

## Interactive 3D simulation tool for Energy Efficiency in Buildings

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**ABSTRACT.** Buildings are responsible for 40% of energy consumption and 36% of CO<sub>2</sub> emissions in the EU. Energy performance of buildings may be regarded as a key driver to achieve the EU Climate & Energy objectives, namely the reduction of a 20% of the greenhouse gases emissions and a 20% energy savings by 2020. In this context the EnEf project was established aiming to improve energy efficiency in buildings by creating an online multilingual e-learning platform for energy efficient building.

One of the most innovative aspects of the platform is the inclusion of a real-time and interactive 3D simulation which complements the theoretical knowledge contained in the learning modules. The simulation presents a virtual 3D building that can be visualized interactively, hiding or showing its different parts to reveal internal elements. At any type the user can set the environmental conditions and modify building features such as the presence of renewable energy sources (solar, wind, geothermal), glazing types, roof insulation, heating type, lighting, etc. Based on these variables the simulation calculates in real time the state of the building and represents it in graphical indicators of energy consumption, heat losses and energy generation. This paper describes the development of the learning platform emphasizing the Web3D-based virtual interactive model of a building.

**KEYWORDS.** Energy efficient building; e-learning; Web3D and simulation; education on smarter use of energy.

### 1. INTRODUCTION

Energy savings and energy efficient buildings are considered a key way for reduction of greenhouse gas emissions, taking into consideration that buildings are responsible for over 40% of Europe's greenhouse effect gas emissions. The construction sector is furthermore one of the largest in Europe and a major motor for its development. The EU Directive 2010/31/EC defines concrete goals for energy savings and for the use of renewable energies in buildings.

A group of small companies and research centres considered the current knowledge of entrepreneurs and managers of the building industry on energy efficiency to be insufficient and sought ways to alleviate that. The group set up the EnEf project aiming and providing an open e-learning platform to train European stakeholders in energy efficient building.

In a first phase the project analysed the gaps of the current training and the more important aspects of knowledge to transmit concerning energy efficiency in building. The analysis included regional reports and surveys in several European countries in order to find the specific interests of stakeholders. Then, we developed the content of the training course and associated simulation. The project outcome consists of an online learning platform that contains both theoretical contents and a virtual simulation of a building.

Virtual Reality and simulation have a great potential in learning and training, especially in technical fields. Virtual Reality complements the theory contained in conventional course modules with a practical side, models that mimic reality and that trainees can experience in first person. It is well known that simulators are used successfully to train airplane pilots and they provide a risk-safe and relatively cheap substitute of real aircraft for the first stages of training. In our case, virtual models serve as a new kind of

textbook illustration that involve the user and transmit more information than conventional 2D drawings, pictures and diagrams.

E-learning generally refers to the use of ICT technologies in learning. It usually involves learning using and has nowadays converged into Web-based training systems or LMS (learning management platforms) that present students lessons in the form of learning modules, track their progress and enable self-assessment via electronic tests. This way, anything we develop for this learning system must be based on Web technologies, including the 3D graphics and simulations. This work uses recent Web development standards, most notably the WebGL API for real time 3D graphics, to create configurable interactive virtual buildings that react to changes in their characteristics and the environmental conditions.

### 1.1. ICT for environmental sustainability as research framework

Following the statement “Sustainable development calls for a convergence between the three pillars of economic development, social equity, and environmental protection” (Drexhage and Murphy, 2010), figure 11 provides a scheme of sustainable development. In an innovative society driven by sustainable development, environmental sustainability objectives are regarded as a necessary priority. The concept of environmental sustainability refers to any process that interacts with the environment and runs with the objective of preserving the environment and its regeneration ability.

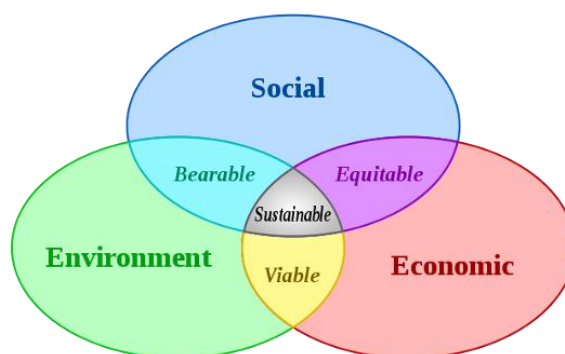


Figure 1. Scheme of the sustainable development

In addition, in the Green ICT roadmap (Ahola et al., 2010), VTT defines ICT for environmental sustainability as “Use of ICT for optimising societal activities in order to improve environmental sustainability”. This roadmap report represents the vision for future developments based on three elements: 1) empowering people, 2) extending natural resources and 3) optimising systems. By analysis of this roadmap, VTT experts have identified four focal topics regarded as the most relevant research topics that have both significant potential in terms of environmental sustainability and great application opportunities for ICT. Energy Efficiency in Buildings, the application domain of the EnEf project appears as a key research sub-topic of “Smart Energy and Buildings” that is one of the four identified focal topics by VTT.

