Virtual Environments for the AEC sector – The Divercity experience

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ABSTRACT: Construction projects involve a large number of both direct stakeholders (clients, professional teams, contractors, etc.) and indirect stakeholders (local authorities, residents, workers, etc.). Current methods of communicating building design information can lead to several types of difficulties (e.g. incomplete understanding of the planned construction, functional inefficiencies, inaccurate initial work or clashes between components, etc.). In that context, Virtual Environments can improve communication between different stakeholders around a visual, and thus intuitive, representation of the planned construction. The paper describes how, within the EC funded Divercity project (IST-1999-13 365), end-users contributed in defining the requirements for the use of VE in the Construction sector and in defining test scenarios adapted to their business needs. The overall outcomes of the project are also be presented and special focus is made on the Design Review Workspace.

1 WORKSPACES IN THE CONSRUCTION INDUSTRY: PERSPECTIVES

1.1 *Collaboration paths*

The AEC sector is in a transition phase through out Europe. Demands for cost effective production methods and proactive interaction with end-users set new goals for productivity and force the stakeholders inside the construction industry to develop new collaboration paths. In many countries, a Partnering model has been introduced which invites client, architect, engineers, contractor and sometimes suppliers and authorities to join a collaborative workspace with mutual interest in pooling all expertise, experiences from the very early stage of the project preparation.

The partnering model distributes responsibility according to the amount of work and encourages the stakeholders to participate in any part of the project where improvements to their work can be implemented. Currently, we have insufficient tools to operate such collaboration workspaces. When talking about international partnering groups the situation is even more difficult to succeed.

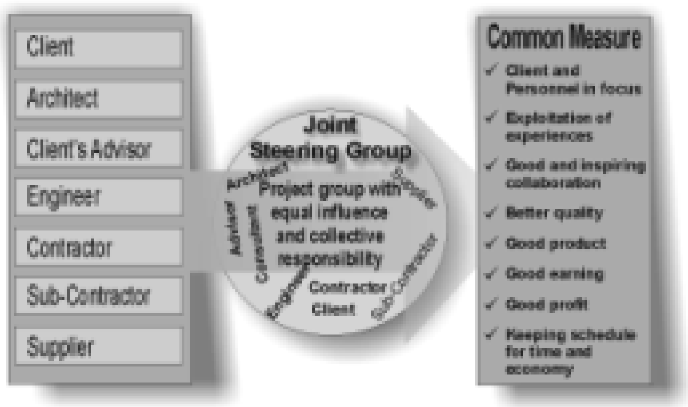

Figure 1: Partnering model showing the stakeholders joining a common project group with mutural goals (jeo 2001)

1.2 *Need for workspaces*

COWI is a major Danish consulting engineering company working in the construction industry all over the world. In the EC funded project Divercity we found some of the tools needed to support the partnering model and, for this reason, we participated to the research and development done within the Divercity project.

Divercity is an example on a end-user co-defined developed workspace and, to our knowledge, one of the most coherent at the moment and might be the future platform for further plug-ins.

1.3 *End-user involvement*

In Divercity consortium, end-users from each stakeholder group are represented: architects, engineers, contractors and clients were invited to join Special Interest Groups (SIG)

From the very start of the project, the end-user representatives have expressed requirements to the system developers and in fact have been collaborating during the project in a form of a partnering model. The pro-active end user involvement have made significant modifications to the software architecture as well as to the individual products. The communication layer is a good example as well as the pre-cad workspace just to mention two. Other demands from end-users have also been evaluated but were decided out of the scope of the project or to be developed in the future, e.g. facility management, total cost monitoring and knowledge sharing inside the workspace. Very important plug-ins which we are convinced will be developed in near future.

