UTILIZING VIRTUAL ENVIRONMENTS IN CONSTRUCTION PROJECTS

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SUMMARY: Construction projects can gain major benefits from application of virtual environments. The virtual reality techniques help designers to communicate with each other, as well as with the decision makers and with the end-users. In the future, the whole product model of a new building should form one virtual building, which can be efficiently investigated utilizing virtual environments. In this article we present some basics of virtual reality technology, and the required software and hardware components from the viewpoint of a construction project. The main emphasis of the article is in the description of the construction project of a new lecture hall at the Helsinki University of Technology, and how a virtual environment was utilized in that project.

KEYWORDS: Virtual environments, virtual reality, visualization, construction project

1. INTRODUCTION

Virtual reality (VR) has been an active field of research during the past decade. The goal of VR is to mimic the nature such that – at the best – users can't distinguish between reality and virtual reality. Although we are still far from the perfect illusion, quite convincing visual, aural, and haptic techniques have been developed to achieve this ultimate goal. Despite all the research, only few practical applications of VR exist. One quite obvious application area is architectural visualization. In a more general level, entire construction projects can gain major benefits from utilizing VR.

1.1 A 3D product model in building design

A model of a building may be constructed merely for presentations at a VR system, but utilization of VR really becomes a meaningful and effective part of the working process, when the idea of a product model is used in the

design process. The idea of a product model is to combine separate drawings into one virtual building. A traditional drawing becomes merely a view to the model at a chosen moment, whereas the whole building and its environment are included in one single product model. Everything is modeled three-dimensionally (3D), and the model is maintained throughout the project from start to hand-over.

Among the benefits of the product model compared to traditional methods is that one can easily produce simulations and presentations applying VR to support project decision. In addition, it provides 3D-information for the needs of the various consultants; bills of quantities for cost control, geometric and structural properties for the life cycle and cost analyses of project alternatives. The product model is also a direct source of construction documents and production 4D-planning. Utilizing VR technologies could be a natural part of the product model working method in the future.

1.2 Objectives of this article

We have two main objectives for this article. From the architectural point of view, our goal is to describe the possibilities opened up by virtual environments for construction projects. From the technical point of view, we aim to present kinds of software and hardware required for successful application of a virtual environment in a case study.

As a case study, we present results achieved in one particular construction project: the construction of a new large lecture hall in the main building of the Helsinki University of Technology (HUT). The virtual environment at the Telecommunications Software and Multimedia Laboratory (TML) at the HUT was actively utilized throughout the process, from the first drafts to the opening of the new hall (Gröhn et al., 2001b).

1.3 Organization of the article

The article is organized as follows: Section 2 gives a short overview of virtual reality technologies, and the facilities at the HUT are described in more detail. Section 3 presents the possibilities provided by VR from the architectural point of view. The case study is presented in Section 4. The main emphasis is on the applied models and the parties involved in the project, as well as in their mutual interaction. Section 5 concludes the article.

2. VIRTUAL REALITY TEHCNOLOGIES

VR technology is a wide topic, covering a variety of techniques and devices. In this section, we give a brief overview of the most important factors to be taken into account when designing a VR system. The same principles apply to the design of models to be presented with a VR system. Such models are called virtual worlds in this article.

At the HUT we have a virtual environment called the Experimental Virtual Environment (EVE). Software and hardware utilized in the EVE are described in this section. In terms of this article, the VR systems similar to the EVE are called virtual environments.

2.1 Overview of virtual reality technologies

Ivan Sutherland introduced his vision of a virtual world in his article "Ultimate Display" in 1965 (Sutherland, 1965). According to him, the main challenges in the creation of a virtual world are to make it look real, sound real, feel real, and respond realistically to user's actions. He successfully summed up the main objectives of implementation of a VR system. It is impossible to implement a perfect one with current technology. Thus the objective is to make the system as immersive as possible by concentrating on the most relevant issues.

2.1.1 Look real

To make a virtual world look real, it must be carefully modeled. Surface materials, small details, and lighting are crucial in creating a realistic environment. Small movement, like trees and leaves swaying in the wind, greatly add to the experience. Any movement in the world must obey the principles of physics to appear realistic. In addition, the visible world should cover a large field of view, and respond realistically to the user's movements. The user should be able to feel the dimensions of the environment. This is typically done by presenting the view to the virtual world stereoscopically, i.e. from a slightly different position for each eye.

Current modeling and animation software enables the creation of realistic-looking virtual worlds, which can even be animated. Typically, these virtual worlds can be pre-rendered, and displayed in a wide screen – even stereoscopically – to create an immersive experience. However, the view must be created in real-time when the user is allowed to move freely in the virtual world. This requirement limits the allowed complexity of the model, forcing modelers to concentrate on the most essential factors. Since small details and accurate lighting are perceptually significant but computationally expensive to render in real-time, they are typically pre-rendered as textures. For example, the lighting conditions in the surfaces of an architectural scene are often saved as textures using a computationally intensive radiosity method.

Stereoscopic viewing requires a different image to be presented for each eye, which can be accomplished in many ways. One method is to use a head-mounted display (HMD), which has two small displays, one for each eye. Optionally a sensor can be attached to HMD to register the movement of the head. HMD can be used to create an immersive environment for one user at a time. Another method is to use a spatially immersive display (SID) – a large display with special glasses for separating the images for each eye. The glasses can be either passive, including red/blue, red/green, and polarizing filters – or active, like LCD shutter glasses. The use of passive glasses requires displaying two images at a time, while with active glasses, the images are displayed alternately for each eye. The third method for displaying stereoscopic images is called autostereoscopy. It does not require any special glasses. However, autostereoscopic methods are often otherwise restrictive; they have a limited viewable region, small resolution, or bad image quality. Most autostereoscopic displays are quite complex and expensive to manufacture, and their typical size is no larger than a normal television set.

