Integrating 3D-GIS and Virtual Reality
Design and implementation of the Karma VI system

Gert van Maren[1], Rick Germs[2] & Frederik Jansen[2]

[1]Department of GIS Technology
Faculty of Civil Engineering and Geosciences
Delft University of Technology
The Netherlands
Phone: +31 (0)15 2782795 Fax: +31 (0)15 2782745
E-mail: gvanmaren@yahoo.com
Web: http://gisvr2.geo.tudelft.nl/3dgisvri/3dgisvri.htm

[2]Department of Technical Mathematics and Informatics
Faculty of Information Technology and Systems
Delft University of Technology
The Netherlands
Phone: +31 (0)15 2782795 Fax: +31 (0)15 2782745
E-mail: h.m.l.germs@twi.tudelft.nl
Web: http://gisvr2.geo.tudelft.nl/3dgisvri/3dgisvri.htm

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Abstract

Virtual reality is becoming a popular tool to visualize 3D GIS data. Direct interaction with the GIS data, however, is often limited. In this paper, we present a multi-view approach to support 3D GIS interaction within VR-environments. This approach is implemented in the Karma VI system, using existing GIS and VR technology. We describe the multi-view approach, the system components and the internal data models, and how CAD models can be imported and be made consitent with the GIS data.

Keywords and phrases: 3D GIS, Virtual Reality, Visualization, and Manipulation.

1.0 Introduction

Virtual reality offers new and exiting opportunities to visualize 3D GIS data. Users can walk through 3D environments, see newly planned buildings and appreciate changes in the landscape. In most cases, however, interaction with the data is limited to viewing. At the most there is some limited form of navigation and interrogation, e.g. the user walks around in the virtual environment and can point to objects in the scene and ask for information from a GIS database. The possibilities to interrogate the GIS database in a more intelligent way and to access more advanced GIS functionality are limited. One reason being that within an immersive environment there is no good 3D alternative for regular alphanumeric input with mouse and keyboard, for instance to formulate a SQL-query. Even if we introduce a spoken language interface, then we will still miss the spatial references and attributes to formulate these queries.

1.1 Multi-view approach

To support 3D GIS interaction within VR-environments we developed a multi-view approach based on three types of visualization: plan view, model view and world view. The ‘plan view’ visualizes the data as a conventional cartographic map. The ‘model view’ provides a 3D bird’s-eye view on a partly symbolic and simplified 3D representation of the data. The ‘world view’ gives the full immersive and photo-realistic 3D display. These views or modes can be used simultaneously or intermittently, and each provides a repertoire of interaction possibilities that is apt -but not necessarily limited- to that kind of visualization and interaction.

The multi-view approach is based on the planning of design projects for large infrastructure works. Research of the planning of design projects in The Netherlands (Verzijl, 1998), (Verbree, 1998) showed that three main design stages can be discerned each with a different use of GIS systems:

- Orientation (plan study)
- Modelling
- Presentation (decision making)

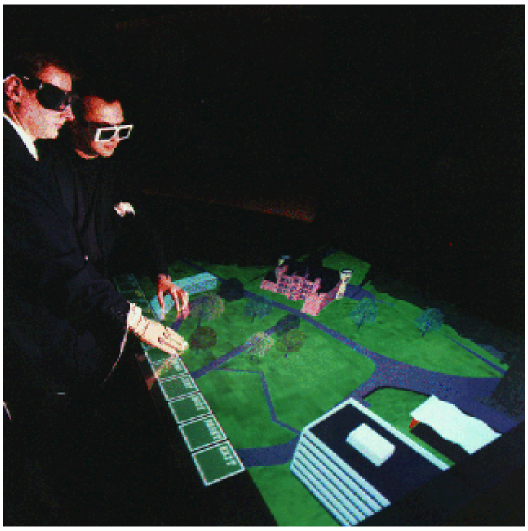
During the orientation stage, the use of GIS-systems is confined to standard 2D functionality for creation, manipulation and analysis of geographic objects. Objects are only indicated by position and contour. Visualization is achieved through 2D plans and maps. In the modelling stage, infrastructure engineers are more concerned with the general arrangement of objects, as well as size, dimension and the relation between objects. The use of GIS-systems in this stage shifts from 2D to 3D modelling and analysis. A 3D-scale model of the construction site and its surroundings is used for both visualization and manipulation of 3D objects. Finally, during the presentation stage, the design will be converted into a form to be presented to all participants in the decision process. This can be done either through detailed drawings, artist's impressions, CAD renderings, photo-collages, or with very detailed and realistic scale models. Visual analysis is the main task at this stage of the plan process and a more realistic visualization will only improve the presentation of the plans.

