

MIXING VIRTUAL REALITY AND 2D VISUALIZATION

Using Virtual Environments as Visual 3D Information Systems for Discussion of Data from Geo- and Environmental Sciences

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Abstract: 3D stereoscopic visualization and virtual reality techniques are increasingly used for quality control, analysis and discussion of 3D geoscientific data in the oil and gas industry. They provide an excellent and easily comprehensible insight into complex 3D structures of the earth's subsurface. However, in many research topics in environmental and geosciences the analysis of data usually also involves data that might be better viewed in 2D. Examples are maps or histograms. The use of virtual environments as visual information systems for the efficient communication and discussion of complex multi-attribute data sets also requires 2D data to be visualized with a high quality. Further it is often not possible to show all the relevant information simultaneously and so an interactive virtual environment is required that provides an overview and the necessary interaction techniques to select additional information, e.g. from a database, to be visualized on request. This article describes the hardware setup installed at the UFZ Centre for Environmental Research and a software solution for how to use this setup efficiently to connect 2D data representations with 3D visualization and interaction. This article is a slightly extended version of the original paper included in the conference proceedings of GRAPP2010, giving some more details and references.

1 INTRODUCTION

At the very end of the last millennium, companies from the oil & gas and the mining industry started to become interested in using virtual reality techniques to analyze their data sets. In order to investigate this method and obtain demonstration software, many oil & gas companies financed research at public research centres and universities, such as the GMD German National Research Center for Information Technology (the GMD is now part of the Fraunhofer Society, (Fröhlich et al., 1999)) or the Virtual Environment Technology Laboratory from the University of Houston (e.g. (Lin and Loftin, 1998), (Harding and Loftin, 2000)). Many companies, such as Norsk Hydro (now part of StatoilHydro) or ARCO (now part of British Petroleum), set up their own virtual environments and developed their own software ((Midttun et al., 2000), (Stark et al., 2000a), (Stark et al., 2000b)). Due to the very expensive hardware that was needed at that time, only little research has hitherto been done out-

side of this industrial field, for example on the use of virtual reality for visualizing data from applied geophysical investigations, such as ground penetrating radar (GPR) or geoelectrical resistivity measurements (Zehner et al., 2001), (Zehner, 2002).

Nowadays large companies like Shell or Schlumberger own a number of visualization centres of different types around the world and use commercial software, such as Paradigm's Gocad (Mallet, 1989) that has been extended for VR use (Cuny and Piroux, 2004) or Schlumberger's Petrel, that can be used via the middleware Conduit from Mechdyne, to quality control and analyze their data, discuss their models within asset teams and present them to the management. Further, more than 500 Geowalls, a low cost stereoscopic visualization environment, have been built at universities and elsewhere, allowing geoscientists outside industry to make use of advanced visualization methods for teaching and data analysis purposes (Johnson et al., 2006). For this reason, current examples of the use of virtual reality in geosciences

have started to include more diverse subjects, such as the 3D integration of outcrop data with regional data (Johnes et al., 2009) or numerical simulations in geosciences, e.g. of subduction zones (Billen et al., 2008). However, despite the fact that many topics in geo- and environmental sciences often inherently involve 3D data, the use of these 3D technologies has still not reached maturity outside of the above mentioned industries and the question is why.

Principally, projection-based systems should be very suitable for discussing geoscience issues because the stereoscopic vision enhances synoptic views of structurally complicated 3D datasets that contain data from different domains (e.g. geophysical and geological data and simulation results) and make it easier for users with different backgrounds and for novices to understand the structures and spatial coherence. Furthermore, due to the dimensions of projection-based displays, these allow for group discussions of the visual information shown.

This article will focus on the use of large projection-based systems for presentation and discussion. It will first discuss what might be missing in current virtual environments to make them more useful for discussions in geo- and environmental sciences (section 2) and will then give an overview of what is currently available to solve this problem (section 3). In section 4 the design of our purpose-built display system is explained and section 5 shows how the software has been implemented and how it is used to interact with the data and virtual models.