2.1.2 Sound real

For an immersive VR experience, a 3D soundscape needs to be created. 3D audio enhances the sense of presence. In addition, it can be utilized in other tasks such as localization, navigation and data presentation (Gröhn et al., 2001a). 3D sound can be produced using either binaural or multichannel techniques. In binaural 3D sound reproduction techniques, the principle is to control the sound signal in the entrances of the listener's ear canals as accurately as possible. For one user this requirement is in practice easiest to fulfill with headphones using head-related transfer functions (HRTFs) (Begault, 1994, p. 52). HRTF-reproduction is the most convenient combination with HMDs.

In a multi-user situation, loudspeakers are more convenient than headphones. One commonly employed method for multichannel loudspeaker reproduction is vector base amplitude panning (VBAP) (Pulkki, 1997). To enable arbitrary positioning of sound sources VBAP uses three nearest loudspeakers for one sound.

To make a virtual world sound real the acoustics of the virtual world should be simulated in real-time. In general, the modeling is based on knowledge of sound sources, room geometry, and acoustical properties of materials (Savioja et al., 1999).

2.1.3 Feel real

To make a virtual world feel real, the user must be able to touch virtual objects. If the user sees a virtual table or chair, but cannot touch it, the immersion is reduced. When the user picks up a virtual ball, he should be able to feel, whether the surface is rough or smooth, and whether the ball is soft or hard. These two cases are called haptic and force feedback. Both of these fields are currently under active research. Haptic devices are still quite immature, case-specific, and expensive, while force feedback is currently used even in consumer-level products such as joysticks, steering wheels, and gamepads.

2.1.4 Respond realistically to user's actions

To respond to the user's actions realistically, the movements of his body, head, hands and feet must be tracked. The system must be very responsive to the user's actions, i.e. it must have a low latency, or the immersion will suffer. The consequences of the actions of the user must obey the principles of the physics in the virtual world. This requires, at least, detecting the collisions between the user and the virtual objects. In practice, only some parts of the user are tracked, a noticeable latency exists in the system, and the physics model is – at best – incomplete.

There are many techniques to track the user. The oldest technique is mechanical tracking. The body part to be tracked is attached to a construction with sensor-fitted joints. This is an accurate and fast method, but typically

considerably hinders user's movement. Magnetic tracking systems are currently the most commonly applied ones. They have receivers for measuring either AC or DC magnetic field, generated by a transmitter. Magnetic tracking systems are quite accurate, but they are subject to distortion from external electromagnetic fields. There are also tracking systems based on optical recognition, inertia, and ultrasound. Each of these methods has its strengths and weaknesses. Also systems utilizing several of these techniques exist. These systems are called hybrid systems.

2.1.5 The reality of current virtual reality techniques

Although the capacity of modern computer systems keeps increasing rapidly, a perfect VR system remains to be seen. There are simply too many variables and too many sensors to connect, as well as too much computation to be done in real-time. There are very complex and advanced systems for specific purposes, but not a single system for fulfilling the dream of a perfect general-purpose VR system. The technology is just not there – yet.

In spite of the lack of a general-purpose system, there are several types of commercial, versatile, immersive VR systems available. The systems range from HMDs and small virtual tables to large-scale virtual environments and beyond. Traditionally virtual environments have been driven by expensive, high-end SGI Onyx computers, but PC-based systems are becoming more and more popular. In either case, the high quality projectors and screens required are quite expensive, as well as are high quality HMDs. Some manufacturers of commercial VR systems are listed in Table 1and Table 2.

Table 1: Some of the off-the-shelf immersive virtual reality systems manufacturers and their web sites.

Fakespace	http://www.fakespacesystems.com/
TAN	http://www.tan.de/
Mechdyne	http://www.mechdyne.com/
Barco	http://www.barco.com/
Trimension	http://www.trimension-inc.com/

Table 2: Some of the high-end HMD manufacturers and their web sites.

CAE	http://www.cae.ca/
Kaiser Electro-optics	http://www.keo.com/
General Reality	http://www.genreality.com/
Interactive Imaging Systems	http://www.iisvr.com/
Virtual Research	http://www.virtualresearch.com/

2.2 EVE – Experimental Virtual Environment

The EVE is a virtual environment at the TML. The main principles of the EVE are the same as in the CAVE (Cave Automatic Virtual Environment), originally presented in 1993 (Cruz-Neira et al., 1993). In the EVE, users stand in a cube measuring 3×3×3 meters. Three of the faces of the cube have rear-projected screens. Figure 1 illustrates the construction details of the EVE. In addition, we have a magnetic tracking system for tracking the user. A wand, and two data gloves are the other devices to support user interaction in the EVE.

At the HUT we research technologies applied in virtual environments, especially human-computer interaction and virtual acoustics. Therefore, we started to develop our own virtual environment, with one screen, in 1997. In 1998 the Computer Science Department moved into a new building, during which the EVE was extended. Currently the EVE is running with three walls, and the floor.
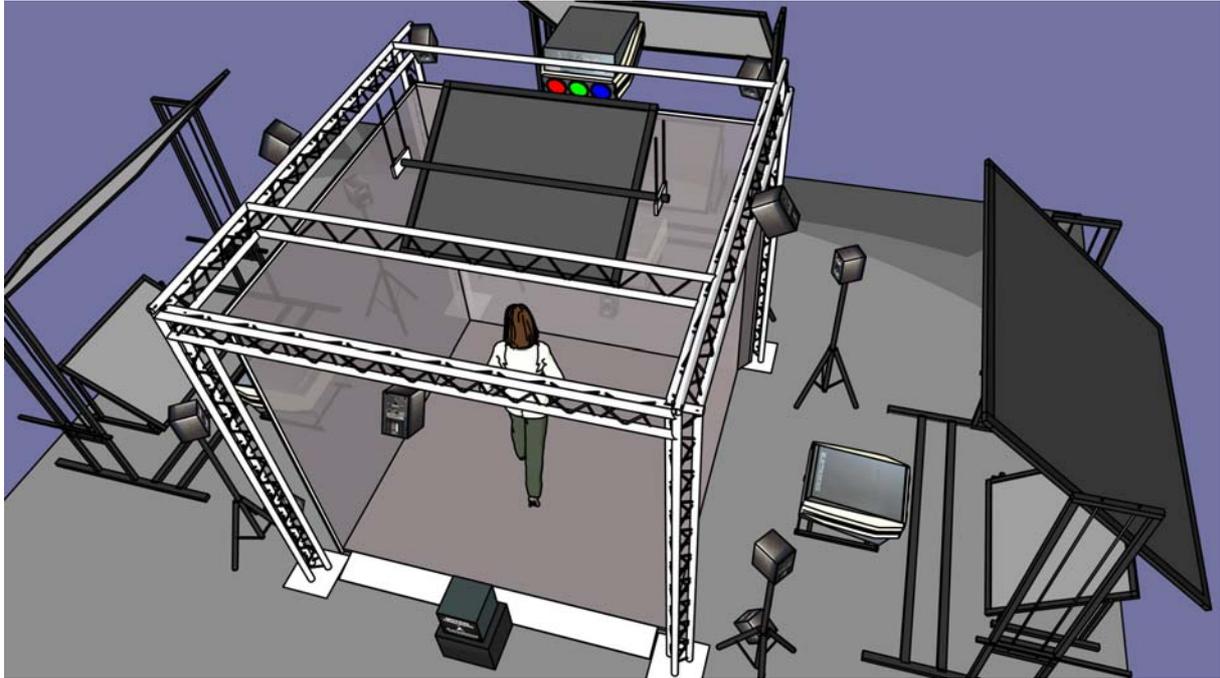
Figure 1: EVE – the virtual reality system at the HUT.