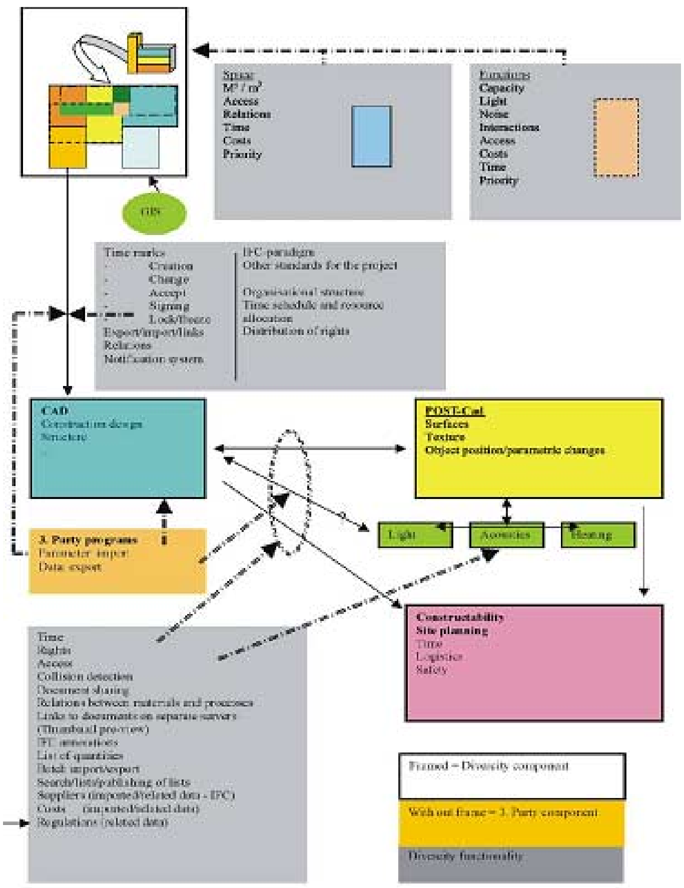

Figure 2: End-user presentation of demands for architectural system design (jeo 2001)

The end-user involvement in the preparation and the planning of test scenarios contributed in ensuring that the VE will meet the requirements of the industry.

1.4 *The industry is prepared*

The close and constructive collaboration between partners from five countries, members of the Di-

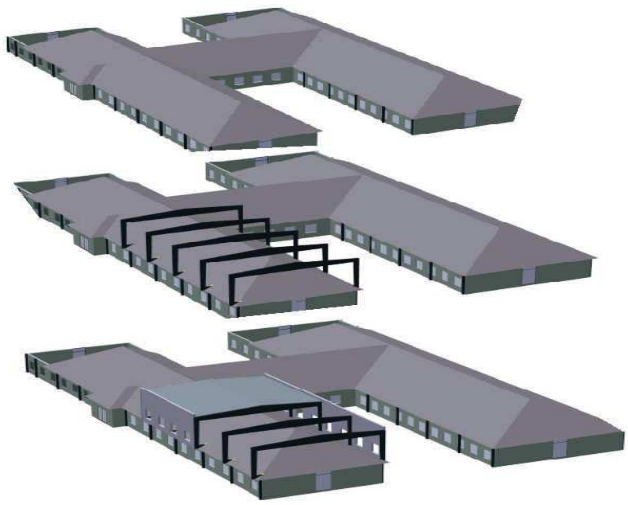

Figure 3: Example of a COWI visualisation scenarios from a construction situation

vercity consortium, have shown differences in the present use of VE and the industry preparation level to implement such tools.

In Denmark the construction industry has started to use VE some years ago. Visualisation has become part of normal acquisition when talking about:

- technically complex constructions;
- alternative design;
- significant end-user involvement.

When one or more of these situations are encountered, advanced tools are used for 3D visualisation.

Figure 4: Example of a COWI scenario related to an office building project

For involvement and adoption of end-user requirements simple walkthroughs are sufficient at the moment. Nevertheless, Market signs clearly define the need for more sophisticated and interactive environments that will make it possible to design and validate scenarios in a distributed workspace.

1.5 *Future workspaces*

Industrial implementation of systems like Divercity will bring the visualisation environment from the "sales and briefing" situation into the production phase where professionals can use the workspace for the validation of sophisticated technical solutions and collaboration between related disciplines (e.g. light design, thermal design, acoustic design, etc.).

The IFC-standard which is a core component in the Divercity framework is progressively been introduced to the Danish construction industry. At the moment COWI is participating in a test of the standard on the new head-quarters for the National Broadcasting Company (DR)

Finally, the real-life test of the IFC-standard combined with test scenarios of the Divercity products along with experiences from ongoing developments enable us to formulate new requirements for future VE components and to bring VE into our business scenarios.