2 WHAT IS MISSING?

The virtual reality systems that are currently state of the art have been primarily designed only with 3D tasks in mind, as the first industries using them such as the automotive industry, architecture and mechanical engineering, were mainly doing design or assembly studies. When geoscience data are presented in a virtual reality environment, usually only the 3D data are shown in the original form and all other data need to be converted into 3D representations.

During the planning phase of a projection-based visualization centre for the UFZ-Helmholtz Centre for Environmental Research, it became obvious that in contrast to design studies in these industries, many use cases in such research centres have different requirements. Investigations in geo- and environmental sciences often contain a large number of different data sets that are spatially distributed and it is often not possible to show all this information simultaneously. Therefore, scientists frequently use Geographic Infor-

mation Systems (GIS), provided that the overall investigation can be represented on maps. GIS connect a spatial 2D visualization (a map) with a relational data base that contains additional information about the objects shown on the map. The maps show the overall structure (e.g. the topography) and additional objects, such as streets, dwellings, borehole locations and soil types. If during a discussion additional information is needed on one of these objects, such as the address and height of a house or physical parameters from a borehole, the viewers can select this object and the information is shown.

If the investigations involve complicated 3D structures that can not be presented on a map, this overall paradigm has to be extended from two to three dimensions and virtual environments become the ideal discussion platform due to the stereoscopic visualization and the direct interaction in 3D space. However, much of the additional information that belongs to the objects that are shown in the virtual environment involves data which can inherently be better visualized in 2D. Examples of this are maps and areal images, statistical plots from data collected in the field, time dependent graphs, soil columns or log plots. All these data need to be at the user's disposal during discussion and accessed by making selections. One option would be to find 3D representations for these data. However, this is not always efficient and preferable and so a visualization centre at the UFZ should be able to visualize these kinds of data at the same time as the 3D visualizations and link them to the 3D model.

Another important topic where additional 2D visualization helps is the orientation of the user within the model. While this is very easy when looking at a virtual mockup of a car, it becomes complicated when orienting oneself within a structurally complicated virtual model of several kilometres in size in each direction, such as the hydrogeological model of the German Bitterfeld site that has been described for example in (Wycisk et al., 2009). Incorporating 2D visualization could help with this task by showing a map with the area under scrutiny and an icon which shows where and at what depth the users are currently located and in which direction they are oriented while they are moving within virtual space.

3 PREVIOUS WORK

Very little work and software is available that really combines 3D visualization and 3D interaction with the option of augmenting the virtual scene with 2D information. Broadly the work can be split into three different categories: Showing virtual 2D wid-

gets in 3D space, using additional gadgets such as PDAs and hand-held computers, and using video wall controllers. Most of this work is targeted more at using the 2D display devices for system control, e.g. for changing the properties of objects and for symbolic interactions such as file selection, and less at using these additional displays for showing 2D information.

One example which shows virtual 2D widgets in 3D space is the Inside Reality Software from Schlumberger (for a picture see (Johnes et al., 2009), Figure 1, lower left). This has been designed as a system for working with data in virtual environments. For the system control, the standard XMotif style window interface is shown on planes in 3D space and interaction is done by pointing at the different menus and icons with a ray.

The Virtual Environments group at the Fraunhofer Society in Birlinghoven, near Bonn, has developed several examples of the use of tracked PDAs ((Simon et al., 2005), (Holtkämper et al., 2007)) and Tablet PCs (Holtkämper et al., 2007) in virtual environments. This approach could also be used to show additional 2D information which would, due to the small displays, only be available to a limited number of people.

Video wall controllers, such as BARCO's Transform-A/XDS-1000 or Vista's Spider are used to mix 2D and 3D visualization on large displays with multiple projectors. They open a large virtual desktop across the whole display and the monitor outputs from other workstations are shown as separate windows that can be freely moved (see Figure 1). For small display systems that involve only one pair of projectors, a simpler solution can be found.