2.2.1 Graphics hardware

The main computer of the EVE is a Silicon Graphics (SGI) Onyx2 with 8 CPUs, 2 GB of memory and two InfiniteReality graphics pipes. The capacity of each pipe is split to produce a stereoscopic image to two screens. The images for the screens are projected with four ElectroHome Marquee 8500 LC Ultra projectors. To view the images stereoscopically, we use Crystal Eyes CE2 shutter glasses. The operating system of the main computer is IRIX that is a UNIX variant implemented by SGI.

2.2.2 Audio hardware

Hardware for sound reproduction in the EVE is built around a PC running Linux operating system. The computer is used for acoustic modeling and audio signal processing. The audio output from the PC is taken from two eight-channel ADAT interfaces connected to two eight-channel D/A converters. The current loudspeaker system in the EVE consists of fourteen Genelec 1029 active monitoring loudspeakers. Multichannel 3D sound reproduction is implemented with the VBAP technique. For more information on the acoustic design of the space and the applied sound reproduction techniques see Hiipakka et al. (2001).

2.2.3 Input devices

There are multiple input devices in the EVE to support user interaction. The input is gathered from a mouse, a keyboard, a wand, a magnetic tracker, and a pair of data gloves. The mouse and the keyboard are simply the common input devices of the SGI computer. They are not used as input devices inside the EVE, but merely for system control and for setting some parameters of the applications.

The magnetic tracker is an Ascension MotionStar tracker with six receiver units. It is used to measure the position and orientation of the users head, hands and body.

Figure 2: The wand used in navigation.

The wand, shown in Figure 2 is constructed from a Logitech Surfman radio mouse and one tracker receiver unit. It has three buttons and a trackball to get input from the user. The receiver unit provides information of the position and orientation of the wand. In the EVE, the wand is used for navigation in the virtual world, for pointing virtual objects, and for manipulating the virtual world.

There is also a pair of 5DT DataGloves in the EVE. There are five optic fibers in each glove for measuring the bend angles of each finger. The gloves are mainly used for manipulating the virtual world. They have also been tested in navigation and pointing virtual objects.

2.3 Applications and software platform in the EVE

For viewing various models in the EVE we need several different applications. We have to integrate different kinds of information such as CAD-models, lighting solutions, computational fluid dynamics (CFD) simulations, and acoustical models. To maintain user's immersion, the images should be rendered at a high enough rate to avoid flickering. In addition, users should be able to easily move around and observe the models from different viewpoints.

Most of the software used in the EVE is written at the TML. For viewing the models, we use an application called EveNavigator, and for audio processing an application called Mustajuuri. Software called WolfViz is used to convert CFD data for proper visualization. In addition, in our software development we employ some external libraries, such as the VRJuggler as platform for applications run in the EVE, the OpenGL Performer for rendering 3D graphics, and the Visualization ToolKit (VTK) for creating visualizations.

2.3.1 VRJuggler

The VRJuggler is a platform for applications run in various VR systems (Bierbaum, 2000). It is developed at the Virtual Reality Applications Center of the Iowa State University. The philosophy behind the VRJuggler is "Code Once, Experience Everywhere". In other words, once you have created a VRJuggler application, you can run it on different VR systems without recompiling. The VRJuggler is a C++ library, developed under the Gnu Public License. It is available for IRIX, Linux and Windows at http://www.vrjuggler.org/.

2.3.2 OpenGL Performer

The OpenGL Performer is a high-level programming interface for real-time 3D graphics. It is developed at the Silicon Graphics Inc (http://www.sgi.com). Typical uses for the OpenGL Performer include scientific visualization, virtual reality, and CAD applications. OpenGL Performer has loaders for several different 3D file formats, and it is available for IRIX and Linux.

2.3.3 Audio software

All software used for sound processing has been written using an object-oriented approach. We have two software components in our audio environment: the DIVA (Digital Interactive Virtual Acoustics) system and the Mustajuuri. The goal of acoustic modeling and auralization is to reproduce the 3D sound of a real space artificially in real-time (Savioja et al., 1999). Such systems have been proposed before, but the DIVA system (http://www.tml.hut.fi/Research/DIVA/) is one of the first to truly create this experience.

The Mustajuuri is a generic plugin-based real-time audio signal-processing tool. With proper plugins this application can be used to run the audio processing for the virtual environment. The Mustajuuri is available at http://www.tml.hut.fi/~tilmonen/mustajuuri/. Arbitrary signal processing modules can be chained in run-time to create a digital signal-processing network. Since most of the functionality comes from the plugins, the system

can be easily extended. By their nature, all plugins can deal with audio signals and events (for example MIDI events).