Summarizing, during the planning and development process, the plan goes through different stages, each using a specific representation of the plans, each addressing specific ways of analysing and visualizing the plans. We therefore decided to use a multi-view approach with a preferred virtual reality display system for each view.

1.2 Virtual Reality

The basic concept of virtual reality (VR) is the direct coupling of the viewing position used to generate the image on the display, with the head position and viewing direction of the user. The head position of the user is constantly tracked and fed into the display algorithm to calculate a correct stereoscopic and perspective display of the scene. This strong coupling of the current eye position of the user and the image offered by the display system gives the user the illusion of 'immersiveness'. Current VR systems range from true immersive to non-immersive displays.

A head-mounted display (HMD) is an example of a fully immersive VR display, which effectively isolates a single user from the real environment. The CAVE (Cave Automatic Virtual Environment) (Cruz-Neira, 1993) is a (fully immersive, multiple screen) projective display system that offers stereoscopic surround projection to several users simultaneously (figure 1b). Other (single-screen) projection systems are less 'immersive' than the CAVE, but a 3D impression can still be maintained. These systems are more suited for visual presentations to groups. An interesting development is the so-called Virtual Workbench (Krüger, 1995): a table with projection through the tabletop: the 3D image can be visualized on top of the table or inside the table (figure 1a). Users are not 'immersed', but rather look from above on the displayed objects. It offers a presentation mode that is normally associated with a 3D-scale model. Finally, even personal computers can offer (non-



Virtual workbench (a)

CAVE (b)

Figure 1. (a) Virtual workbench (VMSD 1998) and (b) surround projection in a CAVE (EVL 1998).

immersive) stereoscopic display, bringing VR to the desktop (Earnshaw, 1993), (Kalawsky 1994).

1.3 Karma VI

We are currently developing a 3D GIS & VR system called Karma VI, based on existing GIS and VR technology to support the design, development and presentation of large infrastructure plans in The Netherlands. Karma VI uses the multi-view mode approach where each view mode has a preferred VR display system. Next to the different view modes, an essential feature of the system is the support for manipulation and editing of GIS data from within the VR environment.

In the following sections, we describe the basic set-up of the system. First, we will introduce the three views for visualization of (3D) GIS data and next, we will describe the system components, data models and functionality in the system design section.

2 Views

Combining the three design stages and interaction modes with the different VR visualization techniques, we derive three modes for modelling and visualization, which we call 'views' (figure 2):

- Plan View
- Model View
- World View

First, we describe the visualization method and preferred display system for each view. After that, we look at the geometric representations of geographic data used in each of the views. Finally, user interaction modes are discussed.

2.1 Visualization and display

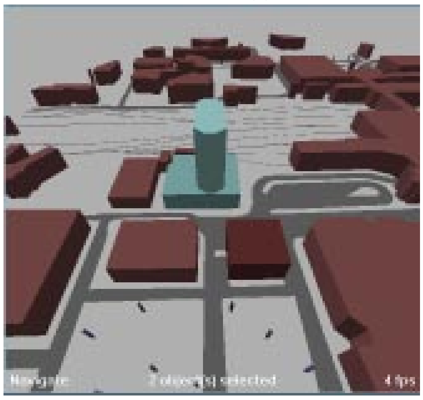
Plan View

In this view, geographic data are visualized in a conventional cartographic map format (figure 2a). Spatial objects are represented by 2D points, lines, polygons and symbols. Thematic data are visualized using standard text annotation and classification techniques. The plan view, as described here, is comparable to the visualization in most of today's GIS systems.