4 UFZ'S DISPLAY SYSTEM

Our head-tracked stereoscopic display system is mainly used for collaboration and presentation. So one major driving factor for design has been high image quality/high resolution and a large screen to support an audience of several people. Further the aim was to employ the system for a wide range of use cases, some of them using it as a CAVE while others as a simple 2D presentation system. The system was built by BARCO BV with an approximately 6x3 meter large main screen and corresponding projections on the floor and sidewings. In order to achieve a high resolution of approximately 6400x1800 pixels and a good image quality, 13 SXGA+ projectors are used to run this system. Figure 2 shows a picture taken in our display system and a sketch of the overall technical setup. The system can be used with both shutter

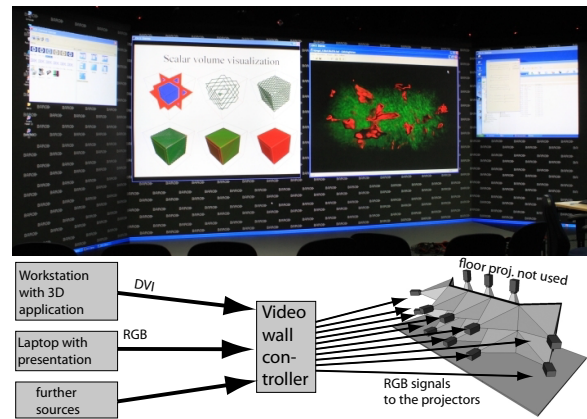


Figure 1: Our projection-based display system run by a video wall controller. Different computers, e.g. a workstation with a stereoscopic visualization application (here showing a volume visualization in the right window) and a laptop with an explanatory powerpoint presentation (here shown in the left window) are connected as external sources to the video wall controller. Image generation for the projectors is done by the video wall controller which also solves problems, such as edge blending. The different sources can then be placed everywhere on the display as windows. While allowing the use of standard software on the display, this essentially means using the display as a big monitor instead of as a virtual reality display.

glasses and Infitec glasses for stereo separation. Rendering is done by a cluster of up to 13 workstations, one for each projector, and/or via a video wall controller.

In the UFZ's visualization centre, rendering can be done in three different modes.

1. The first mode is to run the system purely as a virtual reality system using a cluster of 13 workstations for image generation, one for each projector.
2. The second mode uses a video wall controller for the main screen and the side wings; the floor projection is switched off in this mode. The content is generated on other computers. This mode has already been shown in Figure 1.
3. The third mode uses a combination of the first and the second one. On the main screen and the floor the computer cluster is used while the image generation for the side wings is done by the video wall controller.

Figure 2 shows the configuration that serves as the basis for augmenting virtual reality and 3D interaction with 2D views of data, using the third mode. From the cluster, nine computers are used to generate the images for the main screen and the floor. This part of the display provides a virtual environment, using head tracking and 3D interaction. On the side screens