2.3.4 WolfViz

The WolfViz is a software package implemented at the TML (Mantere, 2001). The package contains three modules. It combines CFD calculations with a photorealistic model, so that the results can be viewed in the EVE. The first module, called EnsightToVTK, converts CFD data to a format readable by the VTK. The second module, called PreViz, creates the visualization and stores it in OpenGL Performer binary database format. The last module, called PostViz, is used for displaying the visualized data.

2.3.5 EveNavigator

The EveNavigator is a viewing application that can be used in the EVE. It is implemented to replace the former viewing applications PostViz (Mantere 2001, p. 74) and HCNav (Laakso 2001, p. 47). The user can load a model to the EveNavigator and navigate in it. The EveNavigator is a modular C++ application, built on top of the VRJuggler. It is using the OpenGL Performer as a renderer. It can also handle user input. The EveNavigator is currently under active development.

2.3.6 VTK and vtkActorToPF

The Visualization ToolKit (VTK) is an open source, freely available (http://www.visualizationtoolkit.org/) C++ software library for 3D computer graphics, image processing and visualization. It is available for UNIX and Windows. It has wrappers to implement visualizations also in Tcl, Python and Java. In the TML we use the version 3.1 of VTK but a newer version is also available.

The basic idea in the use of the VTK is to put together a suitable data processing pipeline to produce a desired visualization as a result. The data is then put through multiple filter modules to extract the usable parts out of the whole data set, to combine different data sets, or to generate more information based on the filter's input. Finally the filtered data is used to create geometrical 3D visualization objects. To use the generated visualization in the EVE, it is converted from VTK object format to OpenGL Performer objects with vtkActorToPF-library (http://brighton.ncsa.uiuc.edu/~prajlich/vtkActorToPF/).

2.3.7 PolyTrans

An application called PolyTrans is used to convert models to formats supported by our software, and for polygon reduction. The PolyTrans is high quality 3D model and animation conversion software from Okino Computer Graphics (http://www.okino.com). It can be used both as stand-alone application and a 3DSMax plug-in, integrating its functionality with the 3DSMax. It supports a wide range of different file formats, including Lightscape, 3DSMax and OpenFlight. In the TML we have a special version of PolyTrans with polygon reduction capability.

3. VIRTUAL ENVIRONMENT AS A TOOL FOR THE ARCHITECT

Traditional presentation materials are not a perfect solution for architects. Architecture is, by nature, a series of spaces seen and felt in motion. Pictures, even the so-called 3D views, are in fact static 2D pictures. Providing tools for the accurate understanding of scale is difficult and requires certain tricks – especially in the early design phases, when there is still very little detail to give a clear understanding. Because it is impossible to make, for example, a perspective of every space from every angle, the client is only shown the views the architect wants to – or has the necessary time for.

Presenting a project in a virtual environment takes care of all these problems. Moving in the space is fairly natural and gives a quite convincing feeling of the space. Our experience is also, that the dimensions of a space are easily understood, even with practically no detailing. Importing a product model into a virtual environment makes it possible to check any space of a project – not only the most presentable ones – without extra work. A virtual environment shows – sometimes quite rudely – the things that the designers have not yet put enough thought into.

The architect's design process is a constant simulation of ideas and possible solutions – from the basic idea to the design of details. The use of a virtual environment should be fast, easy, and require little extra work, in order to

work as a genuine tool for planning and design and help the decision-making. Otherwise, there is a possibility that a virtual environment is used only to make fancy presentations of already made decisions.

To work as an effective design tool, it should be easy to present a product model in a virtual environment. It should be easy to manipulate the model, and there should be a way to export the changes made back to the product model.

3.1 Interaction with other designers

A major advantage is the possibility to discuss the basic concepts of the project with designers, applying virtual environments, instead of seeing the building as a series of 2D drawings. A virtual environment makes it possible to understand the logic of the spatial concept and the implications the placement of the necessary structures and building systems – for example, where to put and not to put the tubes, columns and beams. An abstract presentation showing schematic, even transparent, combinations of space, structure and building systems, might be appropriate in such cases.

3.2 Interaction with decision makers

The decision makers usually have enough power to make the necessary decisions and suggestions. However, the lack of true commitment to the project – as well as superficial understanding of the implications of a decision and of the actual needs of the end-user – sometimes cause problems. Even in these cases the WYSIWYG (What You See Is What You Get) characteristics of a virtual environment help to quickly establish a realistic impression of what the client is getting.

3.3 Interaction with end-users

Usually designers get the most valuable information from the end-users. Traditionally, their merely partial understanding of the design documents has been a problem, especially in the early and decisive stages, when the traditional design documents tend to be very abstract. A virtual world can be fairly simple, and still be quite easily understood by the users. It is possible to get valuable feedback from the end-users in every phase of the design process. Unfortunately, it is common that the interaction with the end-users is shadowed by lack of true power and thus hesitation to make a commitment.