2 DESIGN OF THE DIVERCITY VIRTUAL WORKSPACE

2.1 *Divercity aims and objectives*

The Divercity project (Distributed Virtual Workspace for enhancing Communication within the Construction Industry), aims to develop a "shared virtual construction workspace" that will allow construction companies to conduct client briefing, design reviews, simulate what if scenarios, test constructability of buildings, and communicate and co-ordinate design activities between teams. Both synchronous and asynchronous interaction will be emphasised as well as development of a general framework for integration of building process applications and models. This multi-disciplinary research project develops innovative workspace technologies for the construction industry and evaluates the results on real life projects. The project, under the EU IST program started April 2000 and ends September 2002.

The Divercity framework contributes to the development of an environment that supports collaboration between building process stakeholders and increases the degree of realism as we access digital models of the underlying virtual building and building processes. It is capable of integrating existing building design applications and contains project specific process support. It will also as far as possible meet expected advanced ICT tools and network solutions such as secure peer-to-peer communication over the Internet. The Diversity system takes into account models of the User Environment (UE), the process stakeholders, the design artefact (Virtual Building), parts of the building process, DIVERCITY specific artefacts and ICT tools, and integration of external applications.

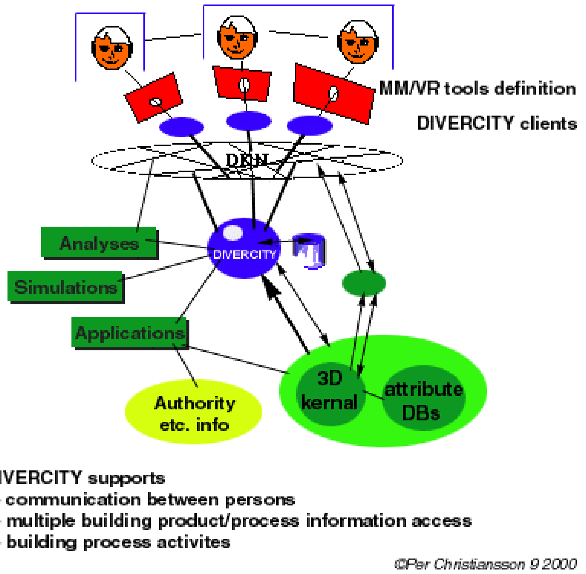

Figure 5: DIVERCITY supports collaborative workspaces and building process applications and models.

2.2 *Divercity design and implementation*

The Divercity design process has been highly creative and involved end users in an incremental prototyping process right from the start. Indeed, it is extremely important to bridge the gap between the user requirements specifications and the actual interface design and implementation of the underlying operational models of the distributed virtual workspace system. This is certainly true as the design relates to a new type of design artefact that will highly influence the traditional working methods and integration of design resources. Two parallel design processes can thus be distinguished (cf. figure 6) in which we distinguish:

- user requirements capture, user environment design and early prototyping;
- implementation of Divercity and end user alpha test (done within the Divercity consortium) of basic functionality of the Divercity products (applications);
- continued implementation and end user beta tests/evaluations of basic functionality of integrated framework and Divercity products;

— final end user evaluation of Divercity, and prototype refinement.

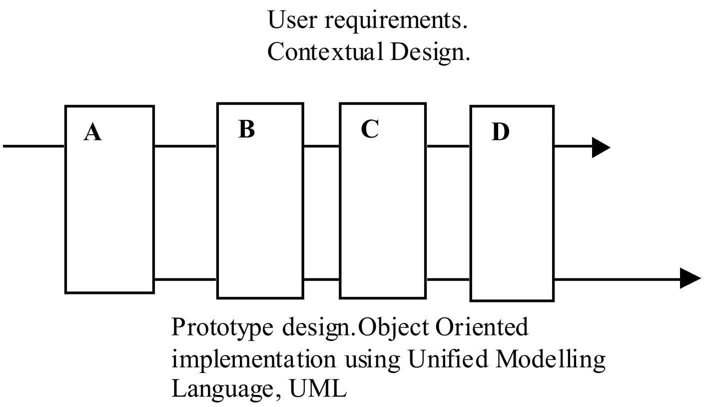

Figure 6: The Divercity User Environment, UE, and system design process. A) Initial Conceptual Modelling, and early prototyping, B-C) Technical implementation and prototype alpha/beta testing, D) Final prototype design, implementation and testing/evaluation.