In this context, the EnEf project attempts to improve knowledge leading to a contribution to:

- Reduce emissions in the construction process
- Improve comfort in housing
- Increase the quality of house construction
- Improve building energy ratings
- Increase resale value of houses in Europe

### 1.2. Approach and Methodology

The main goal of the EnEf approach is to create an infrastructure where the project team will be able to

<sup>1</sup> [http://en.wikipedia.org/wiki/Sustainable\\_development](http://en.wikipedia.org/wiki/Sustainable_development)

understand the use of energy efficiency technologies in European small to medium enterprises (SMEs) in the construction industry, to try to identify barriers and challenges, to analyse gaps in current training systems targeted at SMEs and to understand and absorb lessons from the state of the art.

Thus, the EnEf approach consists of four research methodology stages:

- Understand the area: Here the background, rationale and significance of the project are examined. An exploratory structured workshop was also hosted with target end users in an attempt to understand some of the key issues relating to energy efficiency in the construction sector.
- Define the scope: This stage attempts to frame the scope of the project. It describes the aims and objectives of the research to be conducted as well as the audience to be targeted.
- Develop research tools: the research tools to be used will help capture and prioritize the perceived needs relevant to energy efficiency in building. A survey was created based on the findings from an exploratory workshop. A simple cover letter for the survey and template to help generate regional reports from all partners was presented. Finally, a questionnaire that aims to evaluate the quality of our proposed training modules is also included.
- Test tools. This stage presents how the research tools are evaluated and verified.

## 2. E-LEARNING FOR ENERGY EFFICENCY IN BUILDING

### 2.1. Related work

Since its inception e-learning has taken advantage of advances in ICT technology to assist in learning in many areas, including higher education and lifelong learning. E-learning usually consists of learning materials (textual, graphical and multimedia) and self-assessment tests in specialised Web sites. There have been examples of e-learning systems on energy-related topics such as Energy-Wise (Desai, 2010).

E-learning courses sometimes contain multimedia elements (i.e. embedded videos or animations) that help understand some technical topics. But the use of embedded real time 3D simulations is uncommon. Conventional Web technology that forms the basis of e-learning platforms was not designed to support complex real time graphics and computations and the use of Web3D standards in learning content has been scarce. In (Segura et al., 2009) we can see an example of integration of interactive 3D models in SCORM-compliant e-learning content, in that case about wind generators.

On the other hand, building simulation software has been available for decades. A comparison of 20 recent packages can be found in (Crawley et al., 2008) and (Crawley et al. 2001) describes one of them in depth. The tools described in that study are complex systems aimed at engineers designing new buildings and many include a geometry modelling component in addition to the simulations for different aspects: heat transfer, ventilation, HVAC, lighting, photovoltaic generation, etc. Additionally, some administrations offer software designed to calculate compliance of new buildings to national regulations on energy demand. For example, Spain provides the LIDER software for this purpose.

The system described in this work is not an engineering tool; it is a simplified interactive simulation of a specific building for illustrative purposes accompanying an e-learning course. It is an attempt at joining e-learning, simulation and virtual reality on the Web. In fact, we are witnessing how more types of applications are moving from the desktop PC to the Web as noticed in (Taivalsaari et al., 2011). In a comparable approach Google presented in 2010 Body Browser<sup>2</sup>, an interactive visualization of the human body for educational purposes. The main difference with our approach is that it only visualizes an *inert* body whereas our approach tries to present a *living* building.

### 2.2. Functionalities

The functionalities of the e-learning tool enable users to learn, test their knowledge and understand the main concepts of efficiency energy and the use of energy and consequence of usage. The user could choose a language among six different languages available in the platform. The learning and testing stages are done by in a textual manner and consist of training contents, training materials (pictures with

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<sup>2</sup> <http://www.zygotebdy.com/>

good resolution) and questionnaires with evaluation and results. The understanding stage is mainly done by the visual interactive 3D module.