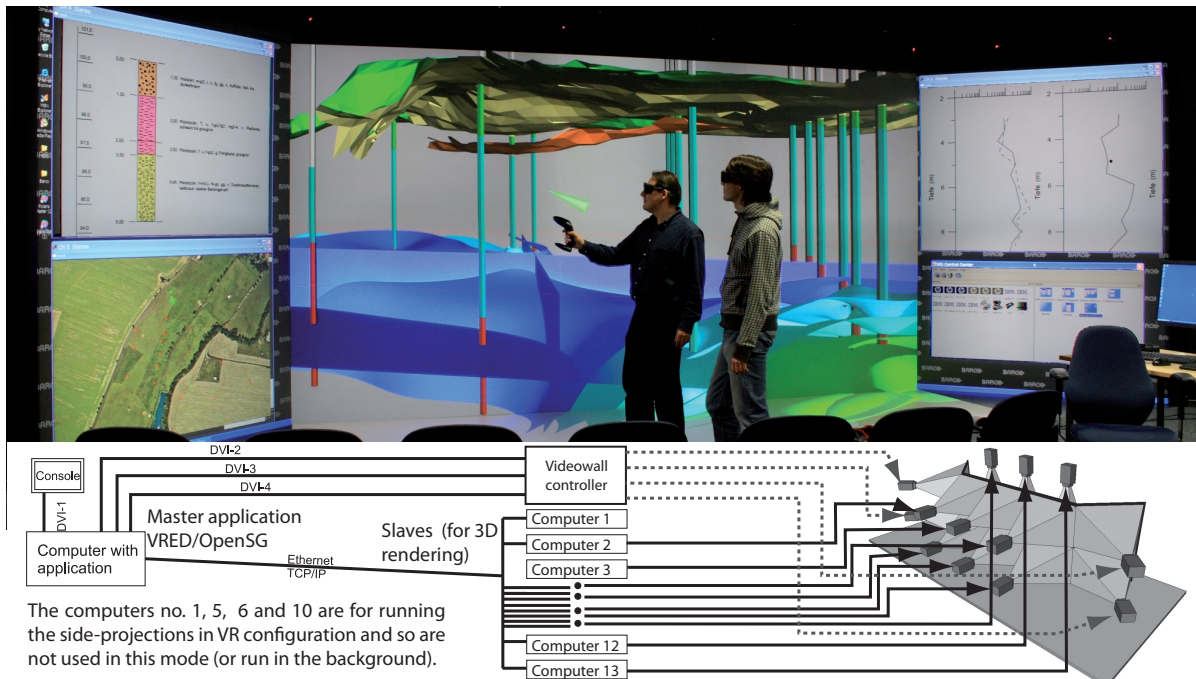


Figure 2: Picture of the UFZ's visualization centre used in mixed mode at the top and the corresponding hardware setup at the bottom. On the rear screen and on the floor a 3D model is shown with which the users can directly interact in virtual space. This part of the system is run by a computer cluster. On the side wings additional 2D information is shown upon the user's request, such as detailed borehole information on rock types or graphs of physical values (windows at the top of the two side wings). The users choose which information is shown by selecting the corresponding objects in the virtual model. A map (bottom left wing) always indicates the orientation of the display in the virtual world and so helps when working with data sets that show geographical information ranging across several kilometers.

the video wall controller is used to show 2D information that has been generated as graphical output on a remote machine.

5 IMPLEMENTATION

In order to demonstrate a system that mixes virtual reality and 2D visualization to visitors at our visualization center a sample implementation has been programmed. Software development for the visualization centre at the UFZ currently comprises three or four basic elements: The open source scenegraph OpenSG Version 1.8, the commercial software VRED from PI-VR GmbH which is based on OpenSG, and Nokia's (Trolltech's) Qt toolkit for developing GUIs and Plugins for VRED. For processing 3D scientific data, we use the Visualization Toolkit (VTK, (Schroeder et al., 1996)) from which we have incorporated the standard pipelines for showing isosurfaces and streamlines into our software by implementing a `vtkOsgActor` class that is derived from `vtkActor` and transforms the polygonal data that are generated by the VTK pipelines

into OpenSG.

OpenSG (Reiners et al., 2002) is a distributed scenegraph which keeps a description of the model in a tree structure which is sent from the master computer to the slave computers. Changes to the scenegraph on the master computer are propagated to all slaves. The rendering itself is done entirely on the slave computers. So, for a mostly static scene, the network traffic is very low after the scenegraph has been transmitted to the slave nodes. OpenSG is available for multiple operating systems (UNIX, Windows, Macintosh), is reasonably well documented and comes with tutorials which, besides showing other features, provide a valuable starting point for setting up a flat multi-channel projection on a computer cluster with one computer as master. One important feature of OpenSG is that it separates the structure of the scenegraph (the so-called "Nodes") from its content (the so called "Cores"), such as materials and geometry. Another is that it allows names to be attached to the different elements of the scenegraph, so that the scenegraph itself can carry information about the shown model. We use these names as identifiers to link additional information to these 3D

objects.