4. CASE-STUDY: CONSTRUCTION OF A LECTURE HALL

The HUT has had a need for a new lecture hall for a long time. The construction project was called Hall 600 and it was carried out during 2001-2002. For more information on the project, see http://www.tkksali600.net. The goal was to build a new auditorium, for an audience of 600, into the existing main building of the HUT. Afterwards, the hall was named as Mellin Hall, after the first professor of mathematics at the HUT, Robert Hjalmar Mellin. Before the actual building work could begin, the designs had to be prepared, and plenty of details had to be discussed between the project parties. One of the methods to improve communication between the parties involved in the project was the utilization of an available virtual environment, the EVE. Figure 3 presents the three evolutionary stages of the Hall 600 model, as well as a photo of the finished hall.
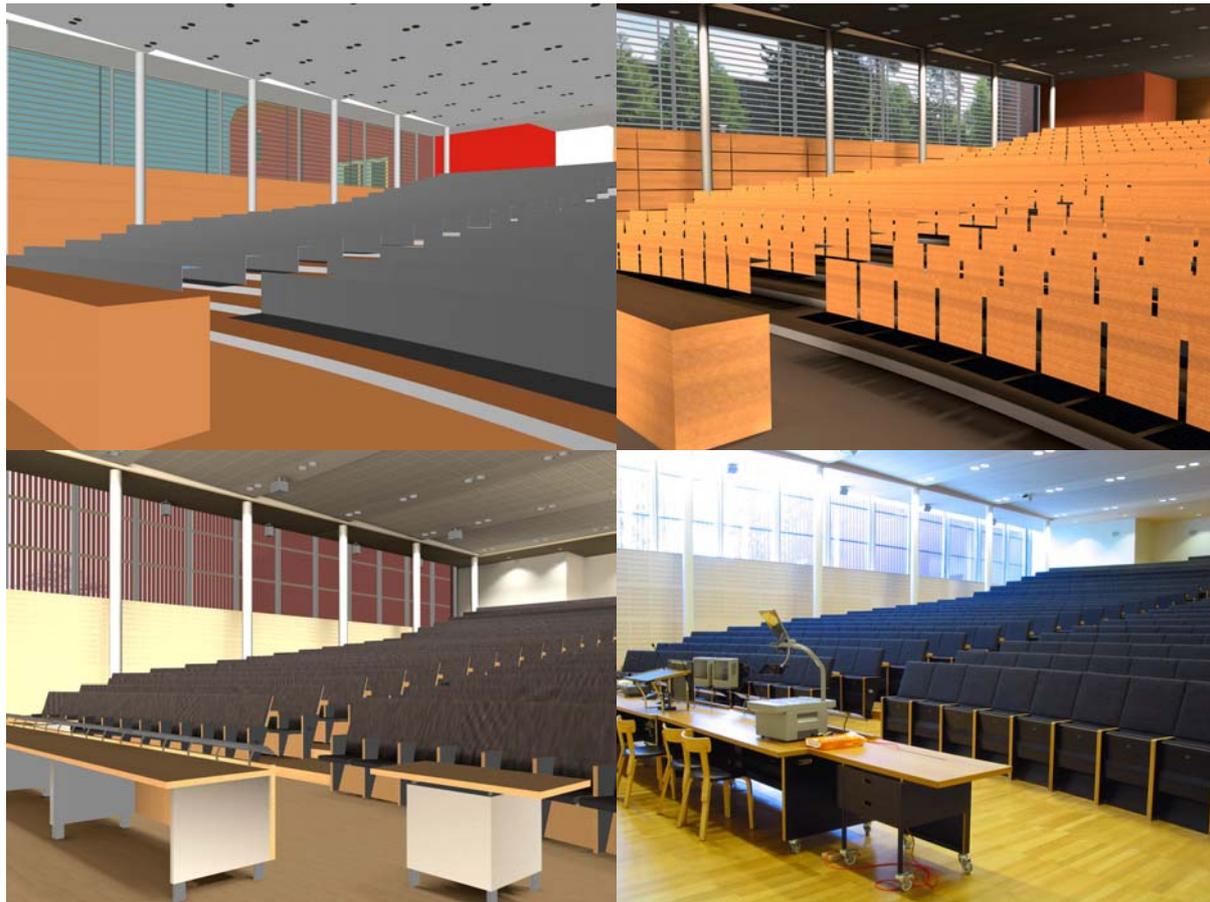
Figure 3: The three Hall 600 models; the first on top left, the second on top right, the third on bottom left and a photograph of the actual hall on the right.

4.1 Parties involved in the project

The Hall 600 project was a cooperation of many parties. The owner of the university buildings and the client in the project was Senate Properties. The user of the new hall was the HUT. The design and construction work was carried out by the project participants listed in Table 3.

Table 3: Design and construction companies in the Hall 600 project.

Architectural design	A-Konsultit Oy
Structural design	Magnus Malmberg Consulting Engineers
Building services design	Insinööritoimisto Olof Granlund Oy
Acoustic design	Akukon Oy
Building and project management	YIT Concept Project Management Services Ltd
Project databank	Rapal Oy

The whole project was a pilot for the newest design, construction and project management technologies on the field of building industry. Therefore, it was natural to utilize the EVE in the design phase. The same project has also been under study in another article (Liston et al., 2001).

4.2 Models imported into the EVE

The models used in the visualization were constructed in an architect's office and in a civil engineering office with industry standard modeling software. The models were then delivered to the EVE. During the project, three different models illustrating the architectural design were created to be presented in the EVE. The first model illustrated in upper left of Figure 3 was exported directly from the architect's modeling software, ArchiCAD. Compared to the later models, it was only a study of the geometry of the new lecture hall. The two other models were processed further with other modeling tools, but the geometry was still based on the original architectural design and 3D product model. They included not only the shape, but also a lighting solution and a material design. The second model, presented in upper right of Figure 3, was still quite a simple representation of the space itself while the third one as depicted lower left in Figure 3 had plenty of details – in the seats, for example.

