Collaborative Holistic Design Laboratory and Methodology for Energy-Efficient Embedded Buildings

Reporting

Project Information

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<tr>
<th>EEEMBEDDED</th>
<th>Funded under</th>
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<tbody>
<tr>
<td>Grant agreement ID: 609349</td>
<td>FP7-NMP</td>
</tr>
</tbody>
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Closed project

Overall budget
€ 11 321 436

EU contribution
€ 7 649 997

Start date
1 October 2013

End date
30 September 2017

Coordinated by
TECHNISCHE UNIVERSITAET DRESDEN
Germany

Final Report Summary - EEEMBEDDED (Collaborative Holistic Design Laboratory and Methodology for Energy-Efficient Embedded Buildings)

Executive Summary:

eeEmbedded features a consortium of 15 partners from 9 European countries, covering the whole knowledge transfer chain relevant to the project goals in 4 types of market segments: 1) End-users including construction, architectural and engineering companies as well as control systems and equipment providers, 2) Research institutes with knowledge on BIM/IFC management, control system modelling and numerical analysis, 3) Academic organisation specialized in BIM, ontologies, interoperability, cloud computing and energy system modelling and simulation, and 4) Renowned software development companies in the AEC sector.
The achieved major results are an open BIM-based holistic collaborative design and simulation platform featuring a flexibly configurable system of interoperable virtual design labs, a related key point driven new design methodology, an energy system information model considering the neighbourhood and alternative energy resources, and an integrated information management framework for the ICT-supported design of energy-efficient buildings and their optimal energetic embedding in the neighbourhood of surrounding buildings and energy systems.

The developed new design method based on hierarchical key performance indicators, key risk indicators, key design parameters and top-level decision values will improve the efficiency and the quality of the complex collaborative design process, knowledge-based detailing templates will provide for energy simulations already in the very early design phases, and BIM-enabled interoperability will guarantee a seamless holistic design process performed by distributed experts working together in a virtual design office on the achievement of better energy performance, CO2 reduction, well-grounded climate and user behaviour estimation and life cycle facility operation and cost estimation, thus extending the platform to a real virtual design lab system.

The developed methodology and the prototyped ICT platform and its component services and tools have been tested and validated by end users in numerous test scenarios and models, as well as on two real pilot projects (W2 Building in Leidsche Rijn complex, Utrecht, Netherlands and Z3 Building, Stuttgart, Germany) within three design scenarios, namely urban, early and detailed design. For the validation, two established methods have been used: 1) Cost Benefit Analysis, with focus on the developed design methodology and the overall design process facilitated by the eeEmbedded services and tools, and 2) SWOT analysis, with focus on the exploitable foreground, i.e. the developed new ICT tools. One of the main observed advantages was the decreased total amount of time for management and design. Timesaving is ensured by using a structured project setup avoiding manual management and suboptimal decisions at the later stages of the design process. With eeEmbedded energy analyses and domain decisions are done faster and better due to the established multi key point evaluation system, including life cycle cost assessment. The eeEmbedded methodology and platform assure that future building design will fulfil better client and regulation requirements due to the integrated key parameter check at any point of the design process, the examined comprehensive design variants and the enabled versatile simulations already in the early design stage.

Activities after project end expected to promote wider uptake include submitting modelling and specification results to standardisation bodies (ISO, DIN) and dissemination networks (FIEC, Encord, buildingSMART), use of the project foreground at industry partners like STRABAG and BAM and for education, at the TU Dresden and IABI, Munich. Further impact is expected with regard to design optimisation in the neighbourhood perspective through the developed holistic methodology and the virtual design office concept and tools, as well as the integration of LCA/LCC and FM in the process.

Project Context and Objectives:
Four global trends have to be kept in mind in designing sustainable energy-efficient buildings and their efficient embedding in the environment and energy infrastructure. First, energy has become more and more an expensive good. Second, the natural environment has to be taken care of - to preserve it and to allow it to recover. Third, climate change needs to be considered. Fourth, as people have started to migrate to large cities and more densely populated urban regions, sparsely populated rural areas have started to appear (as an example, in the last years the new erection of residential buildings in Germany has increased in average by 15%, but in big cities this increase was 41%). All these trends are expected
to have strong impact on the future kind of living in the built environment. Consequently, there will be increasing energy-efficiency demands with regard to the sustainable design of buildings and their optimal and long-term flexible embedding in the natural and artificial energetic environment, respecting that human behaviour, infrastructure and climate will change. Design methodologies and design systems will have to adapt to this on-going change. They cannot stay fixed and deterministic but must be apt to consider individual requirements at different locations and unexpected constellations, particularly concerning energy mix, optimal energy system use and the overall envisaged efficient energetic behaviour of the buildings. This means that alternative designs and redundant and robust design solutions providing high adaptability potential are called for. Needed is a design system that allows easy generation of many design alternatives that can be quantitatively evaluated and prioritized, and that can be easily managed (i.e. stored, searched, retrieved and compared). Such a design system should include stochastic methods in order to judge the on-going uncertain changes and to correctly deal with alternative assessments and vulnerability considerations. In technical terms, this demands an effective knowledge and information management system and an interoperable holistic design system bringing together different experts in one virtual design office and on a common interoperable data basis.

Today, there is a huge potential to optimize the energetic behaviour and sustainability of buildings. This potential can be achieved if, in a holistic approach, not only the building but the building together with the natural and built environment and the energetic infrastructure is considered, and if this is done already in the early design phases, together with all relevant energy aspects and their interactions, like thermal behaviour, natural ventilation, complex and redundant internal and external energetic systems controlled under sustainability and cost criteria, positive and negative impacts from surrounding buildings (energy, shade, wind, reflection) etc. This requires that all kinds of related computational engineering methods and tools are provided in an integrative and interoperable way, i.e. thermal building simulation (TBS), simulation of building energy systems (BES), simulation of the neighbourhood system and their interaction (NES), computational fluid dynamics (CFD), e.g. inside air flow, natural ventilation, wind, lighting, shading, reflection, acoustic and control analysis, and that they are embedded in a common information modelling and collaboration space where models and tools are interoperable and where interdependencies are explicitly expressed so that every domain expert can efficiently provide her/his expert knowledge on the required level of detail and innovation. An important role in that regard is attributed to Building Information Modelling (BIM).

Indeed, the efficient use of BIM for optimizing the total life cycle cost of buildings is one of the major challenges in the construction industry today. Inadequate software interoperability and lack of standardization with subsequent loss of information and knowledge in information exchanges between disciplines and life cycle phases, inconsistent technology adoption among stakeholders and high costs because of the fragmented nature of the industry are just some of the obstacles architects and engineers are facing. Building design optimization requires a structured approach that enables continuous changes in design variables and assessment on energy consumption as demanded by the European energy performance of buildings directive (EPBD, 2010-12). These requirements have been further strengthened by the EPBD recast for achieving cost optimal building designs for the life cycle of the building, moving towards nearly zero energy buildings by the end of the decade. BIM and intelligent software systems are expected to play a crucial role in these efforts with improved visualization, process coordination and exchange of information in all life cycle stages, leading to higher productivity and reduced costs for the design, operation and maintenance of energy efficient buildings.

Today, CAD systems commonly assign three main features to BIMs: ability to store, share and exchange
data, object-oriented building model controlled by parametric rules, and ability to link the data model to various types of analysis tools throughout the building life cycle. On the other side, a large number of energy analysis tools exist, many of which have been developed long before the introduction of BIM. For the majority of these tools, significant efforts and time are required to prepare the necessary input data to assemble the analytical model required to run the analysis tool. Recent development work related to the integration of BIM data based on the IFC standard with advanced tools like EnergyPlus has brought some positive results but at the same time underpinned the existing difficulties and gaps.

Energy-efficient building design adopting the LEED, BREEAM or DGNB methods for sustainable green construction is a complex, holistic process requiring the use of multiple information sources, multiple design and analysis tools and the cooperation of multiple actors across various AEC domains (architects, building services engineers, energy experts, cost estimators, facility managers etc.). In order to create a common basis for cooperation, the use of a standard BIM repository is of vital importance but it is not sufficient to ensure optimized energy-efficient building design. Firstly, a building information model does not contain all data needed for the analysis of energy behaviour, such as climate data, occupancy data, neighbourhood data etc. Secondly, the mathematical models of the used energy analysis and simulation tools require different data structures than BIM and therefore considerable model transformations before the BIM data can actually be used. Last but not least, each Building Information Model typically represents one specific design alternative, whereas for the development of holistic energy-efficient design solutions it is essential to examine, evaluate and compare multiple design alternatives in parallel. Hence, a major challenge is to provide ICT building blocks based on standardized Building Information Models that will integrate, complement and empower existing tools for design and operation management to an integrated Virtual Design Lab. Moreover, in order to achieve that goal, a new methodology for collaborative and holistic work supported by a collaborative holistic design and simulation system needs to be established.

In this context, the initial work plan of the eeEmbedded project was developed. The vision was to increase, by an order of magnitude, the quality of energy-efficiency in building design through the development of an In-Silico Energy Simulator Laboratory. In pursuit of that vision, the project consortium set out to develop an open BIM-based holistic collaborative design and simulation platform, a related holistic design methodology, an energy system information model and an integrated information management framework for designing energy-efficient buildings and their optimal energetic embedding in the neighbourhood of surrounding buildings and energy systems. In this environment, a new design control and monitoring system based on hierarchical Key Performance Indicators (KPI) was envisaged, to support the complex design collaboration process. Knowledge-based detailing templates were to be developed to allow energy simulations as early as in the urban design phase. BIM-enabled interoperability would provide for a seamless holistic design process with distributed experts, and a seamless integration of simulations in the virtual design office (energy performance, CO2, control system, energy system, climate change, user behaviour, facility operation), thus extending it to a real virtual design lab platform. Accordingly, the main goal of the project was defined to “develop ICT building blocks based on standardised Building Information Models that will integrate, complement and empower existing tools for design and operation management to the envisaged Virtual Energy Lab platform”.

The project work was focused on the following 7 research and development objectives:

1) Interoperability of the design targets as baseline for collaborative holistic design using a new Key Point
based design methodology comprising a hierarchy of Decision Values, Key Design Parameters, Key Performance Indicators and related Key Risk Indicators. The developed Key Point system shall act as guideline for milestones and control of the collaborative design process, providing the interoperability and monitoring the progress of the design during its different phases.

2) Interoperability of the information for heterogeneous distributed information resources and services based on system and domain ontology schemas and tools

3) A knowledge structure over the information domain models providing the mapping information needed to transform the domain information models to computational engineering models, as well as the knowledge needed to decide on the necessary level of detail and the respective cross-model structure

4) Holistic collaborative virtual design office based on collaborative and virtual enterprise methods to manage people, tools and information, including a change management component to properly handle the various changes arising during design and enabling to find, retrieve and compare multiple different design alternatives with the help of an advanced BIM-based visualization system

5) Holistic virtual design lab providing quantitative computational support based on efficient cloud computing methods. The tools and services integrated in the virtual design lab will provide the computer power for the various required engineering analysis and simulation tasks and will support the feedback cycles for the interrelationships between the computational models, based on the interoperability of system information.

6) Stochastic approach as part of the overall virtual design lab approach, extending current deterministic models and approaches to cope with the uncertainties in the life cycle concerning climate, energy provision, as well as the usage of the building and the human behaviour

7) Knowledge-supported design methods enabling fast preliminary detailing in the early design phase. This is a mandatory issue to be able to carry out computational analysis and simulations and to obtain conclusive quantitative results about the energetic performance of the building and about the vulnerability of the energy systems already at the early design stages, when fundamental energetic design decisions have to be made that are hardly alterable later on.