Figure 3 shows the main components necessary for this software. At the heart of it is a 3D visualization application that manages the scenegraph, including camera position and orientation, and provides functionality for operating on the scenegraph and adjusting the rendering attributes. Further it must implement the functionality to act as a master for the computer cluster that represents the slave computers. Most of the functionality needed as a minimum requirement could be implemented quite easily using OpenGL. However, at the UFZ the role of this software component is played by VRED, which provides additional features, such as tweaking of the scenegraph, loading files of different formats and providing many adjustments and render options.

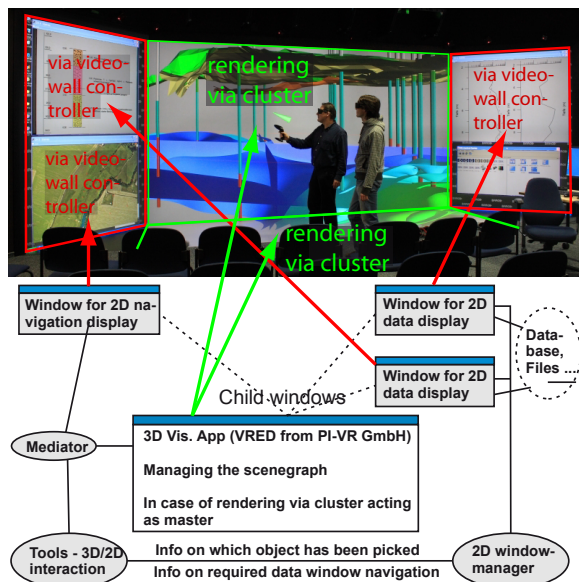


Figure 3: The different components of software that are necessary to run the system in the mixed mode shown in Figure 2. At the heart of it is a 3D application that acts as master for the visualization cluster and provides access to the scenegraph. Child windows are provided to show additional data on request and a map indicating where the users are in the virtual world and in which direction they are looking. The additional windows are shown on the side wings of the display via the video wall controller and are steered using the 3D tools while interacting with the 3D model in the virtual world. The components that have been developed for this work are in grey. See text for further explanations.

In order to show supplementary 2D information, additional child windows are added to VRED which are shown on the display using the video wall controller: Two for rendering additional data (in the picture in Figure 2 visible at the top of the display's left and right wing) and one for showing a map and in-

dicating with a glyph how the user is oriented within the whole scene (in the figure visible at the bottom of the display's left wing). The windows for showing data implement a common interface that provides functions for scrolling up and down, zooming in and out or loading data. They are steered from a 2D window manager that implements the Singleton design pattern and therefore can be accessed from the other components of the program. The 2D window manager loads the configuration that describes which supplementary information it should display for certain objects from an XML-file.

5.1 3D Interaction

An essential component is the set of tools that have been implemented for system control and interaction with the objects in 3D space. In the UFZ's display system interaction is done with a so-called Flystick from Advanced Realtime Tracking GmbH, an interaction device that has 4 buttons and a small bidirectional joystick on the top, and another button at the bottom. The tracking system evaluates the position and the orientation of the Flystick and the status of the buttons and the joystick. Data transmission is done via the open source VRPN toolkit (Taylor et al., 2001). The four buttons on the top of the Flystick are used to switch between different tools. Which tools are available can be configured in a so-called tools-manager class. The tasks that can be done with the tools can be placed in four different groups:

- Navigation
- Interaction with objects in 3D space, such as translating objects or moving clipping planes
- Selection of objects for which additional information should be shown in the 2D windows
- Steering the 2D windows.

All tools are derived from a few simple base classes that are linked to the different buttons of the Flystick.