### 2.3. Training modules

It applies the project-oriented didactic approach, which educational and theoretical basis derives from constructivism: the trainee is treated as an independent, self-organized constructor of knowledge and skills. So, EnEf training is a further training of the entrepreneurs and managers from Building sector, and the main requirements of the target group concerning the type of the training and their training needs are self-managed training, problem based, on-line, that is to say independent, self-organized training.

The main part of the platform is a quite conventional e-learning course. The contents were developed by experts in the field and integrated in the ILIAS Learning Management System. ILIAS is a SCORM-compliant LMS. The lessons are structured in the following seven modules:

- Concepts: general concepts of energy, heat transfer and building
- Legal Framework: both National and European regulations
- Marketing, including economic aspects and building energy certification
- Four modules for the execution of refurbishment
  - Façade Insulation: thermal insulation of external walls
  - Glazing: window designs and materials
  - Installations: energy consuming installations such as heating, air conditioning, water, and renewable energy sources for buildings such as photovoltaic solar panels, biomass
  - Flat roofs: insulation of roofs

The contents were written in Open Office and exported as ILIAS modules with the eLAIX plug-in. As a complete LMS, ILIAS has functionality to track progress of individual learners so they can come at a later time and continue where they left, and the system stores their results in tests. Users need to log into the platform with an assigned account in order to use that functionality. However, following comments from the initial survey among potential users, it was decided to let the platform open without any request for credentials that could discourage new interested users.

### 3. VISUAL INTERACTIVE 3D SIMULATION

A virtual simulation is a computational model of a real system that mimics its behaviour, that is, the evolution of its state and its reactions to external conditions or stimuli. Visual 3D simulations have a strong visual component: models not only have to behave but also look like their real counterparts. We can also distinguish between real time and non-real time (or off-line) simulations. The former reacts instantly to unexpected changes like user input, and thus employs fast or simplified computations and is necessary in interactive systems, while the latter performs more complex computations for a set of predefined conditions with no time constraints, producing a set of results after a possibly lengthy computation.

For comparison, engineering students complement their text books with mock-up systems they can examine and manipulate. The idea here is to provide a virtual building that users can explore and manipulate. We thus seek a visual, interactive and real time simulation. In particular the objectives of this interactive building are:

- To let the user change the external conditions
- To let the user change building features
- To explore the building and its features
- To see the building react to those conditions and features

Several possible types of simulation can be devised for this application. Our simulation does a simplified steady-state simulation for the given conditions. The elements represented in the simulation are based on reports from project EDEA (Montero, 2010) on energy efficient building techniques.

Let us not forget that we are using a pure client side Web-based platform that is not suited to high performance computation. The goal of this tool is then not to produce accurate results, which are probably not feasible in this platform, but to illustrate the knowledge and to raise awareness on the subject of energy efficient building. Figure 2 below shows the main view and user interface panels.