In accordance with these objectives, the main products to be developed were defined as follows:

1) A holistic design methodology based on a hierarchically structured dynamically evolving Key Point system, which guides and monitors the progress of the multi-disciplinary, multimodel and multi-physics design process

2) A collaborative, holistic design platform comprising a virtual multidisciplinary collaborative design office and a set of configurable virtual energy design labs for the design and evaluation of new or retrofit buildings embedded in their energetic environment and covering their energetic performance and vulnerability on different levels of detail
3) A new reference model schema for the Energy System Information Model (ESIM) structured according to BIM-IFC (ISO 16739) and incorporating the topography structure of the energetic environment. This should complement BIM concerning the internal and external energy systems, built on and subsuming the various proprietary data structures existing for energy systems.

4) An ontology-based open interoperability system as baseline for managing the information and cross-dependencies of the multi information models BIM, ESIM and BACS, and the related multi-physics problems and their computational analyses.

5) A multimodel information management method and related management services enabling the integration of the separately maintained domain models, combining them to multimodels wherever needed, filtering out the right views with minimal amount of information, mapping the eeeBIM data to the appropriate computational models and taking care of the interactions and feedback cycles for the multi-physical interdependencies of the computational models, with prototype implementation of the building thermal energy system, the neighbourhood energy systems, natural ventilation and building-wind interactions (cool out and wind tunnel effects).

6) A knowledge management system for fast and grounded design decision-making with characteristic design detailing templates enabling quantitative analyses and simulations already in the early design phases.

The work to accomplish these objectives was scheduled by 7 milestones and performed within 3 phases, corresponding to the project review periods.

In the first period (01.10.2013-30.03.2015) the focus of the RTD work had been on the gap analysis and the requirements set-up for the Key Point driven multi-disciplinary design method as well as the development of use cases for the urban, early and detailed design phase. eeBusiness models were defined from the viewpoints of owners, ICT vendors and designers. Interoperability and collaboration requirements were specified as basis for the continuous design process on tool and management level. The envisaged advanced use of knowledge-based templates was conceptualized and the overall architecture of the eeEmbedded platform with specification of the major components and their main interrelationships was defined. A principal definition of the holistic Key Point based design framework was developed and concretely expressed in aggregated requirements.

The second period (01.04.2015 – 30.09.2016) was focused on the development and implementation of the first prototype of the Service Oriented Architecture of the eeEmbedded platform. For this purpose, multiple developments were done in parallel. The high-level system architecture from the first period was extended and concrete requirements for interoperability of the individual modules and systems of the platform were established. Work on the individual components of the platform comprised development of the eeEmbedded prognosis systems, the energy and CO2 life cycle performance analyses, multi-information and multi-physics modelling as well as the ESIM model. At the end of the period, the developed services and tools were consolidated into a first prototypical implementation of the virtual energy design lab and the virtual multidisciplinary collaborative design office platform.

The third period (01.09.2016 – 30.09.2017) was strategically intended for extensive validation and
verification work, as well as finalization of the implementation work on the developed tools and services towards exploitable foregrounds. The final prototype of the virtual energy design lab and the virtual multidisciplinary design office was completed and the platform progressed successfully from limited test cases towards more complex and more realistic pilot projects from which more general evaluation results and impact perspectives could be concluded. A validation framework was established distinguishing between the verification of results regarding the requirements and design specifications set up at the beginning of the project and the validation of the eeEmbedded platform, methods, services and tools in industry context.

Project Results:

We consider the following results as Top 10 achievements of the eeEmbedded project:

1) Key Point based design method supporting the control of the collaborative design work and the monitoring of the progress against the design objectives.

2) Open ICT platform incorporating the Scenario Manager for process management, the Multi-Model Navigator for checking the models and assigning templates, and an extensible number of simulation and analysis services and a KP analysis tool for decision making grouped in interlinked configurable Virtual Energy Labs for each role and domain in the design process.

3) Structured Key Point setup enabling definition of performance objectives and requirements in holistic and automated manner for verification and validation of the design objectives continuously, at all key points throughout the design process.

4) Scenario Manager (ScM): This brand new prototype application supports the collaborative project process by dynamically assigning and monitoring project tasks and attaching the required data and actions to them. In this way, project work can proceed in coordinated manner with clearly allocated responsibilities, work items and interdependencies for each member of the project team.

5) Project collaboration via consistent use of the BIM Collaboration Format (BCF): The integration of the BCF platform in the ScM ensures effective communication in the project team. The successor in the process is informed about the finalisation of the previous task and receives links to all the data necessary for his/her task.

6) Easy creation and evaluation of variants: The eeEmbedded platform incorporates generic climate, occupancy, construction, HVAC, BACS and maintenance templates that can be assigned to element types, to analyse the impact of various parameters on the sustainable performance of a building.

7) Multi-Model approach: For most of the simulation tools a Multi-Model Container (MMC) was implemented, which means that only one IFC file is needed per alternative, whereas various external information sources and various variants are linked to elements in the IFC file using a variation matrix. E.g. for 50 design variants there is no need to create 50 IFC models but only one model with 50 different variants linked to it.

8) Exchange Requirements (ER) checking: The Exchange Requirements, which are crucial for
collaboration in the project team, can be checked via the Ontology Verification Service (OVS) and missing information highlighted in red in the BIM model. The service is directly integrated in the Scenario Manager, where ER are linked to the specific tasks in the process.

9) BIM-based Interoperability APIs: In the eeEmbedded platform simulations and analyses run as services. This means that the results of various variants are processed without interaction with the end user. Manual work is significantly reduced via the developed APIs. The coupling of data and tools becomes feasible and the pre-processing time for model preparation is brought to minimum, thereby enabling affordable variant examination.

10) Just-in-time result evaluation and decision-making: The developed new decision-making tool analyses the impact of Key Design Parameter (KDP) on sustainable Key Performance Indicators (KPI) such as energy, emissions, thermal comfort and Life Cycle Costs (LCC). In addition, the impact of risks can be analysed. The results are weighted based on the preferences and visualized in a decision value graph, which makes the comparison of alternatives and variants very efficient and transparent.

These results are elaborated in the following sections, focusing first on the developed new design methodology and secondly on the achieved exploitable foregrounds. More details on the project findings are provided in the publicly available Deliverable D10.400 “Final Project Report”, which is accessible via the project web site at www.eeembedded.eu/deliverables as well as in the respective work package deliverables.

1. The eeEmbedded Holistic Design Methodology

EEEMBDED has developed a new ICT based intelligent methodology to design energy efficient buildings integrated in their neighbourhood. It extends existing BIM developments with a multimodel approach for modelling and analysing the building architecture and its systems (HVAC, BACS) considering facility management strategies and integrating sophisticated simulations to optimise energy, costs and environmental impact along the life cycle of the building.

The design methodology was specified by the end-users in eeEmbedded at the beginning of the project. These specifications were used by eeEmbedded developers as basis to implement the tools and services integrated in the platform, which were then applied by the end-users for the design of two real pilot buildings. Finally, the developed methodology for holistic energy efficient building design has been updated taking into account the experience gained from the performed pilot projects.

The eeEmbedded methodology features a clear BIM-based approach. It uses Key Points to drive the design, and Templates to facilitate and accelerate the process. The Key Points are measurable target values that represent requirements coming from clients, regulations, site and designers. They are used as basis for taking informed decisions on design solutions. The Templates contain valuable information to speed-up and streamline the design process while sophisticated analysis methods are applied to a large number of design variants and alternatives making use of cloud technology.

The major aspects of the developed methodology that distinguish it from state-of-the-art design work are outlined below.

1.1. Investing time on project setup
A comprehensive project setup is required to ensure integrated process, information flow and software in BIM-based collaborative design and to avoid problems due to differences in working cultures, work processes and software applications. The more detailed the project setup is, the more straightforward the design process will be later on and the more problems can be avoided in advance. In particular, the project setup must precisely define:

- Project Type in terms of building type, project address, contract type, budget and duration apart from the project name and its description;
- Project structure, i.e. the teams that will be involved and their roles;
- Project infrastructure including the software that will be used and the required format of inputs and outputs (IFC4, CSV, etc.);
- Project requirements coming from sites, regulations and building owners; they must be described, classified and aligned per domain and cross-domain as well as prioritized;
- Key Points translating requirements into four types of measurable target values, namely (1) Decision Values, (2) Key Performance Indicators, (3) Key Risk Indicators and (4) Key Design Parameters;
- Design Check Points linking the key points to process milestones;
- Overall Process setup defining the major design tasks and their sequences as well as the responsible actors together with their interrelationships;
- Exchange Requirements defining the information to be exchanged between the actors (inputs and outputs of tasks).

The benefit for AEC companies is the structured monitoring of all essential project requirements, i.e. which requirements are verified and by whom. In this way, it is possible to know whether the project is progressing within the sustainable requirements and the budget, which is an enormous support for quality control in complex projects. The added value for the client is that he has continuous and transparent proof that all the requirements are met.

### 1.2. Using Key Points in structured ICT supported manner

The eeEmbedded methodology defines a comprehensive framework including rating scale and rules with the end targets in mind. The basis is translating requirements and design criteria into Key Points, which provide the verifiable design checkpoints in form of target values. Key Points have two main missions. On the one hand, they integrate all design criteria and requirements. On the other hand, they guarantee easy and fast evaluation and comparison of design options based on relevant well-defined metrics. This means that already in the project brief requirements and major design criteria are defined top down according to the following steps:

- Choose a Decision Value (DV) and set a target; e.g. sustainable score 85 or Internal Rate of Return of 5%. The Decision Value represents the preferences of the decision makers related to the project goals. It allows prioritizing Key Performance Indicators by means of weighting factors (e.g. Passive House).
- Define Key Performance Indicators (KPI) influencing the DV in order to be able to validate if the building is defined according to the clients’ needs. Prioritize those by weighting factors and set targets based on a requirements analysis. Key Performance Indicators are numeric metrics of building performance related to energy usage. They are influenced by Key Design Parameters and are additionally the basis values for evaluation via Decision Values.
• Define Key Risk Indicators (KRI) and set target values that represent deviations of the building performance due to the stochastic nature of various parameters such as risks related to energy use or to the reliability of the energy system.
• Define Key Design Parameters (KDP) and set targets based on a requirements analysis. Some Key Design Parameters are already defined and act as constraints in the design process, whilst other parameters can be adapted to optimise sustainable targets. Key Design Parameters (KDP) represent the required building properties and usually have a limited value range.

1.3. Structured arrangement of processes, tasks, roles and information exchanges

Implementing the Building Information Modelling approach requires a clear arrangement of processes, tasks, roles and information exchanges. The following questions must thereby be answered.
• Who needs the information extracted from the building information model?
• At which point in time this information is needed?
• Which minimal amount of data has to be exchanged?

eeEmbedded recommends to digitally capture the information exchanges according to the IDM approach (ISO 29481) and to steer and track them during the project.

To carry out this recommendation, exchange requirements are defined for the various BIM uses/phases and configured for the specific project at hand in its digital environment. The developed Scenario Manager (ScM) provides the functionality to setup and run the exchange requirements verification with the help of the integrated Ontology Verification Service (OVS) and/or the externally used IfcDoc tool from buildingSMART.