Beside the architectural models, a model related to building services was also applied during the project. A model of the air-conditioning channels around the lecture hall was attached to the second model, and presented together as illustrated in Figure 4. Virtual acoustic techniques were applied to create a synthetic aural experiment. A CFD flow model including information about air conditioning and heat sources was used to produce a visualization of properties of an airflow field in the hall.
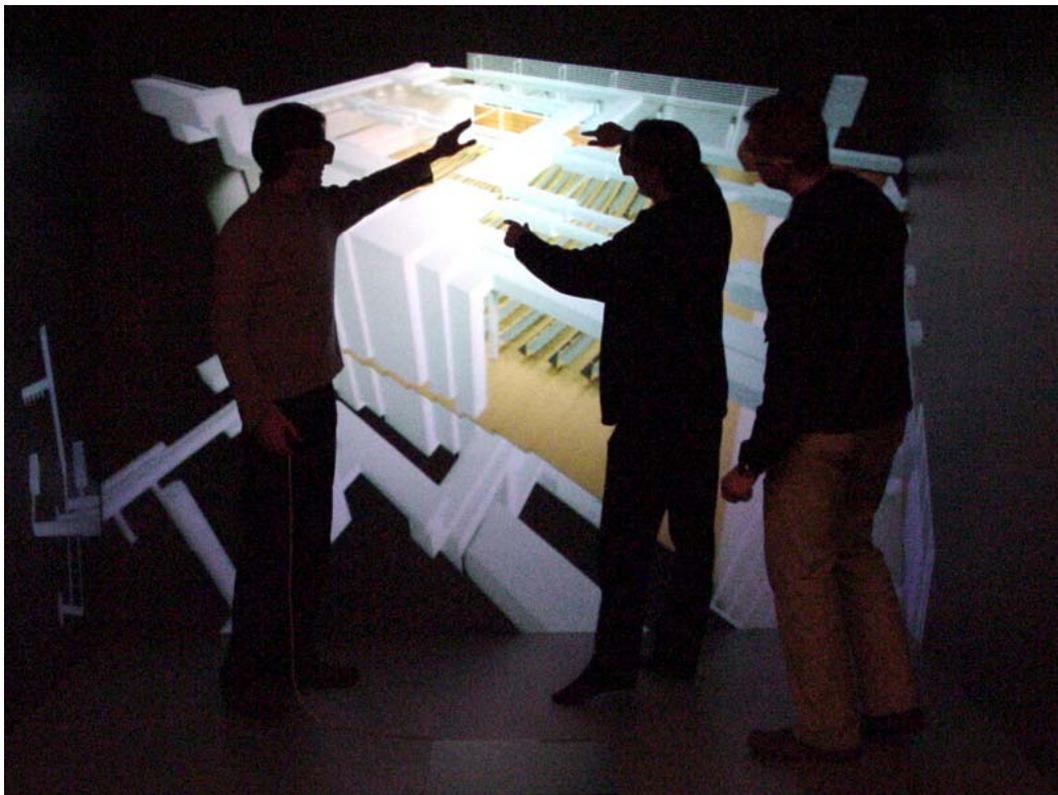

Figure 4: Users examining model of Hall 600 with air-conditioning channels.

4.2.1 Geometry and visual appearance

The visual system of the EVE uses the OpenGL Performer as its rendering engine. It supports various 3D file formats with format-specific loader modules of the OpenGL Performer. The availability of the loaders is why the visual models had to be transferred according a certain transfer path. After the geometry was defined in modeling software, the lighting information was added to the model with Lightscape, a radiosity-based rendering software from AutoDesk. The 3DSMax was used to finalize the model.

The geometry, the materials, and the textures – illustrating the lighting conditions and surface materials – were put together in a 3D modeling software, after which the model database was ready to be converted and transferred into the EVE. During testing we noticed that only few of the OpenGL Performer loaders worked reliably. The chosen transfer file format was OpenFlight 14.2 from Multigen, which was found to work the best.

In general, if the limiting factors, mainly related to textures, have been taken into account in the modeling phase, the OpenFlight file produced by PolyTrans can be used directly with OpenGL Performer-based software without further processing.

The PolyTrans was used to convert the two more realistic models, the second and the third. The model of the air conditioning pipelines was imported in OpenFlight format, although it was not processed in Lightscape to enhance the appearance. The first conceptual model of the actual hall was imported as a simple 3DS file.

The second model was the most suitable for displaying in the EVE. It was simple enough to be used in a real-time navigation application, but it was still able to show the main characteristics of the hall. The third model was more detailed and hence more realistic, but it was far too complex for graphics hardware. The frame rate achieved was not sufficient for public demonstrations and the model had to be left only for internal use in the EVE.

The second model became the actual Hall 600 model, which was shown to visitors in the EVE. The leading group of the construction project and the future users had the opportunity to study the model before the design phase was closed.

Since we needed models to be viewed in the EVE in real-time, we created special guidelines for the modelers to follow, as well as defined other parameters for the transfer path. The well-defined guidelines reduced the total time required for incorporating a new model from days to hours.

The automated polygon reduction functionality of the PolyTrans was used to decrease the polygon count in the entire third lighting model and in some parts of the second model. Polygon reduction was able to make the viewing of the second model very smooth, but the most detailed third model was still too complex after the reduction.

4.2.2 Results of computational fluid dynamic simulations

The airflows in a room, caused by an air conditioning system, are one of the factors having an influence to the convenience of the users of the building. It is very profitable to visualize the conditions related to certain air conditioning design. It is quick to analyze if the requirements are met, and in the case of an unacceptable situation, it is easy to see that the design work should continue. This technique was used in the Hall 600 project and the visualization was also created for the EVE. The flow visualizations were presented at the same time with the realistic hall model, which gave the users better insight into the conditions in different zones of the hall.

The flow data was produced as a result of the CFD calculations carried out by the engineering office Olof Granlund Oy. The pre-processing and the execution of the actual solver part were done at the Olof Granlund Oy in a Windows NT environment. The generated flow data was delivered in an EnSight Case file format to the EVE. CFD software used in the project was CFX-5 produced by AEA Technology plc. Finally the data was processed in the TML with the WolfViz software package to produce the desired flow visualizations.

In the Hall 600 the interesting quantities were the airflow velocity and the temperature of the hall. These quantities were visualized with cross sections, isosurfaces, paths of weightless particles in the airflow, and animated particles moving along those paths.

If a weightless particle is placed in a flow defined by a vector field, it is possible to integrate the path of the particle along the flow as a function of time, and produce lines, ribbons, or stream surfaces illustrating the airflow in a 3D space. The particles can also be animated along those paths. In the case of the Hall 600, the chosen elements were stream lines and stream tubes, colored either based on velocity or temperature. The animated particles were presented as simple red spheres, as illustrated in   Fig. 5.