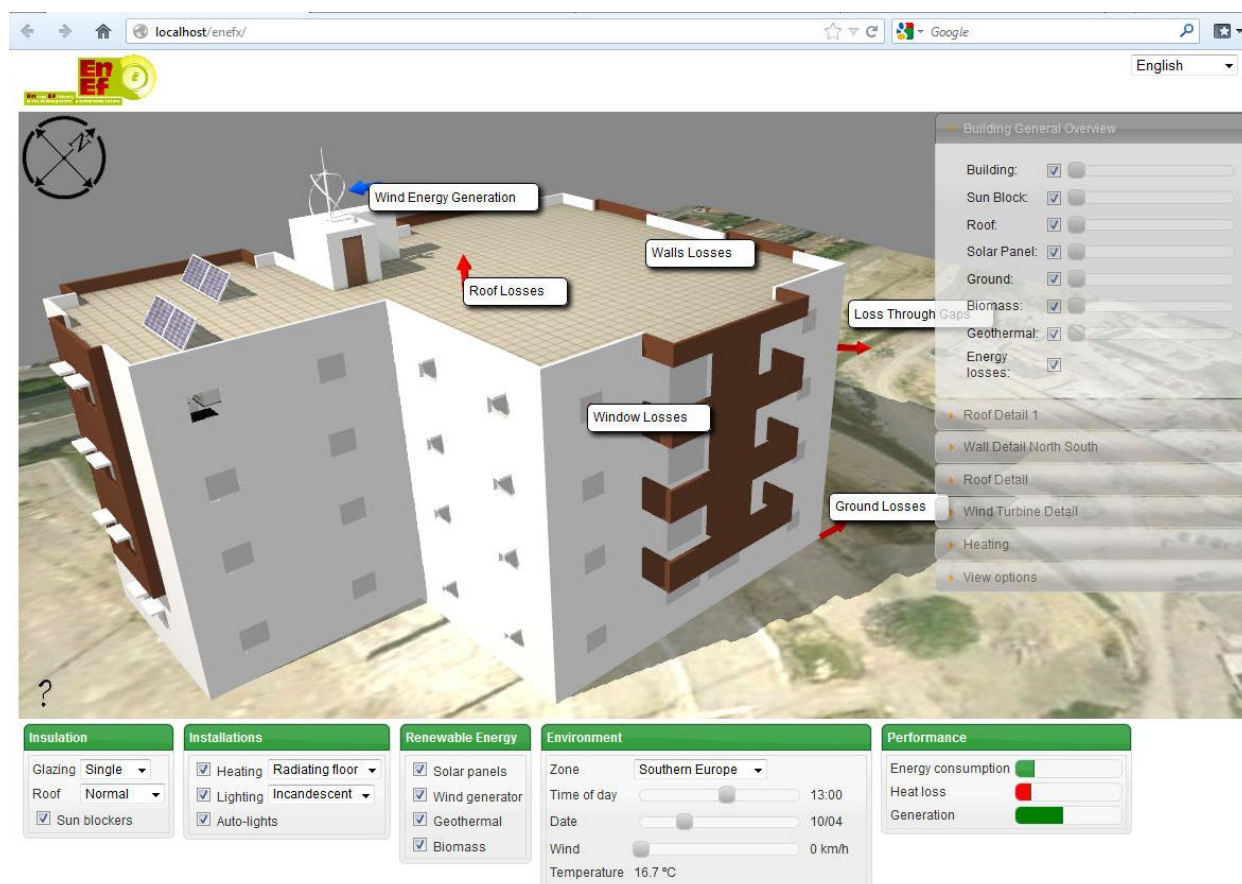


Figure 2. 3D building simulation main screen

Users of the tool can for example see: the effect of the Sun on South-facing windows at noon in the Summer and the Winter, with or without special Sun blockers; the effect of the wind speed on a wind turbine, it installed, and the power it generates (and on the heat losses in windows), the effect of the Sun at different hours on photovoltaic panels, if installed; the different options for roof insulation and its visual and thermal effect; the power consumption of different lighting and heating options; the layers of insulation in specific walls; etc.

### 3.1. Technologies

The whole learning platform resides in a Web site and runs in a Web browser and the simulated building is no exception. The simulation is built with the following standard technologies:

- HTML: The core of the Web. The layout of the user interface and the interactive controls are based on this ubiquitous markup language.
- JavaScript: a dynamically typed scripting language that runs in HTML pages.
- WebGL: an API for accelerated 3D graphics rendering in Web pages through JavaScript.
- XML: a markup format for structured data

All of those are industry standards that are directly supported by modern Web browsers, so that users do not need any additional software or installable plugins to access the system. Several higher level libraries are also used to ease development, namely jQuery, jQueryUI and GLGE.

### 3.2. Visualization

The tool is primarily an interactive 3D visualization system and WebGL is the key enabling technology here. WebGL is a low level imperative graphics API similar to OpenGL. That means a lot of higher level functionality has to be developed to support the kind of visualization and interaction needed.

In our system, a custom XML file contains a definition of several “scenes”, each containing a set of visible objects, a set of labels and a camera position. By hiding occluding parts these scenes highlight different parts of the building such as a general external view, a detail of a room in a corner with sectioned walls, the roof and the basement. Labels identify relevant parts in each scene and are located in 3D space with a line pointing at the associated point.