2.3 *Formulating work models together with end users*

Due to its user centred approach, we have chosen the Contextual Design method (Beyer and Holtzblatt, 1998) to try to take into account, very early in the process, end user work practices and user interface requirements. Five different types of *Work Models* have been elaborated in the Contextual design formalism:

- *Flow*, structure representing communication and co-ordination necessary to do the work (roles, responsibilities, actions / communication topics, and spaces which in Divercity are regarded as project internal or project external memories and virtual/physical spaces);
- *Sequence*, showing the detailed work steps necessary to achieve user intents. Sequence models can reveal alternate strategies to achieve the same intent;
- *Artefact*, showing objects created to support the work;
- *Culture,* representing constraints on the work caused by policy, culture or values, formal and informal policy of the organisation, business climate, self-image, feelings and fears of the people in the organisation, possibility for privacy;
- *Physical,* showing the physical structure of the work environment as it affects the work.

We have in Divercity focused on flow, sequence and artefact models. The flow and sequence models are combined with the artifact models and synthesised to storyboards, see figure 8.

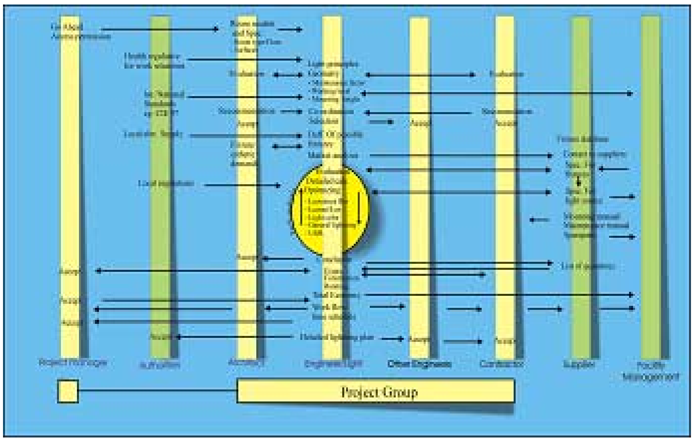

Figure 7: Detailed light design sequence model (Christiansson et.al., 2001)

Using *storyboards*, the design team refines the initial vision into a definition of how people will work in the new system ensuring that all aspects of work are captured in the design. The User Environment (UE) is slowly materialised in the implemented prototype and continuously tested and evaluated (steps C to D in figure 6).

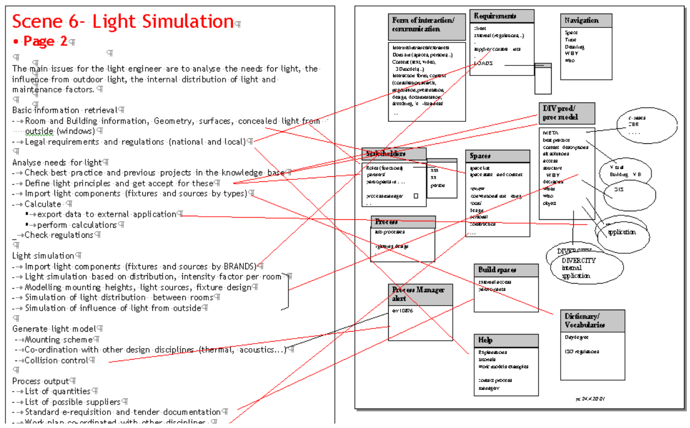

Figure 8: Storyboard for lighting design. Aalborg University and COWI (Christiansson et.al., 2001)

During the test a heuristic evaluation procedure was used yielding formative (to a great extent qualitative) data especially during the alpha and basic functionality tests. Usability metrics (effectiveness, efficiency, user satisfaction and learnability) and evaluation schemes were formulated partly based on experiences from the Xerox Corporation (Xerox, 1995).

3 APPLICATION DEVELOPMENT

Research and Development followed three streams.

- Client Briefing. Concerned with the gain of the client requirements and the development of an initial design concept.
- Design Review. Concerned with the presentation and review of a well developed design, supported by simulations of the physical dynamics of the building.
- Construction Planning. Concerned with the organisation of the site and construction logistics.

While the three separate research domains pursued independent goals, the holistic view of the design process, developed within the Divercity project, allowed a high level of technical integration, resulting in a common application framework.