1.4. Using Design Templates

Speeding up and streamlining the design process while integrating sophisticated analysis methods applied to a higher number of design variants and alternatives within a shorter time works only when smart re-usable templates are integrated into the design process. These templates are dividable into two types, (1) design content templates and (2) process templates.

Main target of the template usage is the higher level of formalisation and the reproducible quality of design and analysis results across projects and domains, the higher productivity of the involved design team, and the highly improved capability to define and examine different design variants. Integration of both template types into design process starts with the setup of the project while using process templates covering the step-by-step workflow including the targeted output quality, and covering the related exchange requirements between the process steps. Moreover, the project setup should also cover the agreement between the involved project partners about content templates. Typical examples for content templates are pre-defined construction templates for building elements (walls, slabs, windows) and equipment (HVAC, sensors and other building automation devices), and/or occupancy profiles as inputs for both the design and the analysis steps.

1.5. Planning an urban design phase focused on energy

Urban design is crucial to take advantage of energy saving potential by using passive heating, photovoltaic potential or natural ventilation. For example, it is widely known that the level of solar exposure
which is strongly linked to orientation and surrounding shadows influences heating, cooling and artificial lighting needs of buildings.

In this line, it is important to create a trend to incorporate urban design and planning concepts into the building design process in order to integrate the buildings energy efficiently in their neighbourhood. Therefore, we recommend having a first design phase focus on urban design, taking into account energy considerations. Furthermore, we see as highly important to include simulations and precise calculations as much as possible in this first phase to increase the reliability of the taken early decisions, which are generally acknowledged as the most influential decisions on the building performance.

The urban design phase should thereby be focused on the development and evaluation of several building cubature and energy supply concepts taking in consideration the integration into the neighbourhood and the use of renewable or conventional resource on site and on district level. To this end it should include: (1) CFD simulations related to the climatic conditions (wind) to optimise thermal comfort and analyse the integration of the building into the neighbourhood, (2) Energy building simulation to rank cubature variants in order to find the optimal energy demand, (3) Estimation of uncertainties when ranking combinations of cubature and energy supply variants that optimise energy consumption and use renewable or conventional resources on site and district level, and (4) Life Cycle Cost analyses to also compare building cubature variants in combination with energy system variants and the life cycle costs.

1.6. Involving facilities management experts in the early phases of design

Traditionally, facilities management and property management (FM/PM) has been regarded with a poor relation to the architecture, engineering and construction (AEC) industry. The eeEmbedded methodology acknowledges that the role of FM is much wider than being involved only in the operational phase. Therefore, FM/PM professionals' involvement in the early phases of design and knowledge sharing strengthens the integrated design process developed in the eeEmbedded project.

The involvement of FM professionals is perceived of high value for the entire facility life cycle. Benefits are seen in ensuring less rework, emphasizing value for money by taking into consideration life cycle aspects such as LCC, LCA, investment costs, maintenance cost, flexibility, adaptability and environmental policies. To date the use of BIM is not common for FM/PM professionals. However BIM tools are capable of simulating and predicting different performance parameters that are very useful for the decision making process at a strategic and operational level. FM/PM professionals do not need to necessarily know how to perform the simulations but should be able to interpret and evaluate the results in form of key performance indicators for making informed decisions in the long term. Potential KPIs generated for FM are related to cost of maintenance and operation, revenue, space management, and environmental and safety issues. These KPIs are integrated in the decision making methodology and supportive decision making tools used during the design phases.

A comprehensive description of the various aspects of the methodology and the developed design scenarios is presented in Deliverable D2.5 “New ways of holistic working for energy optimized and embedded building”, available via the project web site.

2. The eeEmbedded Virtual Lab Platform

The eeEmbedded ICT platform comprises many end-user applications and service components, which support the developed new design methodology in different ways. The combination of design tools,
analysis tools, data management tools and result evaluation tools together with data servers led to the concept of an eeE Virtual Laboratory that can be configured for the different goals and technical domains of the different members of the design team. Combining such laboratories in a flexible environment encompassing data and compute cloud servers linked together via a common service bus enables performing holistic energy studies about the designed buildings in different design phases, starting already from the urban and early design stage.

2.1. Software Architecture

Some tools and components of each Virtual Lab are local software applications, which import and export data files like CAD or FM design. Some others are web components which provide REST-APIs. Therefore, the software architecture is arranged as a service-oriented architecture (SOA). It is structured in the following layers:

• User Layer, providing the user interfaces for all the different design domains. As each user has a specific view on her/his data on this layer, role/domain specific tools are configured individually.
• Virtual Lab Layer, responsible for the data connection among the platform’s users, services and tools. This layer provides also interfaces to additional external tools which are currently not compliant with tools from the user layer. Advanced BIM Tools like the developed Scenario Manager (ScM) are aligned here to enable BIM workflows, data imports, file management and building analyses.
• Communication Layer, providing the overall collaboration infrastructure. All information and data files are shared by Multimodel Containers (MMC) via the Internet with the help of the BIM-it collaboration server using the BCF approach.
• Shared Service Layer, managing the BIM workflows with its messages, events and tasks. Workflow definitions created in the Scenario Manager are analysed by a workflow engine, which informs the users when they have to do their work and what they have to do.
• Service Component Layer, containing all external applications that help to handle the data. These applications can all be automatically called within the Scenario Manager workflows. Furthermore, the clients to web data repositories and simulations are allocated on this layer.
• Repository Layer, including all data servers like BIM servers and template repositories. While storage clouds are used to upload and download files to BIM servers, all simulations run in compute clouds in order to allow analysing and evaluating hundreds of design variants in parallel for the time of a little more than a single one.

The advantage of this layered SOA approach for the eeE Virtual Lab is the possibility to exchange components in each layer without affecting components of other layers. Therefore, it is possible to use e.g. other BIM servers than the EDM model server, other simulation tools than TRNSYS, as e.g. EnergyPlus, or another BIM management server than BIM—it. This guarantees a flexible system without relying on any very specific tools.

2.2. Structure of the eeEmbedded Virtual Lab

An essential feature of the Virtual Lab Layer of the eeEmbedded platform is that it comprises multiple virtual labs, which can be configured specifically for the needs of the separate domains and roles in the holistic design process. In the scope of eeEmbedded the following views and virtual lab configurations have been implemented: (1) Project Manager / Decision Maker, (2) Architect, (3) HVAC Designer, (4)
BACS Designer, (5) Energy System Expert, (6) CFD Simulation Expert and (7) LCC Expert. Further roles can be added using the developed architecture and methodology. Therefore, as a whole a Virtual Design Office is established. One of its outstanding features is that, while differently configured, all virtual lab instances follow the same principal structure which enables their seamless integration into a coherent overall platform. This unified structure comprises three layers:

- User Layer, featuring general purpose or domain-specific authoring CAD tools, any other local domain tools that require user interaction and the mandatory Scenario Manager (ScM) and Multimodel Navigator (MMNav)
- Analysis Layer, which bundles the interfaces to simulation and analysis services allocated on the compute cloud of the platform
- Core Layer, encompassing the needed collaboration, model validation and model management services which are the same for all Virtual Lab instances and provide the functionality for their proper functioning and interoperability within a consistent overall system. This layer includes also the APIs enabling the interaction with the Service Bus and the underlying shared service layer of the platform.

2.3. The eeEmbedded Multimodel Framework

The eeE Virtual Lab platform provides a flexible data concept, which allows sharing any needed information in any data format using a concept called Multimodel Container. Such a container defines a structure that links different kinds of domain models via connections specified in Link Models. Domain models are treated as independent information resources with their potentially own application domain, data schema and data formalization. In this way Multimodels can be applied on any domain. For cross-domain tasks, such as exchange requirement, key point or multimodel checking and validation, overarching lean ontology models capturing only necessary high-level semantics and utilizing link model information are dynamically constructed and used.

There are several ways to realize the Multimodel Container (MMC). It can be implemented as compressed archive file, which contains all models or as a Multimodel that contains only the links to the actual resources. In principal, Multimodel Containers encompass domain models from different domains and each model can be independently processed by the project partners and their respective domain tools. Each partner can thereby create or develop her/his own domain models and link them with existing models. This enables the design partners to recombine the Multimodels based on their demands and the requirements of the project.

This concept was applied because of the many different proprietary data models the involved tools need. The advantage is that not all necessary data has to be added to a single data model. This prohibits redundant information in the overall workflow, reduces model complexity and minimizes the shared and stored data. Hence, the eeEmbedded concept is not to save all information in one huge overarching model, more precisely the building information model expressed via IFC. Instead, we keep each file format as it is and interlink them with each other. Every user of such a Multimodel Container selects the domain models, which are needed for her/his work. Multimodels are packed in ZIP format and attached as BIM snippets to BCF topics in alignment with the general buildingSMART collaboration approach. They are distributed via the ScM and most information is collected through services of the service component layer.

3. eeEmbedded Products and Services
3.1. Project Setup and Requirements Management Service

The definition of all requirements is performed in accordance with the developed new design methodology. It is supported by a newly developed user interface providing a front-end to the underlying ontology framework of the eeEmbedded platform. Utilising VBA, XML, RDF/OWL and JAVA technologies, this Microsoft Excel based user interface functions as editor for the generation and management of the ontology models. In that way, any project manager, BIM manager, decision maker or owner can start using the interface and can easily and rapidly become familiar with it.

Requirements input is decomposed in the following five categories: (1) Qualitative requirements i.e. building functions defined and selected using the OmniClass classification system, (2) Selection of generic product libraries used concomitantly for both building design configuration and for simulations, (3) Quantitative requirements expressed in terms of Key Point TO-BE values, (4) Design process settings for establishing phases and tasks, and (5) Exchange requirements for specification of mandatory eeBIM data exchanges.

Type categories, which are important for later automated template assignments and data filtering, are defined in a first step. They are organised in five abstraction levels: District, Site, Construction, Space and Element. The District Level describes the available internal and external energy supply for the planned building. This includes power plants as well as energy storages and the related values for energy consumption and energy generation. On the Site Level the building site of the planned building is described. The different areas, like parking areas and areas for energy generation (e.g. area for solar panels), are detailed on this level. The Construction Level contains the description of the different construction types like the type of the building (e.g. High School, Police Station, Hospital, etc.) and other constructions. On the Space Level the different spaces within the building are typified. This way certain Ifc space elements can be related to a Restroom, Office Room, Corridor, etc. Finally, the Elements Level represents the lowest level and contains various building element types.

By the definition of Key Point requirements the end user can address the four KP types introduced in the methodology, i.e. decision value (DV), key performance indicators (KPI), key design parameters (KDP) and key risk indicators (KRI).

3.2. Design Tools

Design tools integrated in the eeEmbedded platform are on the user layer of the Virtual Lab. They are either off-the-shelf CAD systems like Autodesk’s Revit, or software products of the consortium partners that have been extended or developed during the project (DDS-CAD - for HVAC Design, and eeBACS Wizard – new tool developed for BACS design). Their purpose in the eeEmbedded methodology is to provide the initial design input for analysis at the respective steps of the urban, early and detail design phases.