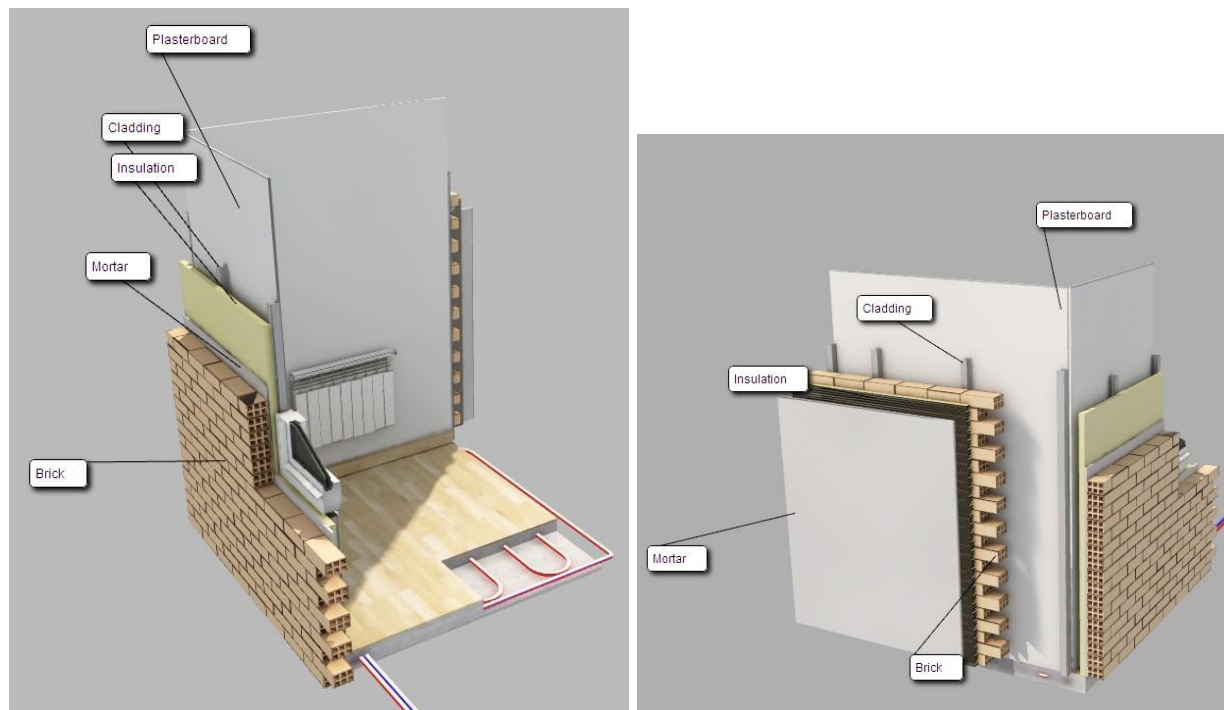


Figure 3. Close-up of a corner showing insulation layers with the rest hidden

We created the software that reads these definitions and builds the corresponding 3D virtual interactive scenes. A panel on the right-hand side shows an expandable section for each scene. Each section lists its objects and labels next to controls for altering their visibility or opacity. For example, a slider control allows the user to change the transparency of the walls in order to show internal structures.

By dragging the mouse on the view, the user can freely rotate the point of view. The mouse wheel moves the camera forward or backward in the direction of view. And when clicking on any of the scenes, the camera starts a transition from the current position to the selected scene.

The complete scene represents an urban building with a flat roof. Sun light is important in this application and so the current Sun position is taken into account and projected shadows are rendered accordingly. Emphasis was put into calculating the correct position for the time and date, and to make the light source colour be affected by its elevation in order to mimic real Sun light.

### 3.3. Interaction

The screen is divided in three parts with different interaction mechanisms: i) the virtual 3D view, ii) the views/scenes menu, and iii) the control panel at the bottom. The first two affect the visualization: rotation and movement of the point of view with the mouse, selection of different scenes and transparency of the main objects.

The last part, the control panel at the bottom contains a user interface that affects the simulation model. The panel has the following sections with interaction controls:



- Environment: sets external conditions for the simulation including geographical location, time of day, date of year and wind speed.
- Insulation: allows selection of roof insulation type, window glazing and window sun blockers.
- Installations: controls heating and lighting, both their type and their activation
- Renewable energy: adds renewable energy sources to the building including photovoltaic solar panels, a wind generator, biomass and geothermal energy.

### 3.4. Computational model

The tool presented is an interactive visualization that allows users to explore the building and see energy related elements in place. But as a simulation tool the building has some behaviour that is governed by a computational model. This model takes as input the variables controlled by the interaction controls listed above and calculates an internal state. Any change in any variable from the user interface triggers an immediate calculation of its effect. The calculations need to be simple enough to keep the system responsive and animation smooth. The state variables calculated and represented are energy consumption, heat losses and renewable energy generation, shown in the graphical bars at the bottom right of the UI.