3.1 *Divercity Software Framework*

After the User Requirements capture that yielded several Work Models describing Workflows and Sequences, a software architecture allowing to support these requirements was proposed (Divercity, 2001, Coudret 2001).

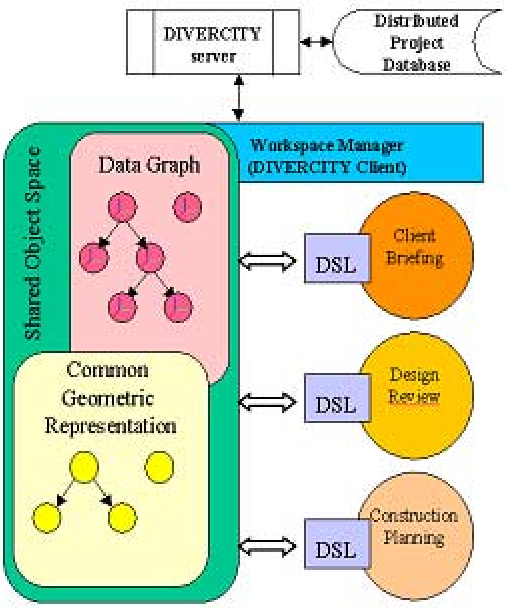

Figure 9. Overview of Divercity Framework

This software framework includes:

- A distributed database to manage large quantities of data (CAD data, simulation data, etc.). The database also needs to provide distribution of the information to multiple users, some of who may wish to access data from remote locations.
- A Workspace manager to dynamically handle (loading, unloading and linking) software components.
- A Shared Object Space (SOS) which is a single, centralised and shared run-time data repository. It's composed of a Data Graph (keeping logical hierarchies of objects) and a Common Geometric Representation (CGR) which is STEP (part 42) and IFC compliant.
- A Data Structure Layer (DSL) for each type of application. DSLs handle their own graph (in the way best suited to the application they are supporting). They are registered to the SOS so they can be informed of changes in the Data Graph.

3.2 *Product Modelling*

One of the main aspects of the DIVERCITY project is to deal with building information. We have chosen to use the most open product modelling technology for the building construction available today : the Industry Foundation Classes (IFC) developed by the International Alliance for Interoperability (IAI http://iaiweb.lbl.gov/), as well as the ISO Part 42 of STEP (Standard for The Exchange of Product data) to keep track of a common geometric representation within the DIVERCITY kernel.

The IAI is an action oriented, not-for-profit organisation. Its mission is to define, publish and promote specifications for Industry Foundation Classes (IFC) as a basis for project information sharing in the building industry (architecture, engineering, construction, and facilities-management). The information sharing is world-wide, throughout the project life cycle, and across all disciplines and technical applications.

3.3 *STEP Part 42*

The Part 42 is an integrated generic resource for geometric and topological representation within the STEP ISO standard (STEP Part 42). Basing our common geometric representation on this standard will enforce common comprehension of the geometry by the different Data Structuring Layers (DSL). One of these will be based on the IFC classes but for rendering purposes we will use another DSL specialised for Virtual Reality high quality rendering.

Another aspect of this Part of STEP is that it is the basis upon which specific models for concept and design modelling (AP203) or even the IFC are build upon.

3.4 *IFC*

The IFC define a single object model (i.e. an object oriented data model) of buildings shared by all IFC-compliant applications. IFC project models define individual buildings for which compliant applications can exchange information accurately and error-free.

The IFC are public and "open" for implementation and use by any member. Defined by members of the industry and extensible, they will evolve over time. Software implementation of IFC is proprietary to protect the data and technologies of member companies that compete in the market.

Many of the actual leader CAD software vendors (AutoDesk, Graphisoft, Nemetschek, etc.) support importing and exporting IFC compliant data. While a new version is now available as of Oct. 2000 (2.x), it is not yet commercially supported by any CAD software. The consequence of this is the decision of the DIVERCITY partners to stick to the previous version (2.0) which is widely supported by the aforementioned CAD software companies.

3.5 *IFC DSL*

All building simulation application bundled as DIVERCITY modules will need to interact with a DSL that will support their needs in terms of semantic knowledge about building models. The IFC provide such power and thus will be included in a DSL upon which the later described simulation environments will retrieve the needed information.