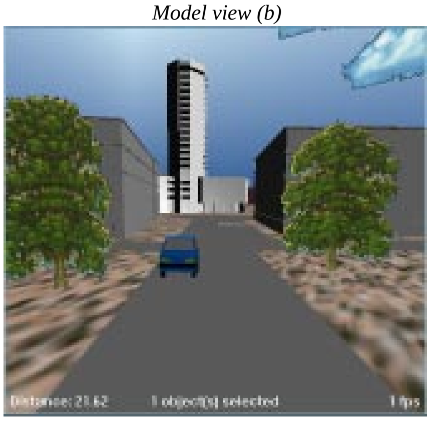
Model View

The model view offers a so-called bird's eye view on geographic data (figure 2b) which makes it possible to visualize 2_D and 3D data. Visualization in this view is kept simple and the user looks down on the model from the bird's eye viewpoint, as if it is an ordinary 3D-scale model. The resemblance between

Plan view (a)



Model view (b)



World view (c)

Figure 2. Different view modes visualizing a part of the centre of the city of Utrecht in the Netherlands.

the model view and an ordinary 3D-scale model is not just a coincidence. A 3D-scale model offers an overview on the area of interest, giving users the ability to make changes to the model without losing sight on the (overall) effects of these changes. Visualization in the model view is aimed at just that type of functionality: to let users 'model' their 3D geographic data.

World View

This is the immersive, first person view on the area of interest. The purpose of this view is to give a realistic impression of the changes in the landscape, using both visual and auditive output. The user can 'walk through' the geographic data, which are visualized using detailed 3D CAD models and textures (figure 2c).

For each view, there is a preferred display system. The plan view is most efficient on a monitor with window and mouse interaction. For the model view, a virtual workbench will be an appropriate display system (see figure 1a). The world view is best viewed with a truly immersive display. A HMD can be used, but display systems with surround projection, such as the CAVE are preferred (see figure 1b).

However, it would be very inconvenient to always have to change display system when turning to another view. Therefore, all views should be supported on all available systems. For example, it should be possible to open a window in the world view to display the plan view. Similarly, it should be possible to display the world view on a standard monitor, even if this would mean loss of stereo and sense of immersion.

2.2 Geometric representations

Each view has its own visualization features, and will consequently need its own geometric model representation. These representations range from 2D symbolic (plan view), to 3D realistic models (world view).

The plan view requires 2D symbolic representations that are defined in a (x, y) coordinate system, and are built up out of points, lines and polygons (areas). The model view relies on a 2_D geometric representation. The 2_D representation is actually just a 2D data representation, where each 2D point, line or area feature is given an additional 'height' value (z-coordinate). Only one z can exist at any (x, y) coordinate. That is why this geometric representation is called 2_D; in a real 3D coordinate space, any combination of (x, y, z) is allowed. To model the ground level, TINs (Triangular Irregular Networks) are used. True 3D objects can be represented by elementary 2_D building blocks (e.g. for houses, buildings and other constructions). Finally, the world view needs a very detailed 3D CAD model, enriched with texture maps and procedural models (e.g. to create vegetation, traffic and weather conditions). 2_D TINs can still be used to model the ground surface.

2.3 User Interaction

The three views require different ways to navigate through, and interact with the data. The plan view is best suited for specifying, selecting and exploring data. A user will be able to navigate through scrolling, panning and zooming or through browsing via hypertext links. The user interface will accommodate most features of today's GIS systems, using standard interface components like menus and icons.

The model view lets a user arrange infrastructure objects like buildings, roads and bridges. Therefore, objects can be grouped or organized in a hierarchy or layer and manipulated using relations and constraints. These relations, constraints, layers and other hierarchical structures will have to support manipulation and interaction. View point changes and navigation can be steered by gestures (using a data glove), real head movements or by using more conventional devices like a trackball.

In the world view, attention is directed to navigation and evaluation by 'looking at' the infrastructure objects and their surroundings. Because of the lack of overview, manipulation of objects is not considered useful in this view. The user's main activity will be navigating through the 3D scene from a first-person viewpoint, gathering information like object attributes and distance from the viewpoint. In an immersive VR environment, input devices like a data glove or 'magic wand' are preferred.

GIS functionality (i.e. analyses and queries) should also be supported in all views, although each view may have a specific way of interaction to select objects and to specify the query operators. For instance, in the world view, it would be most natural to have the symbolic (alphanumeric) information specified with a spoken-language interface, while in the plan view a more conventional interaction method may give a better user support.