Architectural design is accomplished by using a CAD tool that is certified to export standard BIM-IFC files. In eeEmbedded predominantly Revit has been used but Nemetschek’s ALLPLAN is another possible option. The emphasis of the project in that regard has been on the specific modelling and exchange
requirements that need to be fulfilled to ensure correct energy and LCC analyses. Indeed, ensuring the quality of the model is essential for a streamlined process and the delivery of the schedule analysis services and design steps. The most important factor for modelling is to use software which supports the open IFC standard and enables tool-neutral information validation. The IFC model is one of the main sources for analysing each step in the overall design workflow and it allows transferring different exchange information within and between the different design domains. It includes project, site, topography, surrounding neighbourhood buildings, storeys, spaces, and construction elements. The latter comprise walls, windows, doors, slabs, roofs etc. Terrain geometry and mass models of neighbourhood buildings are modelled as different object but connected to IfcSite. Normally, IfcSite means the construction site in closed sense. However, for energy-related analysis the geometry of neighbourhood buildings should be available within the IFC model as mass models whereas the neighbourhood buildings are normally located outside the construction site in the closed project-specific sense. Here it must be pointed out that creating an IFC file that fits all needed software applications is not a straightforward task. Despite following the outlined modelling and exchange requirements and recommendations developed in the eeEmbedded project there are still a number of challenging issues regarding the correct generation of IFC data for the purpose of energy-related analyses and simulations, which are not yet fulfilled by legacy authoring tools. They are discussed in the project deliverable report D9.4 regarding the validation of the eeEmbedded platform on the example and experience obtained from the performed tests and pilot studies.

HVAC design software (DDS-CAD) facilitates complete design and calculation of pipe and duct systems. Based on the intelligence information extracted from the architectural BIM-IFC, integrated calculations like air flow requirements, heat/cooling loads etc. enable developing optimal HVAC systems for the building and its use. With DDS-CAD’s openBIM commitment, all types of available open construction library elements can be used, even though the components must be enriched with technical data. The role of HVAC design software in the early design stage is to import and analyse Space/Zone client requirements like occupancy, schedules, room temperature, activity, level of comfort etc. in addition to the spatial variants like area/volume, shape, location, glazing properties, sun blinds and so on. When these requirements are collected, and the external climatic conditions such as winter/summer temperature, humidity, solar radiation etc. are taken into account, a set of design criteria is applied to build up one or several variants of the HVAC systems. The different variants provide for comparing options with regard to different building cost, physical space requirements, operating expenses and so on. They must possess a minimum of information contents for the BACS design, and all components must be assigned to an IfcDistributionSystem with correct enumerated type. Components like Air Terminal, Damper, Air Handling Unit (AHU) etc., where there is a direct link to the BACS software must obligatorily contain this information. Using the knowledge obtained from the HVAC design allows meeting TO-BE KPIs and KDPs quicker and better. Our approach to this information flow is to use standardized „openBIM“ knowledge templates to all disciplines.

Including building automation and control systems (BACS) design into the holistic eeEmbedded methodology is a new finding of the project, which goes clearly beyond the current state-of-the-art process. In order to perform the BACS design, two steps have to be performed in advance: (1) Proper IFC based BIM model of all spaces/zones of interest, and (2) Definition of functional relationships within the HVAC design as well as the usage of proper IFC standard functional descriptions (such as IfcValve, IfcBoiler
The first and most important added value by using this approach is that energy efficient solutions are designed in an early phase based on the provided models. In addition, the developed solutions are comparable with previous projects and templates can be reused in other projects.

The developed eeBACS Wizard of the eeEmbedded project supports designing BACS consistently using BIM-IFC data and interacting with architectural and HVAC design using the shared model data and the collaboration and resource management tools of the eeEmbedded platform. It starts by analysing the available HVAC model and suggests a minimal setup of control strategies based on the desired energy efficiency class according to EN15232. The user can then customize the solution according to additional key points. The tool provides templates for products including costs and approximated energy usage over the lifetime.

Last but not least, on the user layer of the eeEmbedded platform stands Energy System Modelling (ESIM). Especially within the Urban Design stage architects and clients are interested in elaborating and comparing different system approaches of energy system concepts on a general systemic level. The analysis of current design steps involved in the creation of an energy system showed the informational gaps and the need for a unified description of energy systems. In that regard, the identification of core parts within the energy system in combination with a cross-domain-oriented set of properties was the starting point for a concept targeting the development of a unified modelling approach.

Systems Engineering with its related modelling languages UML and SysML is the approach in eeEmbedded used for the description of energy systems. Based on the analysis of existing approaches, a formal specification and conceptualization of the ESIM ontology was achieved.

### 3.3. Scenario Manager

The Scenario Manager (ScM) is a new product developed within eeEmbedded following the holistic design methodology based on the IDM approach. It can support any BIM project in different design phases and it was developed as a general tool, which supports team management, process management and data management for every project participant as mandatory part of the User Layer of every Virtual Lab configuration. Its features comprise:

- **Team management**, comprising the definition of BIM teams, assigning users to teams and determining the team roles for all users (BIM manager, architect, energy expert, etc.);
- **Process management**, comprising the definition of workflows for the different design phases, specifying control points and design loops, assigning users to tasks and issuing of notifications when users have to work on tasks;
- **Data management**, comprising the requirements setup, checking the data quality based on the exchange requirements, automatic upload/download of models to/from servers on the cloud, communication support via BCF topics and Multimodel Containers and support for the preparation of results for KPI visualisation.

The developed ScM engine enables the communication of multiple Scenario Managers within the eeEmbedded platform, which is achieved with the help of the central BCF server, BIM—It. The engine is responsible to load process models (BPMN diagrams) and to verify the status of the current running process. It notifies the Scenario Managers about changes in the workflow, for example, when a task was completed or a problem like failed ER checks or failed key design parameter checks occurs. Users can
upload any file to the workspace and can download all files from other users where they have access rights. The workspaces are synchronized each time a handover to the next user in the workflow is done. The data, which will be synchronized is held in a Multimodel Container which is attached as BIM snippet to the communicated BCF topic. This is an enhanced approach for BIM—it which previously was focusing only on IFC data.

A BPMN editor included in the ScM supports the major BPMN elements like user task, flow, exclusive and parallel gateway, start event and end event. The project manager models the workflow and uses tasks, which are specified in the key point setup table. S/he can assign to every task one user and some ERs. The ScM emphasizes in every task which actions are supported in that workflow stage. The data is transferred to and from the related tools automatically. Hence, the user does not have to care about how to store the data. Once the user has completed a task, he can finish it and the handover to the next user will be done automatically as defined in the BPMN diagram.

3.4. Multimodel Navigator

The Multimodel Navigator (MMNav) is the second mandatory tool in each Virtual Lab configuration on the User Layer of the eeEmbedded platform. It enables the user to check key design results arising in the various domains of the design process. It provides also advanced functionality to set up new construction conditions and to execute various simulations of proposed design variants and alternatives by the design team.

The MMNav was developed on top of the bim+ platform of Nemetschek. It is a multi-media-based navigation and visualization application that allows users combination of different graphical representations of results elaborated in the eeEmbedded design scenarios. The tool runs on standard Internet browsers and does not require software installation. For this reason, the MMNav is available everywhere and on any device, which could be decisive for decision makers.

The application features:
• Identification of graphical and numerical deviations, such as comparison of pre-set TO-BE design values with actual AS-IS Values;
• Assignment of new construction templates, space use templates, or other numerical settings such as climate data, latitude or longitude, north direction etc.; this allows users to run simulations as early as possible and to examine different materials and construction variants;
• Ordering the execution of different simulations under variant conditions - Energy, Wind, Life cycle costs etc.;
• Visualisation of analysis and simulation results, including multiple KPIs;
• Storing design decisions and corresponding construction conditions and support of communication issues.

Simulation results are automatically attached to respective individual objects via the ScM after a simulation service is run. These results are immediately accessible for the user by clicking on the attachments in the menu on the right side.

3.5. Collaboration and Resource Management Services and Tools
Collaboration and resource management services and tools are in the core of the Virtual Lab environment. They are responsible for the common use of the eeEmbedded service bus (Communication Layer) and for the intelligent access to the Repository Layer (Storage Cloud) and the analysis and simulation services (Compute Cloud). In the current eeEmbedded platform realisation these services include: (1) BIM-It, supporting the BCF-based communication, (2) the EDM Model Server, providing a number of BIM-related data management services, and (3) a set of Cloud Services facilitating the parallel analysis of multiple design variants.

The BIM-It web application is a modern collaboration platform built for easy interoperability and exchange between partners in all project types of the AEC industry. It was the first available product to support the BCF API, shortly after it has been officially released by buildingSMART International in early 2015. In eeEmbedded, the Scenario Manager utilizes the developed BCF API to connect multiple platform services with BIM-It.

The EDM model Server (EDM) provides a full featured repository for storing and manipulating ISO 10303 STEP EXPRESS based data, of which IFC 2x3 and IFC4 are two implementations. A fully featured EDM server provides services adapted to both thin clients like web browsers and smart phones, and fat clients like CAD systems and other full IFC data handling clients.

Opposed to the more common file based storage for IFC BIM data, EDM stores data as models, where each model can logically refer to other models. While a model can be exported and imported in its entirety as a file, it is often necessary to export and import subsets of a model with operations like extraction and merging. The database system is designed to hold any number of models and each model has no size or instance number limit. EDM can also store as part of the model data files in the same way as any other attribute. Supported file and transfer formats include the ISO10303 Part 21 Step Physical File Format (SPFF) and Part 28 XML format, IfcXml, an implementation of P28 XML, and for Web Services SOAP xml (Simple Object Access Protocol) and JSON (JavaScript Object Notation).

The Merge/extract functions developed in eeEmbedded are powerful features for adding, replacing and extracting subsets of data, for example domain models (HVAC, BACS, EL) in an IFC file, or embedded “non-traditional” data like lease areas or maintenance data.

Cloud Services are used for the energy simulations performed on the eeEmbedded platform. Calculations involved in energy simulations demand large computing resources, hence deployment in the cloud is an inevitable prerequisite for efficient exploration of design options towards achievement of optimal building performance. Development work on cloud services exploited prior availability of all analysis tools as cloud enabled applications and delivered a cloud framework abstraction that provides plug-ins for major existing cloud frameworks and can easily cope with future cloud frameworks with minimal developer effort. The resulting cloud services comprise: (1) a Broker Service that translates requests from the eeEmbedded service bus to various cloud frameworks, and (2) Plug-ins to implement different cloud engine interfaces. The Cloud Broker Service encapsulates all the details of the underlying cloud infrastructure masking differences and implementation details (like hosting server location or specific cloud system details), thereby providing a uniform eeEmbedded Cloud API. To guarantee that the Cloud Broker Service is globally accessible, in the eeEmbedded service bus an advertisement/registration mechanism is used to publish service availability. In particular, the Broker Service has been used to perform energy simulations.
with TRNSYS and CFD simulations with the 3D Wind and 3D Therm applications using the developed API.

The simulation management is enabled by a Simulation Model Mapper which is part of the analysis domain reflecting special needs of the used analysis tools as well as the used cloud environment.

3.6. Model Validation Services

The model validation services are another important part of the core layer of the Virtual Lab environment. While not mandatory for the functioning of the overall system, they are mission critical for the achievement of efficient high quality design because they ensure that modelling errors and gaps are largely avoided by the exchange of model data within the design team, requirements are met and key points are appropriately observed or deviations identified as early as possible.

The ontology-based Exchange Requirement Checking Service enables capturing the information exchanges according to the buildingSMART Information Delivery Manual (IDM) as well as steering and tracking them during the design process. It helps to systematize design tasks, level of information agreements and exchange requirements (ER) for the various BIM uses/phases and configure them for each specific project in a digital environment. Invoked via the Scenario Manager, it provides the functionality to setup and run ontology-based exchange requirements verification and visualization. The added value is in insuring the model quality and the compliance with the information requirements of the successor in the design process.