The navigation-tool is linked to the small joystick on the top. By pushing it forward, the users fly in the direction they point and by pulling it back, they fly backwards. Moving it to the left and right turns them. The pick-tool is linked to a small button at the bottom of the Flystick. By pressing it, the current transformation is evaluated and a ray shot through the scene, checking if an object is intersected. A translation tool, for example, was then implemented that was derived from the pick-tool, but subsequently changes the translation of a selected object following the movement of the Flystick until the button is released. By using multiple inheritance, different tool

combinations can be provided. For direct 3D interaction, a tool is provided to move objects and snap them back to their original positions. This can be very helpful during discussions when some of the objects disturb the view.

When looking at the 3D distribution of scalar data, such as the distribution of contaminants, multiple isosurfaces are often generated. The isosurfaces that are near to the viewer often hide the ones behind them which disturbs the view of the 3D course of the scalar field. As an example of data-analysis supporting 3D interaction we have implemented a solution where the user can use 3D tools to define a clipping region by manipulating the 3D widget that is shown in Figure 4. A rectangular parallelepiped is defined by 8 cubes at its corners and represents the volume of interest. Outside of this volume the isosurfaces are clipped, and so are not visible. A small sphere can be moved within the defined volume that represents the point where 3 additional axis-parallel clipping planes inside the volume intersect, so that chair-cuts can be interactively defined within the volume. In Figure 4 in both cases the left front upper octant, which lies near to the viewer is clipped away. The clipping is implemented using suitable vertex and fragment shader programs and so can be used interactively and independent of the number of clipping planes the graphics board supports.

For the manipulation of this widget, two tools are provided. The first is for translating the cubes at the corners and so for reshaping and transforming the volume of interest. The second tool is for defining the chair-cut: translating the sphere moves the 3 clipping planes within the volume while picking one of the cubes at the corner selects which octant should be clipped away and makes the necessary adjustments to the clipping planes. In this way the user can, for example, analyze very well the course of the different isosurfaces around a borehole as shown in the picture at the bottom of Figure 4.

The tool that connects 2D and 3D visualization is derived from the pick-tool and makes use of two additional classes. The first allows it to evaluate which screen of the display the pointing ray intersects and the second is the 2D window manager class. Depending on which screen has been intersected, different actions are performed: If the intersected screen is one of the side screens, the user must keep the button pressed and can then use the joystick, that is normally used for 3D navigation, to scroll and zoom the 2D window on the corresponding screen. If the intersected screen is the main screen showing the 3D model, the program checks for the intersection of the ray with the scene and reports the picked object to the 2D window man-

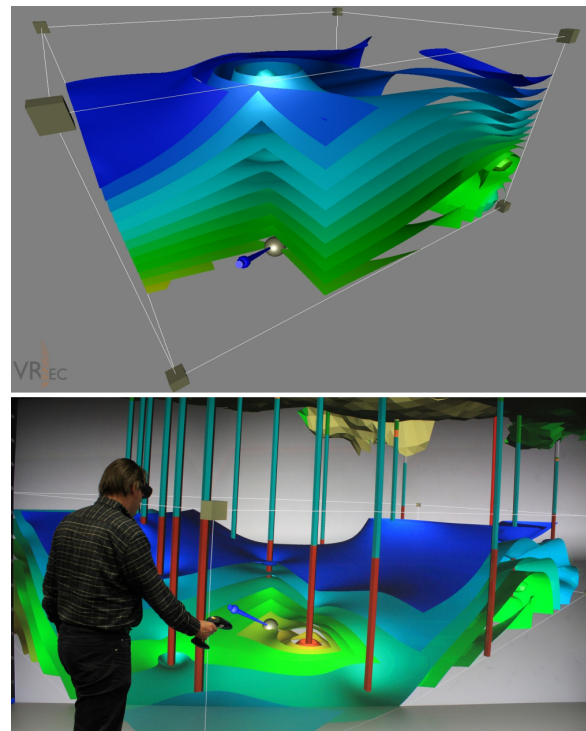


Figure 4: Example of the direct interaction with the 3D model in virtual space: Definition of a clipping box and a chair cut through a data set (isosurfaces) using a 3D widget, at the top as a screen shot and at the bottom showing a person interacting in our display system.

ager, so that the suitable supplementary information can be shown on the side screens.