Volumes containing information may be sliced to create cross sections. The cutting may be done with any type of an implicit function, but an ordinary plane is the most often used one. It produces a flat sectional plane, which can be colored according to the information in the data set. Planes were used in this project also to produce cross sections in x, y, and z directions. The coloring was done again based on either velocity or temperature. An example of velocity cross sections is presented in   Fig. 6.
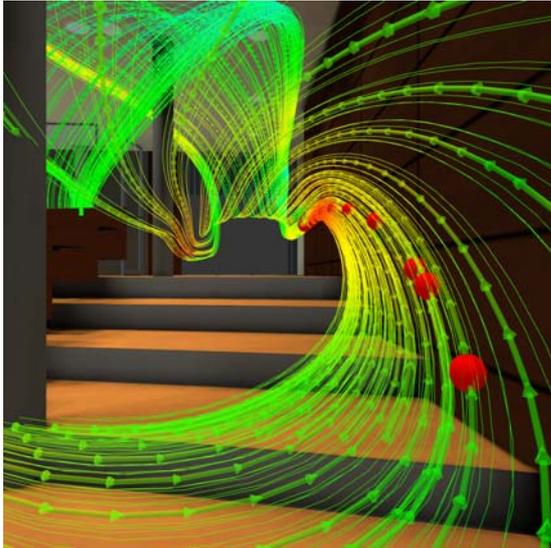
Fig. 5: Particle paths in Hall 600 flow model.
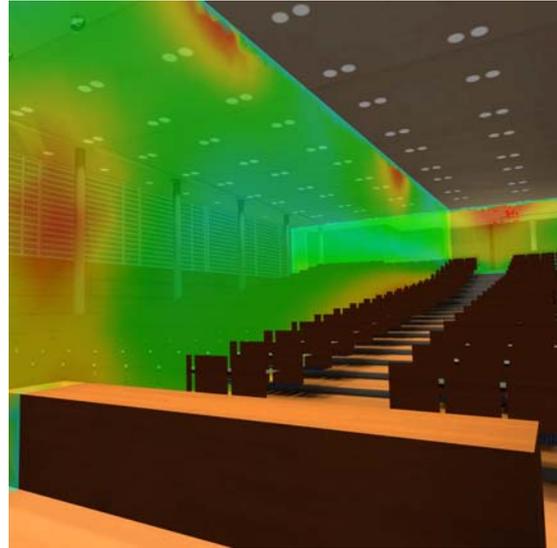
Fig. 6: Cross sections illustrating velocity of airflow in Hall 600.

Isosurfaces are arbitrary shaped surfaces, on which the magnitude of a chosen quantity is equal. They can be used to study important critical values of a quantity in a data set. Isosurface divides the volume in two regions. In the other side of the surface the value is higher and in the opposite side lower than the reference value on the surface. The isosurfaces in the case of Hall 600 were created from either velocity or temperature values. An example of velocity isosurfaces is depicted in Fig. 7.
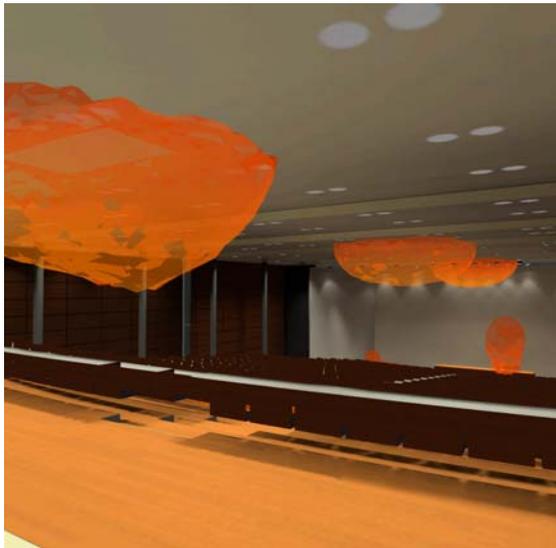
Fig. 7: Isosurfaces near ventilation illustrating velocity of airflow in Hall 600.

4.2.3 Acoustic model

Especially in a lecture hall, the acoustical properties are important, as the level of reverberation should be suitable for speech. The acoustical design of Hall 600 was made by Akukon Oy. They provided us the acoustic model in Odeon format. Odeon is commonly used software for acoustical design, the file format of which is supported by the DIVA software. The model was utilized in real-time dynamic auralization, in which user was able to move around the hall and listen to its acoustics in the EVE.

To enable the dynamic auralization, the DIVA software continuously received information on the listener's

position and orientation. The applied sound source was an anechoic recording of male speech and it was located in front of the lecture hall. Based on this data consisting of acoustic model plus position and orientation of both the listener and the sound source, the DIVA software provided the real-time acoustical simulations. As a result, the speech was heard from the correct direction, and as natural sounding as possible, while the user moved around the hall. In addition to the careful modeling of the direct sound and early acoustic reflections, a late reverberation was added, producing a realistic auditory scene.

4.3 The design process of the Hall 600 and the EVE

In the first stage, the project was presented as three alternative designs. The differences between the alternatives were, for example, the extent of renovations in the existing building, new use for the former apartments, entrance solutions for the disabled persons, ways of getting natural light in the foyer and alternative roof, and skylight and window constructions for the lecture hall.

The alternatives were visualized with simple VRML models and perspectives. The product model was also used to produce cost (YIT) and lifecycle (Olof Granlund Oy) evaluations of the alternatives. On the basis of the presentation material and evaluations, the client chose the basic solutions to be realized.