The specification of the Exchange Requirements and the corresponding mapping to a specific data schema is part of the overall project setup. However, in order to prepare for later ER checks some additional preparation work is necessary. Therefore, the tables used for detailed ER specification are extended to provide links to the ER check definitions, which are specified separately using SPARQL queries.

The ER Checking Service can be invoked through the ScM for each design task. After the ER check has validated the data model input the result file highlights all information gaps in the provided design alternative. Depending on the Exchange Requirement specification, the ER check validates a single data source or a multimodel. The result is shown in colours in the ER table and/or at the BIM objects in the MMNav. These colours indicate whether information is available (green), not present (red) or calculated/derived from other information (orange).

While ER Checking is responsible for the quality of the input models, a deeper Key Design Parameter (KDP) Check aims to validate the quality of the results of a certain design task. The requirements for that are also defined during the project set up phase. The KDPs can thereby be interpreted as extension of the ERs: ERs define that an entity and respective entity attribute(s) should exist in the input model, while KDPs define the ranges in which the attribute values are valid.

Before the KDP check can be triggered, similar to the ER Checking, the related Multimodel Container and its content has to be transferred to the KP ontology. This transformation is realized in several steps. In the first step, the relevant element types are transformed into OWL. This is achieved by transforming the types from the Excel sheets into SPARQL as an intermediate step. The SPARQL code is then interpreted by the
Ontology Verification Service (OVS) and the types are mapped into OWL and linked with the defined Link Ontology. After this step, the predefined schemas of the KP ontology and the IFC ontology are linked with the types. The result is a linked schema of KPs, types and IFC elements. After the schemata are created in OWL, the instances are generated. The target values of the KPs and the types are defined in the project setup where the specific links between KPs and types are defined. Similar to the schema generation, instance generation also uses SPARUL code. For the comparison of the set TO-BE and the actual AS-IS Key Point values the IFC model is transformed into IfcOWL using the free tool of buildingSMART (http://ifcowl.openbimstandards.org/IFC4_ADD1/index.html).

Both the TO-BE model and the AS-IS model are encoded in OWL. The KP check produces tabular results in a similar manner as the ER check service. The results can be visualised in the MMNav via automatically generated colour codes, which show the level of fulfilment of a selected design parameter for all BIM elements associated to it. This is a very useful feature since it allows quickly identifying gaps and critical points in the design.

3.7. Energy Simulation and Analysis Services and Tools

Energy simulation and analysis applications are required to properly assess energy performance and enable objective evaluation of various design variants. In the scope of eeEmbedded three such applications have been integrated: (1) TRNSYS, providing for comprehensive thermal analyses/simulations in all targeted design phases, (2) 3DWind, providing for simulation of wind influence to assess building location and orientation with regard to the neighbourhood and verify key parameters already in the urban design phase, and (3) 3DThermalCFD, providing for deep fluid dynamics simulation of selected critical zones to evaluate thermal comfort in the detailed design phase.

3.7.1. Input Preparation (Pre-Processing) Tools

Typically, energy simulation and analysis tools imply sophisticated mathematical models and therefore require complex preparation of the input models. Currently, this is mostly done manually by an energy expert to ensure that the simulation model reflects the design intent correctly. However, as energy performance is affected by a high number of design parameters, whose influence is not easy to predict, the design process involves only a very few variants. This leads often to suboptimal solutions.

The eeEmbedded methodology suggests an approach to improve that situation by re-engineering the simulation and analysis tools and thereby splitting the pre-processing, analysis/simulation and post-processing steps into separate processes. This enables preparing a large number of parameter variations by the end users (architect, HVAC designer or energy expert) with affordable efforts, which are then executed in parallel on a compute cloud and compared and evaluated based on the computed KPIs by a specialised Multi Key Point Analysis Tool.

Critical in that regard is the achievement of a high degree of automation in the input preparation. This involves the following steps:

• Semi-automated assignment of design variants in the MMNav;
• Automated generation of stochastic parameter variations to enable optional uncertainty analysis in order to better estimate life cycle risks;
• Automatic generation of a Variation Model, linking the defined parameter variations to the base BIM-IFC design model;
• Using BIM2SIM plug-ins for the simulation tools to perform the transformation of the data from the BIM
model to the analytical simulation input models; here the most difficult part is the proper interpretation of
the geometry and the topology of the building and the respective generation of 2nd level space
boundaries, which are needed for the thermal simulations;
• Using the developed cloud API to provide for fast parallel computation of all generated variants.

The first two of these steps are performed by tools embedded in the ScM on the User Layer, whereas the
subsequent three are performed automatically with the help of the support services on the Core and the
Analysis Virtual Lab layers.

Design variants are created on BIM level using the MMNav. The process is facilitated by the use of a
library of templates for various climate and occupancy profiles as well as various element construction
types (for walls, slabs, roofs, ground plates, windows, doors) and the associated materials. Essential in
that regard is the association of element types to standard OmniClass items which can be done in the
project setup phase and enables initial fully automatic template assignment.

Using templates, parameter variations can be easily done in the MMNav. Creating a design variant only
requires the input of the desired parameter changes, whereas all other data is automatically interlinked to
the new variant from the imported base BIM-IFC model.

In case of a desired Uncertainty Analysis, the developed specialized Sampling Service is used. For that
purpose, some parameters are additionally configured. These are the chosen number of samples, the time
interval for the output time series, the building location and the number of days each sample should
comprise.

When the sampling service is performed, it produces required occupancy and/or climate samples and
saves the generated data in the multimodel. In addition, the Link Model is updated with the new stochastic
variants. Thus, not only architectural and engineering design variants can be examined but also parameter
ranges, reflecting the uncertainty of the design values at a certain project stage can be taken in
consideration to enable better-informed design decisions and better understanding of the designed
building’s performance.

3.7.2. Thermal Simulations with TRNSYS

Energy analysis is included in each part of the design process. Following the intended overall approach,
sophisticated analysis tools modelling the thermal as well as operational behaviour of the building as well
as main components of the energy systems need to be integrated into the workflow to support the
decision-making process. In eeEmbedded, the software system TRNSYS-TUD is used for this kind of
analysis.

TRNSYS is the abbreviation for TRaNsient SYstem Simulation program, which was initially developed 35
years ago by the University of Wisconsin in Madison, USA. The software is on sale as commercial
software package targeting energy experts. It is continuously updated whereby parts of the software code
are distributed in source form but the main core parts are available only as binaries. To enable the use of
newly developed software modules and approaches which are unique compared to the commercial
version, the suffix TUD was added to the original trademark TRNSYS to indicate the difference between
the commercial tool and the research-orientated solution TRNSYS-TUD.

The simulation package in eeEmbedded is adapted and configured for modelling energy systems and
related buildings. It is based on a modularised concept, which provides a high level of flexibility when
analysing various kinds of energy systems while involving peripheral conditions and related phenomena. In
the eeEmbedded context, it acts as a common placeholder for similar software systems used for transient
thermal building and energy system simulation. In a productive environment, a comparable tool with similar
functionality such as EnergyPlus could be used too.

TRNSYS-TUD covers components which are designed for pre-processing purposes, e.g. to transfer the building model provided by the architectural domain into a simulation model covering the building geometry, energy system components (depending on the design stage) as well as user behaviour and climate conditions. This complements the assignment of design variants in the MMNav providing for BIM2SIM model transformation and some additional input features.

The quality of the geometrical model provided by the architectural domain plays an important role to automatically run the analysis process as a service. The analysis software benefits from the output of the architectural domain (Urban, Early and Detailed Design) as well as the HVAC and BACS domain (Early and Detailed design). Other inputs can be included as well like stochastic samples. If inputs are missing, default templates or default values can be used based on client requirements or an internal template library.

3.7.3. 3DWind Analysis for the Urban Design

3DWind is an end-user application for aerodynamic analysis of a building embedded in its urban environment to obtain the best building cubature (shape and orientation) regarding wind comfort indices, local wind potential for renewable energy use and natural ventilation design (as a result of the combination of solar radiation and wind flow). It can be used as complementary tool to Energy Simulation applications in the Urban Design phase.

In the context of eeEmbedded, IFC files are used for the description of the neighborhood geometries (buildings and terrain), as well as templates and Link Models that empower collaboration and coupling of computational fluid dynamics (CFD) with other simulation applications that are critical to the Urban Design phase. Architects continuously receive feedback from the CFD analysis and can easily make decisions about the building cubature, which are critical for all consequent design phases.

Automations have been developed for the construction of suitable models for 3DWind simulations from an IFC building model of any level of detail and any design phase. The translation of weather wind data to proper boundary conditions for the atmospheric boundary layer has been developed and automated. Specifically for the wind analysis around the building, wind-rose data are used which describe the mean wind velocities, the magnitude, the direction and the duration of the wind at a specific site within a typical year. The analysis provides results regarding wind comfort KPIs for the key point supported decision making process. The two predicted KPIs concern two representative wind velocities, the first one is the velocity at the building entrance and the second one the velocity at city canyons around the building. The simulation results are synthesized by applying frequencies of occurrence to each of the examined wind directions and wind speed magnitudes, as weighting factors.

3.7.4. 3DThermalCFD Analysis

Analysis for the prediction of microclimate conditions inside buildings provides the capability for accurate estimation of thermal comfort conditions in buildings and the optimization of HVAC layouts to ensure that:

- interrelated and dynamic aspects of building performance (passive and active elements, i.e. energy demand and supply reduction options) are adequately considered and reflected in the predictions of energy performance, finally resulting in indoor comfort;
- the building design performs as close as possible to what is anticipated;
- not only energy consumption needs are addressed but also the risk of overheating, peak loads and indoor air quality are assessed.
3DThermalCFD is a computational fluid dynamics application enhanced with heat transfer equation and buoyancy terms in Navier-Stokes equations. It is used in conjunction with energy simulations in order to provide detailed data in spaces of particular interest. Currently, the coupling of Energy Analysis with the CFD analysis algorithm is a subject of ongoing research work and a significant amount of manual work is required in order to exchange data/results between the two types of simulations. This manual work within eeEmbedded is significantly reduced and the coupling becomes feasible.

The CFD model includes all the HVAC and BACS installation alternatives in order to evaluate the effectiveness of HVAC systems under both energy performance and thermal comfort criteria. The special characteristics and the installation of the chosen HVAC systems are taken into consideration and alternative scenarios can be examined.

In the Detailed Design phase the thermal comfort KPIs concern the percentage of the occupied space where thermal comfort requirements are fulfilled. Examples of suitable KPIs are the Predicted mean vote (PMV), the percentage of people dissatisfied (PPD) due to discomfort, the percentage dissatisfied (PD) due to draft, and ventilation effectiveness (EN 7730:2005, EN 15251:2007).

Apart from spatial and temporal 3D representation of KPIs, results interpretation is based on 3D stream lines “coloured” with temperature, spatial distribution of air temperature and air speed and turbulence intensity distribution in 3D space or at levels of occupants head and legs. These results can be visualized stand-alone or via the common Multimedia Navigator of the platform.

3.8. LCA and LCC Analysis

The life cycle cost (LCC) and life cycle analysis (LCA) tool using RIB’s iTWO system helps in implementations of activity/time-based considerations for a sequence of alternatives. The LCC/LCA workflow is processed within different modules in iTWO such as Element Planning, Bill of Quantities (BoQ), Job Estimation, Activity Model, thereby transferring results to each of these activities to generate the whole life cycle cost and assessment of different alternatives within the project. The LCC/LCA process is important to identify the key performance indicators (KPI) at each stage over a period and providing practical guidance on the application of LCC for each use case.