The environment controls are used to calculate the current Sun position. The user can select among four different locations in Europe. For each one, the tool knows its geographical coordinates and the average monthly temperatures. From the current time of day, day of year and geographical coordinates, the software calculates the Sun position in the local horizontal coordinate system (azimuth and elevation).

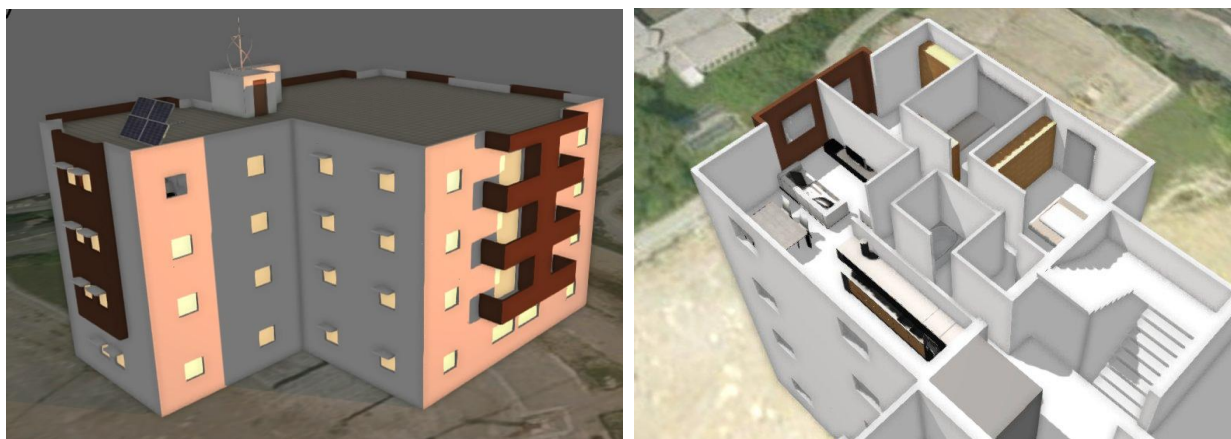


Figure 4. Building at dusk with lights on

The air temperature is estimated by assuming a daily sinusoidal variation between the minimum and maximum temperatures for the current month in the current location.

If there is a wind mill present, the model calculates its power generation based on the current wind speed and air density. We assume a 5 kW generator, a typical power for vertical axis urban wind turbines. The turbine has a cut-off speed of 20 m/s, so if the wind is stronger than that the rotor will stop and no power will be generated.

If solar panels are present, the model calculates energy generation based on the current Sun position with respect to the panel (cosine of the angle between the panel normal and the Sun direction). The available panel is currently fixed in a South orientation and 45° elevation giving a maximum power at noon.

For biomass energy a fixed contribution is added if present. Geothermal, on the other hand, is considered a source of heating and is only taken as a reduction in power consumption when heating is enabled.

Installations such as heating and lighting add to the power consumption when enabled. The user can select between incandescent and low power illumination which have different power contributions.

Finally, heat losses are calculated from the selected insulations (roof types, glazing type), the external air temperature and wind speed. A rough approximation is used to account for the different factors based on the convection laws (proportional to temperature difference and to wind speed).

#### 4. PILOT TRAINING AND TESTING

A first prototype of this online learning system is, at the time of writing, being tested by potential users in small construction companies and other interested parties. This pilot training will gather evaluations, comments and suggestions in all participating countries. From an analysis of the pilot test results a final improved version will be prepared.

#### 5. CONCLUSIONS

There are definitely opportunities for taking advantage of ICT in energy efficiency management and education. In particular, we have shown advances in the application of the newest Web 3D standards to online e-learning on energy efficient buildings. The software described presents a virtual reality simulation of a building with configurable features and external conditions that computes current energy performance values. The simulation is simple, given the requirements of interactivity and the limitations of Web scripting. But it is adequate for the illustration purpose of the system, i.e. an innovative substitution of the illustrations and diagrams in conventional text books.

Apart from the technical limitations that impose simplifications (both visual and computational) the technology used might face a deployment problem as it new and not yet supported in every browser and hardware the final users may have.

A future system can take two possibly simultaneous directions: to improve the simulation and to extend the flexibility of the system with more configurable features and even including a full building design component. The technology still has potential to support such improvements.

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