3 System design

To realize the above-mentioned concepts, we are currently developing a 3D GIS & VR system called Karma VI, using standard GIS, VR and CAD components. In this section, we will present the system design by describing the system components, data model and system functionality.

3.1 Components

GIS

For the GIS, we have chosen for one central data server. This way, Karma VI can act as a client on the central data server in a client / server architecture and existing GIS applications can make use of the same data. Furthermore, data consistency and integrity can be maintained better if the spatial and attribute data are stored in one central database. In addition, many users can access the same data simultaneously.

We selected the Spatial Database Engine from ESRI (ESRI 1998) as our GIS data server. SDE is capable of storing and retrieving spatial and attribute data in a centrally maintained database built on open relational database management system (RDBMS) standards. We use Oracle (ORACLE 1998) as our RDBMS.

Karma VI is built as a client application on SDE and uses the SDE client library to connect to the server. On the server side are the SDE server process, the relational database management system, and the actual data. SDE uses *cooperative processing*, which

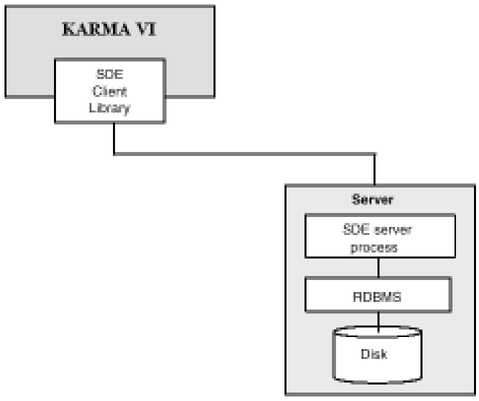


Figure 3. SDE architecture.

means processing occurs on both the SDE client library and the server, depending on which is faster (SDE 1997) (figure 3).

VR

For the VR-visualization, several modules are being developed to support the different views. These modules are developed using one VR toolkit. The modules run on all the available equipment, either simple monitors or more specialized equipment such as a CAVE or a Virtual Workbench. Each system is able to support all the views, using multiple screens if necessary.

We selected the WorldToolKit (WTK) from Sense8 (SENSE8 1998) as our VR toolkit. The WTK is a portable, cross-platform development system for visual simulation and virtual reality applications. The interaction and visualization features of Karma VI are built using the WTK library functions. For each of our target platforms (desktop workstation/pc, virtual workbench and CAVE), different user interaction modes and interfaces are required.

CAD

CAD model data are imported from external CAD-systems. At this stage, manipulation of the 3D CAD models will not be part of the Karma VI system. In the future, we might decide to add extra functions to be able to manipulate the 3D CAD data from within the system. Figure 4 shows the components and the different views

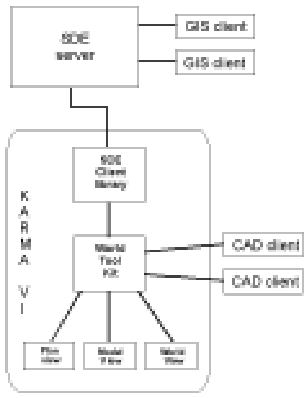


Figure 4. System components and views.

3.2 Data model

3.2.1 SDE

SDE is a continuous, nontiled spatial model for adding spatial data to a relational database management system. In a RDBMS model, data is stored in tables consisting of *rows* and *columns*. A row represents a particular occurrence, or instance, of a feature while the columns contain the attributes of the feature. Attributes can have many types, such as dates, text strings, or numbers. A geometric shape of a feature is another type of value, stored in a column that defines an abstract geometric data type (figure 5).

SDE stores geometric data and spatial indexes in separate tables, using a key in the shape column to perform a join. Geometric data (shapes) are stored as (x,y) coordinates. Points are recorded as a single (x,y) coordinate, lines as a series of ordered (x,y) coordinates, and areas as a series of (x,y) coordinates defining a set of line segments that have the same starting and ending point (figure 6). Shapes may be either 2-dimensional (x,y) or 2_ -dimensional (one z-coordinate for each x,y pair).