To ensure that these simulation environments will find the necessary information will be effectively available in the IFC model, a project wide survey is been held to gather each simulation environments needs in terms of product data. Based on this survey a guide will be elaborated to help simulation environments in locating their requested information from the IFC classes hierarchy.

4 DESIGN REVIEW

The Design Review is an important phase in the design/construction process where the inputs are represented by a rather precise architectural design (usually drawings on a 1:100 scale) and the outputs are precise definition of all technical domains related to the design (e.g. structural design, heating and thermal, lighting, acoustic, fire safety, etc.).

Current software tools supporting detailed design review already exist. Nevertheless, these exiting tools suffer from two important limitations:

— Lack of 3D-real time inspection features. Consequently, members of the project team spend too much time trying to (i) understand the project information and (ii) describe this information to one another;
— Discontinuities between the different software tools. This makes the re-use of the results of one phase in the design process as an input for another phase practically impossible.

Therefore, the Design Review workspace within Divercity looks at enhancing reviews by combining Product Modelling technologies with Simulation Environments in order to allow project teams to visualize and to interact (in real-time) with the project on a multidisciplinary basis. Continuous design is a major feature here. This means that the architectural design resulting from the conceptual design phase can be fed into the Design Review workspace and that the detailed design can be fed to the Construction planning workspace without any data loss therefore bringing important improvements to the overall process.

This workspace provides a set of design tools to analyse the design from different perspectives to achieve an optimum design solution. The major novelty of this work is it’s contribution in bridging the gap between the architectural and the technical aspects of the design in order to promote a holistic approach where different stakeholders would evaluate the project from different points of views, very early in the design process.

Three key simulation features are addressed: the lighting, thermal and acoustic properties of the design. In order to display the results of these simulations the display component of the system needs to integrate the results with the project data. In addition the system also allows users to manipulate the simulation parameters, so that what-if scenarios can be evaluated from within the 3D environment, rather than having to use an external system.

The design review workspace exchange project related information with existing off-the shelf tools (such as CAD tools by using a product database based on IFC standard). The database maintains information about design components (i.e. geometry, cost, acoustic properties, thermal, time etc).

4.1 *Thermal simulations*

These simulations enable to assess both energy consumption for a given period and thermal comfort. This allows for example to calculate the annual energy consumption of a building with respect to the architectural choices made (surface of glazing, materials used, orientation, etc.) and the activities that are done in the building rooms. Thermal comfort conditions will be calculated in order to verify that comfort conditions are met in all the building. Comfort conditions will be represented symbolically in the 3D scene (for example by colouring in red-hot zones and in blue cold zones). Thermal simulations are done by integrating an existing simulation package called TRNSYS (TRNSYS).

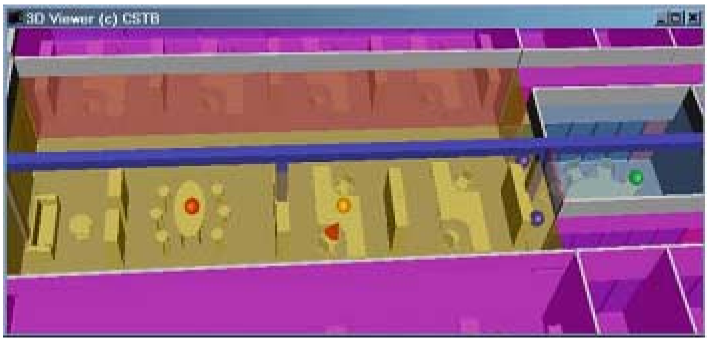

Figure 10 : 3D view of a thermal simulation restitution

4.2 *Acoustic simulations*

Acoustic simulations allow to combine images with sound in order to have an impression as close as possible to the “reality” of the project. Acoustic simulations are a complex process which requires consideration of the geometry of building, the materials used, the localisation of the sound source (inside, outside), the type of the sound source (transport, equipment, human activities, etc.). Furthermore, the human hearing system is extremely sensitive and makes the task of creating a convincing acoustic simulation very challenging. Acoustic simulations are done by integrating an acoustic simulation package developed and patented by CSTB. Such acoustic simulation are used for evaluating the acoustic properties of buildings and noise levels.