The LCC/LCA model establishes a link between the BIM-CAD model and RIB’s cost accounting model. The BIM Qualifier provides users with functions that allow checking the IFC4 data and correcting it, if necessary, or improving the quality of the data. Element planning calculates the quantity estimation for different CAD models. The Bill of Quantities (BoQ) features a structured document, using a hierarchy for collecting and summarizing values at each level in the structure. It contains all the works subject to cost/ecological assessment for each project alternative. The job estimation model is used to produce the cost of each BoQ item using a cost code or commodities. Estimate details are parameterized so that detail resource quantities, productivities and cost factor are calculated. The activity model links the estimate or BoQ to an activity schedule. This allows estimation using time dependence variables by linking with a calendar catalogue. Thus, the data is transformed into an activity schedule, which is an important tool for the life cycle analysis.

The added value of using the LCC/LCA tool of eeEmbedded is in the holistic evaluation of the examined design variants, assessing and weighing energy efficiency gains against life cycle economic criteria using a unified KPI/KRI approach.
3.9. Risk Assessment Service

The goal of the risk assessment service is to analyze the effects of uncertainty on a building’s energy performance. In this context, the main contributing uncertainties encompass categories of variables like thermo-physical properties (e.g. climate and material properties), occupancy and occupant behavior as well as energy system reliability. The assessment of the resulting energy risk has a large impact for the decision making process, as the risk has direct influence on the exploitation and maintenance costs. Stochastic realizations are generated by the dedicated Sampling Service and can thus be applied for each design variant. They describe several scenarios for the building life cycle that are dependent on aleatory uncertainties, e.g. climate conditions and occupancy. Unlike design variants, which are configured manually by an end user in the MMNav, the stochastic realizations and their respective data variations are generated automatically by the Sampling Service and are afterwards stored into a respective Multimodel Container. For the needs of the TRNSYS energy simulation, each stochastic realization consists of a data sample, which is constituted by time series of climate and occupancy variables and thus reflects varying climatic and building usage conditions over time. After the export of the Multimodel Container from the MMNav, the dedicated sampling service is functioning as an on-demand service for the preparation of samples for the energy simulation and can be started directly from the Scenario Manager.

For occupancy sampling, a first-order Markov chain technique is applied. This technique has been chosen for its flexibility as well as moderate computational cost. The sampling operates at zone level, where zone is a flexible term that can reflect a room, a storey or the whole building. As input data functions one transition matrix per zone type. It consists of probabilities, which describe the number of occupants changes from one amount to another at a certain point in time. The generation of this matrix is based on the existing occupancy data of a comparable zone. The sampling itself generates a time series for each zone, consisting of an occupants number for each time step.

For the climate sampling method performed prior to the energy simulation, there are three challenges. The first is to generate realistic high-resolution climate samples, consisting of multiple parameters each (outdoor temperature, wind speed, solar radiation, etc.) and for a time span of up to 30 years. This disqualifies pure mathematical methods for time series prediction like ARIMA. Secondly, to use these samples for uncertainty analysis, they need to reflect the natural uncertainty of future weather events. This disqualifies the artificial averaged data sets typically used in energy simulation (e.g. TRY). Thirdly, computing time has to be in line with a workflow approach centred on information gain and possible revaluation. This disqualifies complicated atmospheric models used by meteorologists for weather prediction. In view of that, the following approach applied in the project satisfies all three demands. For locations of interest, a database with the measured weather data of the last years is created. It is important that these data sets comply with the requirement for fine resolution of all required parameters, which means that a time interval of 10 minutes is desired. Any missing data points are filled in with average values. When performing the targeted uncertainty analysis, each energy simulation run is supplemented with one of these data sets, chosen randomly from all available sets for the location. After the simulation of all samples in TRNSYS-TUD, the simulation engine provides a set of KPI values as required by the variation model. Based on such a KPI output data set, certain Key Risk Indicators (KRIs) can be derived in post-processing based on the value distribution of each KPI, which results from uncertainty for the simulation input. Such KRIs can be defined as statistical indicators, deduced from the value distribution of a KPI. Examples are energy system reliability, energy system maintainability, energy system availability, investment costs, revenue and so on.
3.10. Multi Key Point Analysis Tool for Decision Making

Decision making, broadly defined, is a combination of interconnected activities that include gathering, interpreting and exchanging information, creating and identifying alternative courses of action, choosing among alternatives by integrating the often differing perspectives and opinions of stakeholders, and implementing a choice and monitoring its consequences. In eeEmbedded we acknowledge the multidisciplinary nature of a construction project employing several experts performing different types of analyses and simulations and thus creating a large number of results to be explored and analysed. The most general case of decision-making within a building design process can therefore be expressed as an end decision that is the product of a whole series of domain decisions (i.e. financial, environmental, functional and physical) and the interaction of the interested parties.

Due to the complexity of construction projects and the large amount of information created during a design process, the integration and visualization of data is critical for well-founded decision making. The developed KPA tool supports teams to work in structured way, while also enabling flexibility and interaction within the analysis of variants and thus facilitating the decision making process. The tool is critical for rapid comparison of different evaluation criteria.

The KPA tool is developed as a web-based decision making application that uses graphical multi-attribute utility analysis to evaluate and compare alternatives based on Key Performance Indicators. Most of the calculations and all of the visualizations are computed and rendered in the browser, while only some minor touches are done on the server side.

The tool contains three main modules. The first module is the simulation synthesis, which performs sensitivity and uncertainty analysis. The sensitivity analysis calculates and visualizes the standardized coefficients for each design parameter in relation to each KPI and is used to prioritize decisions for the design parameters that have stronger influence on the KPIs. Uncertainty analysis is used to visualize the fluctuation of the KPIs in the presence of uncertain parameters, such as weather data or user profiles. The employed sensitivity analysis was developed in the previously funded FP7 project ISES. In eeEmbedded we added the uncertainty analysis as described in the preceding section.

The second module is the KPI analysis, which uses advanced plotting graphics for multi-dimensional data visualization, such as hyper radial visualization, parallel coordinate plot and radar charts. All the plots are developed and used for analysis purposes, thus allowing the user to investigate the relationship between the various variables in depth. By using these plots the user has the option to thoroughly investigate a wide range of alternatives and data used to create those alternatives. In addition, criteria selection based on different requirements for each KPI is possible, reducing the number of alternatives based on these requirements.

The third module is the Decision Value (DV) analysis, which graphically represents the preferences of the decision makers related to the project goals. Each Decision Value is calculated as a weighted sum of the results of fitness functions over each KPI. This allows prioritizing KPIs by means of a weighting factor. The users can set up their requirements and group the KPIs with a weighing factor within the Scenario Manager or through the requirements setup in the KPA tool. The main purpose is to reduce the wide range of variants to the ones that better represent the stakeholder preferences of the initial project setup. However, this does not mean that the highest DV alternative has to be chosen, stakeholders can choose a reduced number of alternatives that could be analysed in further detail using an iterative process.

Integrating results from analysis and simulations from different software tools and having these results
represented with advanced graphics facilitates the decision making process. Consequently, it creates better understanding of the influence of different design parameters towards the design variants and offers a comprehensive way to manage them. Calculating and visualizing the Decision Values enables end users to obtain a holistic view of the project priorities.

Additional information is available in the attached file containing supporting figures to the above text. More information is available from the project web site and especially from the available project deliverables that can be accessed at www.eeembedded.eu/deliverables.

Potential Impact:

*eeEmbedded* delivers new methods, tools and data models for energy efficient design and operation of component products, facilities and buildings including integrated life cycle considerations, poor performance indication and cost prognosis through simulation, which is of upmost importance, particularly for large scale facilities.

Today there are considerable gaps in determining an optimal and sustainable energy mix taking in consideration life cycle operational costs, as well as in analysing and identifying underrated performance in order to draw the right conclusions already at the conceptual design stage and hence before implementation. *eeEmbedded* developments will have noteworthy impact on collaborative processes in the AEC industry and the related supply and FM industries. *eeEmbedded* partners will transfer knowledge to designers and decision makers for adoption of the developed new methods and tools within various activities as presented below.

1. Business and Socio-Economic Impact

We see the business and socio-economic impact of the *eeEmbedded* project in the following 5 thematic aspects: (1) impact on energy efficiency, (2) environmental impact, (3) value chain impact, (4) standardisation impact and (5) wider societal implications.

1.1. Impact on Energy Efficiency

*eeEmbedded* can contribute considerably to achieve the mandate of the Action Plan on Energy Efficiency in Europe, i.e. 20% saving by 2020 compared to the numbers of 2005, stabilized energy consumption at a level of 1990 by 2050, and achieving EU energy independence. The contribution in the construction sector will have a leap effect because about 90% of the EU wealth is invested in the built infrastructure, with strongest impact expected from the refurbishment and retrofitting of old buildings. *eeEmbedded* includes both new and existing buildings in its integrative view, as well as the surrounding used as open space. It has the potential to increase the holistic energy investigation of new and existing buildings due to its BIM-integrated easy-to-apply energy analysis services and tools as well as its multi key point evaluation tool including risk assessment, which can considerably reduce design and investment risks.

Energy saving in buildings is heavily depending on their daily operation throughout the life cycle. It has been estimated that 80% of the energy consumption in buildings is due to their operation and only 20% to their construction. This proves that there is a great need and also great potential for energy savings in buildings, existing as well as new, at relatively small cost. The current situation in Europe requires a large range of related which must be implemented urgently. *eeEmbedded* can contribute significantly to such initiatives through its integrative approach, coherently considering energy efficiency, operational issues...
and life cycle costs already at the early design phases, and by enabling investigation of numerous design
variants in parallel which is not possible in the conventional non-BIM design approaches.

eeEmbedded clearly demonstrates the opportunities to optimize designs driven by targeted performance.

eeEmbedded developments illustrate the need to formally capture, structure and detail targets and
requirements during the design process and make them computer interpretable. References to systems
engineering methodologies were made which are well known in other industries even though in most
countries traditional specifications and room books are still daily practice and potentially hold many
inconsistencies limiting automated verifications and code checking. This need to improve requirement
management is one of the key messages for wider uptake of the eeEmbedded project.

1.2. Environmental Impact

eeEmbedded can also contribute to the fulfilment of the Kyoto Protocol 1999 and related agreements such
as the Bali Declaration 2007 and the SET Plan that declares its target to reduce the greenhouse gas until
2020 by 20% compared to 1990 and to reduce CO2 emissions by 60-80% until 2050. Due to the leap
effect of renewing the building stock the efforts of the construction industry will have stronger impact on the
targets for 2050 and only partially on those for 2020. The scale of that impact depends heavily on the
activation potential of knowledge through easy-to-apply integrated concurrent engineering tools in
collaboration environments and an integrative view of the complex energy multi-systems under dynamic
demands. Single tools, single views or single products and services do have mainly an under-potential
impact. With its innovative virtual design office platform featuring an open web-based ICT environment
with a set of configurable virtual design labs eeEmbedded provides a best practice example of the
integrated use of services and tools towards the achievement of the desired environmental impacts.