5.2 2D Information Display

As mentioned already a GIS system provides a 2D spatial visualization (a map) that shows the overall structure (e.g. morphology) and different objects, such as streets and houses, and connects these objects to a database that contains additional information that is displayed when these objects are selected. For our 3D analogy we can not use a commercial GIS system as these only support 2D spatial representations. Instead we directly use the scenegraph that describes our 3D visualization and within each node is associated with a unique name. Upon making a selection in 3D space, this name is used as an identifier and passed to the 2D window manager which then retrieves the additional information from the database. Depending on the nature of the information (e.g. image, time dependent data) a suitable widget is chosen and the information is shown in one of the 2D windows on the side wings. Figure 5 shows an example of the application of this functionality, using the above-mentioned tool

to connect 2D and 3D visualization.



Figure 5: Example of requesting additional information on one of the objects shown in 3D space. The person picks one of the boreholes in order to see the additional 2D information, which is shown on the left screen.

5.3 2D Navigation Display

With regard to navigation, the information from the 3D interaction device goes through a mediator which passes it to both the 3D window/3D display and the 2D navigation window. The current position and orientation is always projected into the map view. The 2D navigation window then displays a map of the region and indicates the user's position and orientation using an arrow glyph.

6 EXAMPLE DATA

For demonstration purposes real data are loaded which stem from the initial site analysis of a project that deals with direct gas injections for stimulation of the biological degradation for remediating organically contaminated groundwater ((Beckmann et al., 2007) and (Pohlert et al., 2008)). The data comprise borehole locations including the stratigraphic columns, the constructed geological model with the stratigraphic units and 3D gridded scalar data volumes with the measured and then interpolated contaminant concentration. The scalar data are converted to VTK file format, loaded into the system, contoured using VTK, and then shown as isosurfaces. Their visualization can be limited to a volume of interest and clipped as described above. Boreholes and stratigraphic units are loaded from files and are shown as geometry. The tools for translation and snapping back of objects are, in this example, constrained to be used on the stratigraphic units as these often disturb the

view in discussions. Additional information, such as supplementary drawings of the stratigraphic columns and permeability measurements within the boreholes, are provided as images.

7 CONCLUSIONS

This article first explains why there is a need for current virtual environments to be extended to include the capability to show non 3D data, such as textual information, maps and graphs, if they are to be used as visual information systems for complicated 3D geoscience multi attribute data sets in the same manner how Geographic Information Systems are used for discussing 2D data today. As one possible solution a system has been described that combines hardware and software and provides virtual reality capabilities, such as user-tracking, stereoscopic visualization and direct interaction in 3D space and that can augment the information given in the 3D model interactively with supplementary data, using additional windows.

We so far have not evaluated the system quantitatively. As visitors to our center often lost their orientation when navigating within large scale virtual models (even the ones that actually modeled it), it is clear that an additional 2D map view which shows the current location and orientation helps very much. The same goes for providing additional 2D information that is needed to explain the data set. We have yet to evaluate if our approach, using the peripheral parts of our display for showing this information is superior to other approaches, e.g. those which involve using hand-held PCs. However, we usually have several visitors simultaneously and so it is preferable to show the additional 2D information on large screens. Current problems with the system as shown are the wide angle of view where it is difficult to maintain an overview of the information on all the screens. Furthermore people sometimes complain about the 3D visualization abruptly ending on the side of the main screen. However, when the additional 2D information is no longer needed, the system can be switched in about a minute to full VR mode (and back) without ending the application.

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