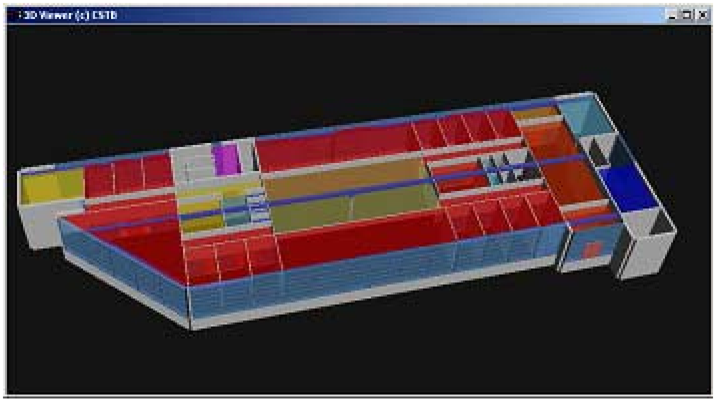

Figure 11 : 3D view of avatars representing acoustic simulation listener and sound sources inside a building

4.3 *Lighting simulations*

The lighting simulations module is developed using a radiosity technique. This technique provides reviewers with photo-realistic rendering of the construction project. By simulating shadows and secondary lighting effects the quality of the 3D rendering is greatly enhanced. In their initial form, radiosity systems only accommodate static environments, and would force a complete re-

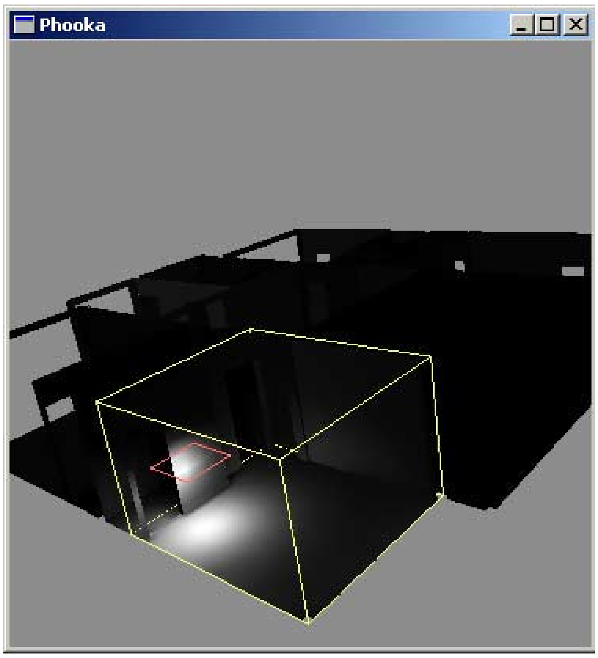

Figure 12 : Radiosity simulation inside a building

evaluation of the global lighting situation for each modification. CSSI (member of the Divercity Consortium) has recently published a new radiosity algorithm with optimisation methods for near real time realistic rendering. This algorithm allows the refining processing of the scene lighting on the fly which means that interaction between the user and the scene now becomes possible. The rendering and interactions are done in real time by using the current state of the lightning. For example, a window closing will be identified by the algorithm as a lightning change and the impacted areas only will be processed in background once the interaction ends. Then, once available, results of the progressive radiosity algorithm will be passed to the 3D real-time rendering engine so that the user will be provided with a more and more realistic rendering of the scene. It is just a question of seconds with a rather complex scene to reach the energy equilibrium, which represents the correct lighting.

5 SOME COMMENTS ON COLLABORATION BETWEEN SCIENCE AND INDUSTRY

To prepare efficient and problem solving workspaces in the future, it is essential to strengthen the collaboration between science and the construction industry. Only by exchanging experiences and visions, new workspaces can be implemented and adopted by professional end-users.

The Divercity project has succeeded in gathering science and industry in a collaborative, exploitative and enriching workspace. The project was originally been divided into fields of specialisation, but as the work progressed, new collaboration paths emerged. The traditional barriers between special disciplines were broken down to establish collaboration scenarios based on mutual visions.

Fruitful collaboration between academia and research centers on one hand and industrial end-users on the other hand yielded day to day collaboration (e.g. lectures from University staff to end-user groups about new findings and also seminars carried out by end-user experts at the university) as well as several spin-off activities.

This collaboration should evolve and the traditional barriers between Science and Industry should continue to diminish on the basis of common and collaborative road mapping of future R&D strategies for the use of IT in Construction where shared virtual models should play a key role.

6 ACKNOWLEDGEMENTS

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