The next phase was to present the chosen basic solutions for the new lecture hall – the exterior and the interior, including seating, materials and lighting – for general discussion in the EVE. A presentation to the project group (designers, representatives of the Senate Properties, and the HUT) was arranged. The model at that stage was quite coarse, with very little material and scale information. Still, it was possible for the end users to visit their future workspaces for the first time. It was possible for them to get a general idea of the size and feeling of the spaces they were going to get. No extensive changes in space arrangements were suggested.
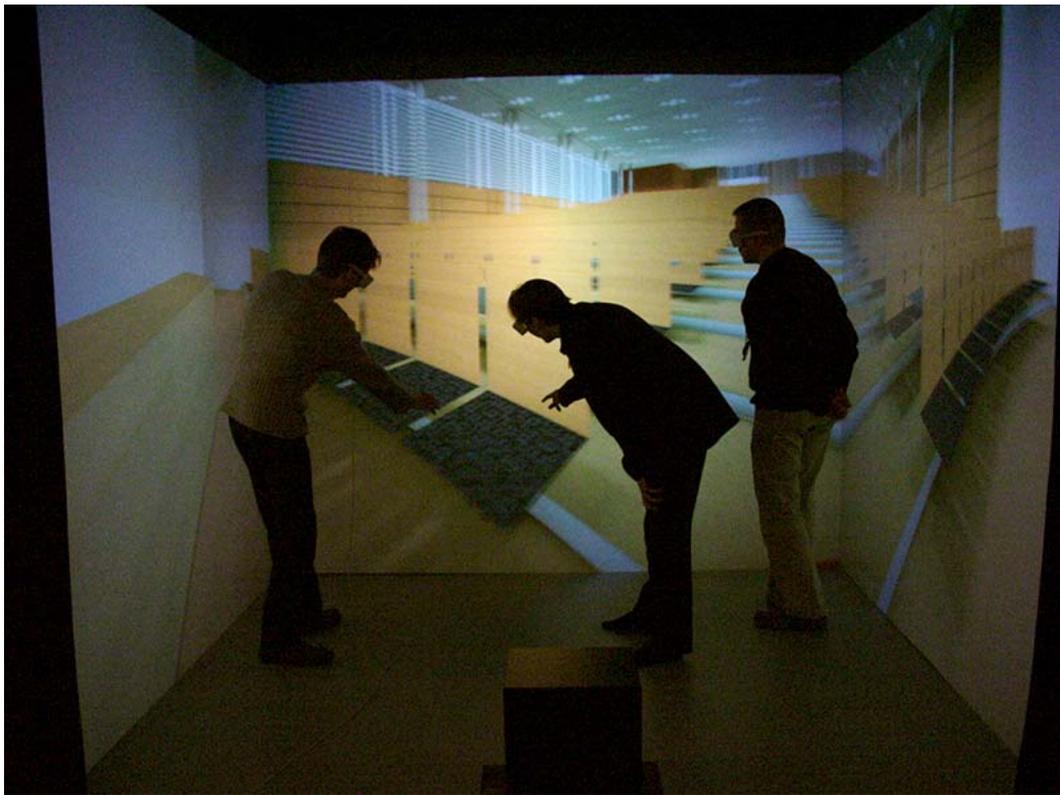
A presentation of a model developed further was arranged in spring 2001 for Professor Paavo Uronen, the Rector of the HUT and Mr. Aulis Kohvakka, the General Director of the Senate Properties.

Fig. 8: Three users in the EVE studying a detail in the Hall 600 model.

Limited space for the construction of the lecture hall and the pre-planning stage decision to have 600 seats in the

lecture hall (the most in the HUT campus) made the design of the space a complex problem. The use of the EVE was very helpful in balancing the contradictory demands: the width and depth of the hall, the distance of the first and last rows from the lecturers and the screen, the radius and slope of the curved seating, the distance between rows, the placement and width of the gangways, and so on, together with materials gradually creating the characteristics of the space.

A presentation of the same model was arranged in spring 2001 for the end-users. The hall will be mainly used as a lecture hall for the first year students and occasionally for more festive events. There had been critical discussions earlier, whether there was any need for natural light in the lecture hall. After discussions with the teachers of mathematics, in particular, the design group was convinced that natural light and views to the outside world were a necessity. As the architects already had proposed a large window on the eastern wall, an effort was then put to avoid the glare of the morning sun.

Another subject that came up was the contradiction of the big number of seats and thus relatively long distance from the last seats to the front, and the preferred traditional method of teaching by writing on the blackboard. Actually, no ideal solution for the problem was found. So the hall has a large screen, the size of the whole front wall, intended for overhead, video and data projectors – but there will also be blackboards for the teachers who want to use them.

The final check-up model was made in early autumn of 2001, while the construction work had been going on for quite a long time. The final combination of materials, lighting, and seating was checked with a model before giving permission for the manufactures and the construction company to proceed. The detailed model proved to be too complex for the EVE graphics hardware, so the project team mainly used the final product model to produce photorealistic stills and QuickTime movies.

4.4 Results of the case-study

As a design process, the product model approach, together with the use of a virtual environment, proved to be a good combination. Starting with a relatively simple model, the alternative proposals and desired changes in the architectural design were relatively easy to make. Still, due to the virtual environment, it was possible to the users to get a realistic in-scale impression of the future spaces. Attention in presentations at this stage was rightly paid to the questions of general layout and concept without the nuisance of distracting details. Adding details to the model as the project developed brought up further things to consider. Finally, the designers came to a detailed photorealistic model to check the last details.

The partial failure of the most detailed third model in the EVE was a disappointment to the designers. Some quite crucial information was lost in the polygon reduction phase and some of the shapes, in the seating, for example, were distorted. Still, the model was too complex to achieve a sufficient frame rate for public demonstrations. This showed that for best results, the real-time viewing requirements should be taken into account from the beginning, instead of using a polygon reducer on the finished model. Paying more attention to the use of complex details only in eye-catching crucial points could have produced a more acceptable result.

This study has opened up new questions to be considered in the future. From a perceptual point of view we should investigate, if virtual environments give the right impression of the space. Another interesting problem is how to incorporate into a virtual environment all the necessary things that make a place meaningful. These things include materials, tactile qualities, meaningful and random sounds, movement in space, scents, people, and connections to the world outside.

5. SUMMARY

In this article, we presented the main principles applied in creating virtual environments. To be convincing, virtual environments should look real, sound real, and feel real. In this article our focus was in the application of a virtual environment in the construction project of a new lecture hall at the HUT. The EVE virtual environment at the HUT was actively utilized throughout the project. All the participants of the project, especially the designers and end-users, were enthusiastic about the possibilities opened up by the EVE. In the future, virtual environments should be an integral part of construction projects.

6. ACKNOWLEDGMENTS

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