During execution of the eeEmbedded project, best practice information was collected on development of
energy neutral buildings or even districts as e.g. through the Dutch GEN research - Gebieden Energie
Neutraal (Neighbourhoods Energy Neutral) http://www.gebiedenenergieneutraal.nl/over-gen/alle-gen-
producten/ . This enabled positioning the eeEmbedded results in a wider perspective.

A roadmap towards energy neutral districts clearly outlined the relevance of the following aspects in the
following specific order: (1) the organisation of all stakeholders of a district, (2) the “financial engineering”
of the investment costs, revenue streams, business models and organisation, and (3) development of the
technical solutions to be selected from a macro point of view and optimized for single buildings, the so
called micro point of view.

While eeEmbedded contributes to the micro point of view, the design approach and the platform
architecture show how the higher views can be incorporated in a consistent overall ICT concept. The
Dutch initiatives “De EnergieSprong” and “de stroom versnelling”, demonstrating the relevance of
economy of scale and mass scale renovation concepts, show how technical solutions and simulation
requirements are affected if national government, housing corporations, contractors and suppliers team up
in a consortium and procure technical solutions on a large scale. For example, for the stroomversnelling
project roofs, facades, kitchens, bathrooms, energy modules, led lights, equipment like washing machines
and dishwashers were procured for 10.000 houses, clearly showing the need for pre-fabricated and
configurable solutions. In line with this development the term “complex templates” was introduced and
exploited in the eeEmbedded project. This impact of standardized, configurable solutions on the entire
environment development methodology definitely needs further investigations.
1.3. Value Chain Impact

eeEmbedded is focusing on consultants, software companies and researchers that are part of the value chain in the AEC industry by helping to manage the energy performance of a building in order to ensure profitability.

Since more and more professional building owners are deciding to concentrate on their core business, they are becoming keen to delegate the risk for their buildings to experts. This has resulted in an emerging market of Private Public Partnership (PPP) and Integrated Project Delivery (IPD) projects, where contractors are taking over the risk for the planning, construction and performance of a building during a significantly long life cycle phase (typically 25 to 30 years).

eeEmbedded supports PPP and IPD contractors when taking over the responsibility for a long value chain, from planning over to construction until operation.

The eeEmbedded Virtual Energy Lab Platform is a platform for engineers. It impacts the way of working of:
(1) Designers, Architects and Building Services Engineers, (2) Product/component providers of HVAC equipment, energy supply equipment and building elements, (3) Construction companies, and (4) Energy experts providing detailed analyses and recommendations in complex design situations.

1.3.1. The eeEmbedded results demonstrate technically and methodologically how design teams should collaborate and iteratively develop and optimize a design, exploring various design ideas and optimization options, including operational and life cycle cost considerations. However, in this regard the biggest challenge for the success in real life remains change management regarding overall collaboration in the project teams which is beyond the scope of the eeEmbedded project.

1.3.2. The project results impact also the digitalization strategies of construction companies because the importance of data handling and data mining becomes more and more obvious, driven by the complexity of sustainable project developments. In that regard eeEmbedded is expected to contribute to the rise from BIM Level 2, which is advanced current practice in the construction industry, to BIM Level 3. This need to link data and to support process orchestration can be explained very well with the eeEmbedded prototypes and methodology. Projects like eeEmbedded steer the focus on web developments which will lead to greater awareness for the need of wider IT capabilities in the construction sector.

1.3.3. Product developers can benefit from the eeEmbedded Virtual Energy Lab Platform through the possibility to examine life cycle related stochastic processes via cloud-enabled simulations, the link of BIM and product catalogues and improved coordination with the designers. Hence, better choice of components and better ee-performance of the installed equipment and the used prefabricated building elements can be achieved.

1.3.4. Energy experts can benefit firstly through the adaptation of energy analysis and simulation tools to run on cloud using common BIM data, and secondly, through the developed features for highly automated multi-model management and the possibilities to explore parallel simulation scenarios instead of limited in time one-by-one simulations. They will be able to integrate product catalogue data and consider different variants and configurations taking into account life cycle aspects of both the designed facility and the component products.

1.4 Standardisation Impact

Various eeEmbedded results promote new understanding of the energy aware design process and related ICT concepts, services and findings that can be taken up by standardization bodies and/or public
organisations developing world-wide regulations and recommendations. The Multimodel method extended by a new Link Model aligned with the Semantic Linked Data approach of the World Wide Web Consortium and further extended by a Variation Model will provide valuable input to the new CEN/ISO project ISO/NP 21597 in which two eeEmbedded partners already participate. The developed design methodology promotes consistently the ISO 29481 information delivery standard and finds already a warm welcome by end users within the project and beyond. This will help to understand ISO 29481 better, extend it further and apply it more consistently in practice in the context of the growing use of BIM as a new method of working. The consequent and coherent use of the OmniClass industry standard in a fully digital environment enables automated assignment of object types to BIM data thereby saving tremendous amount of manual work and ensuring well-structured design progress. OmniClass is promoted by numerous internationally influential institutions but is currently seldom used in interoperable ICT context like the one demonstrated by eeEmbedded. Hence, the eeEmbedded example is expected to contribute to this qualitatively new dimension of OmniClass use and its further uptake in the AEC industry.

Contributions are to be expected also in the frames of buildingSMART, including (1) the extension of the BCF specification to incorporate the Multimodel Container approach, (2) the BIM2SIM tool and the related model specifications that can contribute to the ongoing development of a model view definition suitable for BIM-based energy analyses, and last but not least (3) the gap analysis performed by developers and end users with regard to BIM-IFC that can contribute significantly to future refinement of the ISO 16739 standard leading to its broader applicability and, more importantly, to its broader penetration in industry practice compared to proprietary CAD vendor solutions. Currently interoperability on the basis of the IFC standard is more difficult to achieve than by vendor oriented models such as gbXML, even though the latter lack the generality of the IFC-based approach. Fostering the level of penetration of BIM-IFC on larger scale may have decisive influence in the future.

1.5 Wider Societal Implications

Impact of eeEmbedded results can also be sought in the broader context of some global challenges that have to be kept in mind in designing sustainable energy-efficient buildings.

1.5.1. SME Involvement: Potential target users of the eeEmbedded Virtual Energy Lab Platform include organisations that depend on access to computational power to advance their business objectives and that may sacrifice or scale back new projects, design ideas, or innovations due to sheer lack of computational bandwidth. This is especially important for SMEs, which are abundant in the highly fragmented construction sector.

1.5.2. Opening the market for specialized software vendors and start-ups: Today’s software market in the construction sector is increasingly dominated by large ICT vendors, with more and more takeovers of innovative SMEs. Platforms like eeEmbedded fundamentally relying on standardised data and software solutions as well as on flexibly configurable specialised tools and basic freeware services can protect such innovative SMEs and the use of standard data against such trends. eeEmbedded provides an opportunity for opening models and tools to many different vendors and establishing broader acknowledged interoperability standards in terms of eeBIM and tool interoperability in the energy domain.

1.5.3. Software interoperability: eeEmbedded has shown that the topic of software interoperability deserves much more attention than it receives in today’s practice. Data transfer has to take place in the backend while current software applications, including offered cloud solutions, only offer data transfer via front-ends. Until now, most BIM-CAD systems provide data communication within their programs, while in
the future it will be required to address information from outside the software, independent of the graphical user interfaces offered by the large CAD vendors. This will not only help design, construction and energy experts to learn and apply a wider variety of tool and service options but will also help innovative SMEs to preserve their competitive advantages and not spend the majority of their development efforts incontinuously adapting their tools to proprietary solutions. The eeEmbedded distributed service-oriented solution is, as good example, a significant step in that regard. According to the evaluation by the project end users the complexity of the framework is not a barrier against its practical usability. The methodology can be easily transferred to a different setting, the KPI method can be adapted to other design cases and the implemented decision-making process can be quite generally applied.

1.5.4. All above aspects will also have implications with regard to employment. A study performed by end users during the evaluation of the project results showed that, while eeEmbedded and other related developments will most probably lead to a decrease in employment in large companies due to the achieved higher automation degree, in SMEs considerable job increase can be expected due to the involvement of better qualified personnel, increased involvement in BIM-based developments and participation in larger and more complex projects.

2. Exploitation of the Project Results

eeEmbedded addresses the Green Market, an important segment for building or equipment component product suppliers, facility operators/managers and building designers (architects and engineers). It impacts the construction sector to become integrative considering the whole building life cycle, which is also mandated by the recast of the Energy Performance of Buildings Directive of the EC (2010/31/EC). The Green Market share is expected to grow significantly in the near future, especially for the renovation of existing buildings, but also for the design and construction of new buildings. eeEmbedded provides tools which will help to improve the competence in this area, where there is a considerable market potential for BIM applications that are enhanced by functionality and interoperability, supporting energy-efficiency and CO2 emission calculation and cost prognosis. Concretely, the eeEmbedded exploitable results are seen under two perspectives: (1) Exploitable Knowledge, and (2) Exploitable Products.

2.1. Exploitable Knowledge

Exploitable knowledge of eeEmbedded is in first place the developed holistic design methodology based on a hierarchically structured dynamic and evolving Key Point system which guides and monitors the progress of the multi-disciplinary, multi-model and multi-physics design process. Together with the variant analysis capability by services and the developed decision-making approach the eeEmbedded method will have positive impact on the sustainability of our built environment and will thereby contribute to the 2020 targets of the Energy Performance of Buildings Directive (EPBD). The optimisation potential was proven on the eeEmbedded pilot projects via a comprehensive Cost-Benefit Analysis which showed achievable scalability to a wider range of construction projects and neighbourhood developments. Applying the eeEmbedded method impacts the way of working in a more structured and disciplined way than currently practiced. This will bring a higher performance and efficiency in projects as the processes will flow more easily. It will also result in higher employee satisfaction because various commonly occurring communication gaps will decrease. Together this is expected to bring better project result and make
Evaluation of the developed methodology showed that it is very powerful and near to a fully working and productive environment. The possibility for examining a wide range of design alternatives and variants allows parallel data handling, while the KPI method in combination with the developed decision making approach allows a very efficient process to choose proper configurations. The methodology can be easily extended to a broad spectrum of applications and can be applied to broader construction topics. The complexity of the method requires knowledgeable personnel but does not limit the practical usability. Moreover, the accumulated exploitable knowledge can be used as basis for further research and development in participating research and academic organisations, design consultancies and software developers.

For the knowledge transfer of achieved research results to the private sector the TUDAG which is a supervised by TU Dresden joint-stock company will be engaged on short-term. It is already planned to negotiate an agreement about maintenance and distribution of all products of the eeEmbedded platform. This agreement will include the Open eeBIM Platform Services, outlined in the dissemination section, developed commercialized software packages, and consultancy activities/services related to the developed innovative design methodology and procedures.

2.2. Exploitable Products

The developed eeEmbedded products will be exploited through five principal exploitation channels:

1) Marketing the eeEmbedded platform as a whole or partially;
2) Applying the platform or its components in the partners’ own companies to raise efficiency, become a market leader in the company’s field of activity and improve its expertise and services (e.g. for new building components and construction projects, complex energy aware design of new buildings, refurbishment, retrofitting etc.);
3) Providing consultancy to the industry, especially with regard to specific sophisticated client requirements;
4) Improving competitiveness for participating in new RTD projects, which is of particular interest to all partners;
5) Improving education, graduate and qualification programs.

