annual average.

From these results, E4RSim suggest the user the choice of several retrofitting strategies of the database,

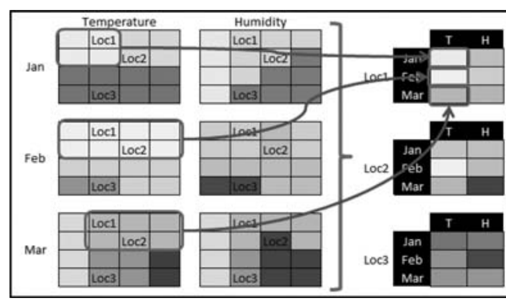


Figure 10. Dynamic weather data generation.

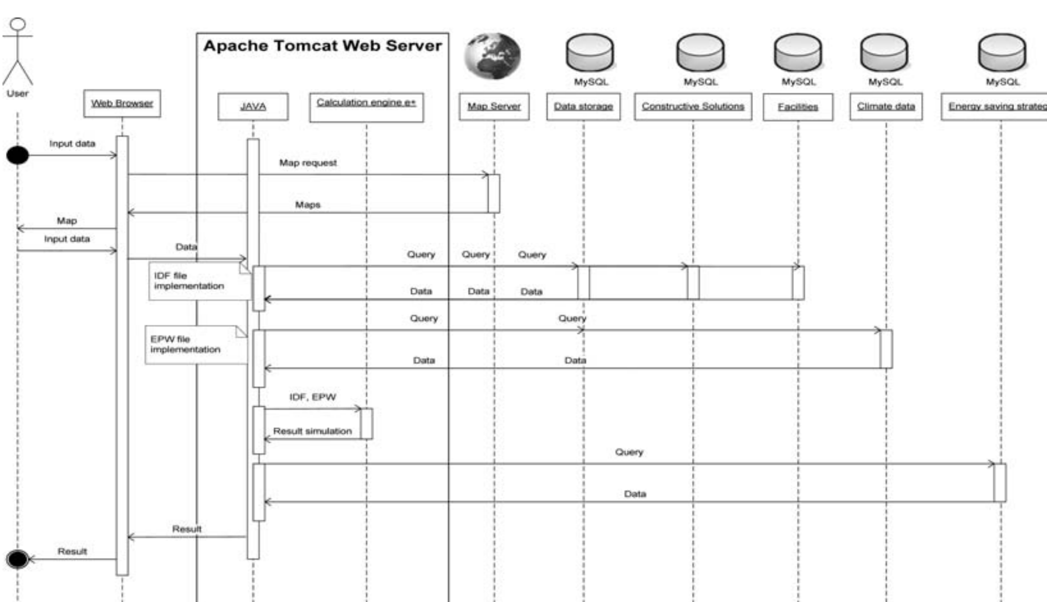


Figure 9. E4RSim scheme.