The integrated eeEmbedded platform will be exploited as

a) Technical Virtual Energy Lab to study new products and services before their realization and perform an in-depth analysis of poor performance under life cycle conditions in order to undertake the right tuning and draw the right operational decisions;

b) Holistic engineering design tool for the design and redesign of facilities and buildings to study in depth alternatives under various life cycle conditions, in order to come up with the best balanced design decision for the facility owner;

c) System analysis tool to analyse the energy and emission behaviour of existing facilities and buildings, in order to find out their weak components or poor operation and to make suggestions to the owner for redesign, retrofitting or reengineering of the operation processes.

The individual component products and services that have been developed within eeEmbedded are listed in more detail in Table B2 of this report. They will be used either as stand-alone tools or together with other...
tools providing a BIM based interoperability infrastructure, and will be exploited and marketed separately by each eeEmbedded partner, as deemed suitable for their individual exploitation needs. Three categories of services and tools can be distinguished in this regard:
a) Open eeBIM platform services, including the developed Scenario Manager, Multimodel Navigator, Ontology Verification Service and the related design template specification and data structures; these services are also part of the cross-project dissemination initiative outlined in the next section;
b) Commercial applications or plug-in modules, including the developed 3DWind and 3DThermalCFD analysis tools, the LCC/LCA plug-in for the iTWO system, the TRNSYS-TUD energy analysis program with the developed new eeEmbedded plug-ins, the new eeBACS Wizard, the EDM Model Server including the developed new eeEmbedded features, and the Multi KPA tool for result visualisation and decision-making;
c) Extensions to existing commercial applications such as Allplan (Nemetschek, architectural design), DDS-CAD (DDS, MEP design), Case Builder (Fr. Sauter, BACS design) and Granlund Designer (MEP equipment design including consideration of FM requirements).

2.3. Return on Investment (ROI)
The profit for the consortium partners from their participation in the project has been calculated to determine whether the project yields a positive payback and will have value for their business. An objective indicator is thereby the financial saving/gain (or loss) from the project participation in relation to its cost. The calculation has shown that a breakeven point will be reached up to 3 years after the end of the project (i.e. the ROI value will become 100%). This is a very short period of time compared to other investments in the AEC industry. Moreover, specific short-term plans for exploitation of project results have been already drawn by the end user partners.

Within BAM the eeEmbedded project will definitely contribute to the awareness, functional and technical specification of the future proof system architecture, which should anticipate BIM Level 3. The need to link data and to support process orchestration can be explained very well with the eeEmbedded prototypes and methodology. BAM will explore the scenario manager setup, linking it with initiatives like the NBS toolkit (https://toolkit.thenbs.com/), lean information planning and agile techniques. Exploitation of such an orchestration platform could soon become a business target.

At STRABAG the KPI method and the decision making process will definitely be applied (and extended). However, the frontend-based interoperability between software tools, like it was done with the Scenario Manager, will not be pursued further. For the future development, frontend-based communication as well as process standardisation activities will be reduced based on the lessons learned from the eeEmbedded project that the way of communication in current practice is not sufficient for practical implementation. Instead, within other research projects, STRABAG will work further on a data management system based on web technologies, while storing geometrical information procedurally and not descriptively. Only with this foundation the KPI methodology, the decision making tool and the design alternative management will gain their full power. To find alliances, the strategy will soon be discussed with other construction companies within the ENCORD platform and its 5D initiative.

At CEMOSA the developed eeEmbedded design methodology is already being integrated in CEMOSA’s services related to design and refurbishment of singular buildings. The developed Scenario Manager will be integrated in CEMOSA design processes and the KPA tool will be applied for evaluation of buildings and infrastructure designs. On medium term the eeEmbedded design methodology is planned to be

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adopted and integrated in services related to the design and refurbishment of infrastructures.

3. Main Dissemination Activities

Numerous activities have been undertaken for the dissemination of the developed concepts, the RTD findings and the achieved project results using a large variety of dissemination tools and channels. The main dissemination activities are summarized in the following subsections. A detailed list of publications and performed dissemination actions are provided in Table A1 (listing 28 published papers and book contributions) and Table A2 (listing a total of 92 dissemination actions).

3.1. Branding

A project logo has been created at the outset to define a project identity and provide clear reference in all relevant dissemination material such as deliverables, newsletters, posters, presentations, external and internal communications etc. The logo is also used on the project web site, social networks and relevant pages of partner web sites, where a link to the project’s web site was also mandatorily provided. Additionally, the EU logo and partner logos have been included on all project presentations.

3.2. Project Web Site and Wiki

The Web Site of the project can be found at [http://eeembedded.eu](http://eeembedded.eu). It was established in December 2013 and is being continuously developed and updated since then. Its layout features four sections: (1) Header, (2) Footer, (3) Widget window, and (4) Content section.

The Header contains the project logo and the menu structure. The Footer contains organisational information of the project (area, funding scheme, duration etc.), contact information of the Coordinator and the European Commission as well as latest news. The Widget window is dedicated to upcoming events and allows also subscribing to the project newsletters and webinars. Last but not least is the Content section which is steered by the site menu. It comprises 4 static and 2 dynamic subsections. The static subsections provide an overview of the project, its objectives, introduction and link to the project Wiki and brief partner descriptions with links to the relevant partner web sites. The dynamic subsections comprise the downloadable publications (subdivided into Deliverables, Papers/Abstracts and Presentations), and summaries and links to performed and upcoming events.

The web site had more than 2000 visits in the last project year with over 6500 page views or downloads. The average duration of web page visit was about 5 minutes.

The project Wiki was created because of the need to use well-defined cross-domain terms, definitions and specifications so that researchers and experts with different background can settle on a common language and avoid misunderstandings. However, due to the interdisciplinary nature of the eeB domain the Wiki provides valuable knowledge and insight not only to the project partners but to wider audiences as well. Besides its use as knowledge source and controlled vocabulary, it can be applied also as a tool enabling project collaboration in eeB and related domains.

3.3. Dissemination Tools and Channels Used by the Project
In order to disseminate the developed concepts and findings versatile print and online media have been used as briefly outlined below.

The use of print media involved:

a) Project Flyer, distributed electronically and by ground mail to dedicated interest groups and laid out at various conferences, workshops and other events
b) Publication of 7 Newsletters sent electronically to subscribers and available for download at the project web site
d) 28 papers and articles published in scientific journals, conference proceedings and books
e) Press Releases by BAM, CEMOSA, Nemetschek and RIB.

The use of online media involved:

a) A series of 6 Webinars presented online and also available for download at the project web site
b) Publication of 10 videos in the established eeEmbedded YouTube channel, see https://www.youtube.com/channel/UCkgcav2Q9ZbhPzAY2a2sYwA
c) Video presentations at the organised workshops and expert seminars by the project as well as at the CIB World Building Congress in Tampere, Finland
d) Active profile of the eeEmbedded project in LinkedIn (2 posted headlines in average per month), see https://www.linkedin.com/company/eeembedded

3.4. Organised Major Dissemination Events

eeEmbedded was actively engaged in the presentation of project results at various public events. Besides participation with presentations in 58 conferences, workshops and other events the project regularly organised or co-organised together with related FP7 projects eeB dedicated sessions at the European Conferences for Product and Process Modelling (ECPPM) held in 2014 in Vienna, Austria and in 2016 in Limassol, Cyprus, and at the Sustainable Places Conferences in 2014, Nice, France, 2015, Savona, Italy, 2016, Anglet, France and 2017 Middlesbrough, UK. Invited presentations were given at the BIM International Forum in Lisbon, Portugal, 2014 and the LC3 Lean & Computing in Construction Congress in Heraklion, Greece, 2017.

Furthermore, dedicated expert seminars and exhibitions were organised by the project in the frames of the 5D Conference in 2015 at Konstanz, Germany and the CIB World Building Congress in 2016 at Tampere, Finland, and eeEmbedded road shows were organised in the frames of the buildingSMART International Summit in 2017 at Barcelona, Spain and the German Architectural Summit in 2017 at Mainz, Germany. These events were attended by over 50 persons in the mean. In addition to these events, eeEmbedded co-organised with the FP7 Design4Energy and HOLISTEEC projects a dedicated session “Modelling, Information Management and Simulation for Energy Efficient Design Embedded in the Neighbourhood” at the ECPPM 2016 conference where it contributed in setting up and structuring the session program as well as through presentation of 6 scientific papers.
3.5. The Open eeBIM Concerted Dissemination Effort of European FP7 Projects on ICT for eeB

eeEmbedded is one of the initiators and primary contributors to the Open eeBIM joint initiative supported by several FP7 projects. Its aim is to provide powerful open software services that allow the exchangeability of third-party software for energy efficient design and analysis, as for example EnergyPlus, TRNSYS or the developed 3DThermalCFD tool for energy simulation, or Allplan, Revit and DDS-CAD for BIM-based computer-aided design.

All partners from the FP7 projects HESMOS, ISES, eeEmbedded, HOLISTEEC and STREAMER have agreed to participate and create a legal non-profit entity which supports the future exploitation and dissemination not only of the results of these projects but also from other subsequent H2020 projects in the area. However, while this new legal entity should be a non-profit organisation, there are two different options for its legal framework and implementation that need yet to be analysed:

1) The legal entity may be organised as an association located in a specific country and city.
2) The legal entity may become part of an existing non-for-profit organisation. The advantage of this approach would be to minimize the costs and effort for registration as well as for administration, since an existing service could be used. This option will also offer a wider visibility to the public right from the beginning, not least by using existing information sharing channels of the mother organisation.

buildingSMART International is considering to install a competence platform, where EU projects or similar initiatives from other regions could meet, share and provide their results.

Regardless of the chosen legal format, a central effort will be the maintenance, dissemination and uptake of the already established Open eeBIM Platform Services Web Site (https://openeebim.bau.tu-dresden.de/openeebim/index.html) which is intended to become the official web site to share software prototypes of related EU research projects. It will offer:

- Download of free and open source software;
- Documentation about the software;
- Contact persons of licence software prototypes.

Besides software that is already available from former projects like HESMOS, ISES and the integrated German project Mefisto, Open eeBIM Platform Services will include several eeEmbedded developments like the Scenario Manager, the Multimodel Navigator, the multimodel information management services, the knowledge management system and the ontology-based verification service which are freeware, as well as several free to use specifications (BIM API, Multimodel Container, Link Model, Variant Model, ESIM).

3.6. Further Dissemination via Networks

AEC companies such as BAM and STRABAG are active in various networks like FIEC (European Construction Industry Federation), ENCORD (European network of Construction Companies for Research and Developments), the 5D initiative and buildingSMART and will deploy eeEmbedded results to prioritize actions, to point out links and remaining challenges, to reflect new proposed R&D projects, to challenge running projects and to ensure that discussions and projects do not start from scratch. Developed software will be available for reuse via the Open eeBIM Platform Services initiative mentioned above (see
3.7. Further Usage in Education

The partners BAM and TUD’s Energy Systems chair will explore the opportunity to deploy the model of the BAM Well Building in further research and for education purposes. The purpose build model is to be updated and can continuously be extended over the coming years. Within BAM the model, the requirements, the templates, tradeoffs and simulation outcomes will be used for training purposes. A fruitful collaboration is foreseen. By this effort we are addressing an urgent need to test R&D prototypes with a realistic data set, which is currently hardly available.

Similarly, TUD’s institute of construction IT will exploit the models with the help of Nemethschek and SOFiSTiK in master courses - to enable BIM and energy related knowledge acquisition by students and in training courses in convincing realistic environments.

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Related documents

Last update: 2 May 2018
Record number: 226649

Permalink: https://cordis.europa.eu/project/id/609349/reporting

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