3.2.2 WTK

The data model used in the WTK is designed to support visualization and interaction of 3D models (WTK 1998). Geometric data, as well as other objects needed for visualization (e.g. light sources) are stored in a hierarchical 'scene graph' (figure 7). This scene graph consists out of different types of 'nodes', each having their own effect and functionality. For example, geometric data can be stored in a 'geometry node', and a 'group node' can be used to cluster several geometries (e.g. to store a multi-part shape). A 'level-of-detail node' is used to store several representations of the same object, ranging from simple to highly detailed geometry. Only one of these representations is visible at any given point, depending on the level of detail needed for visualization. Additionally, every node can also contain user-defined data (e.g. thematic attribute data).

3.2.3 Karma VI

As described in section 2, Karma VI uses three types of visualization: plan view, model view and world view. In the plan view, which visualizes the data as a

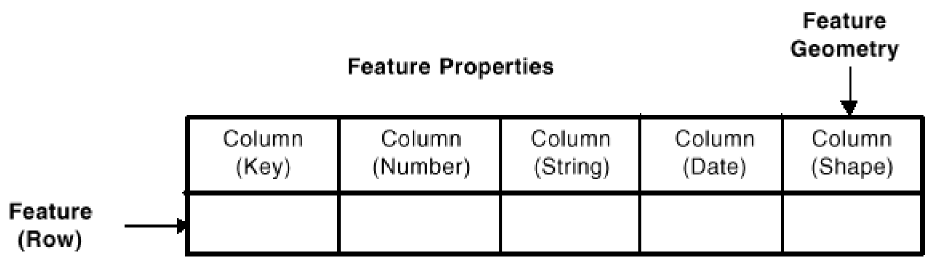


Figure 5. The relationship of a geographic feature to the relational model (SDE 1997).

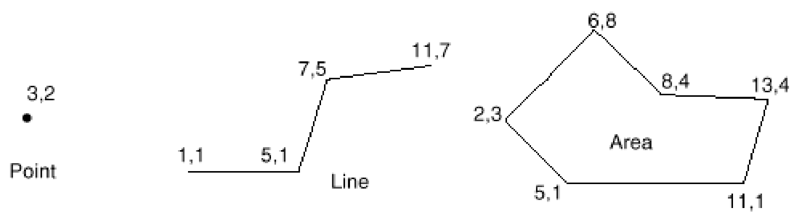


Figure 6. Geometric shapes in SDE (SDE 1997).

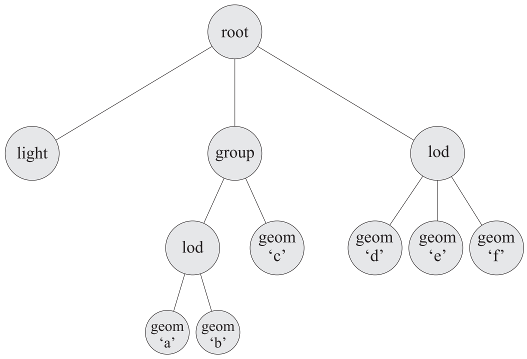


Figure 7. Example of a WTK scene graph.

conventional cartographic map, only 2D symbolic representations are required. In the model view, which provides a 3D bird's-eye view on the data, simplified 3D representations are necessary. The world view, which gives a full immersive and photo-realistic 3D display, requires 3D CAD models of GIS objects.

Each view uses its own geometric model representation of the data stored in the GIS database. Since all views use the same GIS data, consistency between the views is maintained. Karma VI is designed in such a way that it can handle all (2D as well as 2_D) shape types that can be stored in SDE. The shape coordinates, which are retrieved from SDE, are used to define the WTK geometries for the plan, model and (part of the) world view. Shape attribute data are used to correctly generate and/or display 2_D and 3D geometries.

For the plan view, 2D polygons are created from the 2D shape data. This is a straightforward task for area features. However, since geometries in WTK are built up out of polygons, point and line features have to be converted. Therefore points are represented by small triangles and lines are buffered. In the model view, these 2D polygons are extruded by one of their attribute values, creating 2_D geometry. For example, 2D polygons that represent buildings can be extruded by a 'height' attribute (figure 8). In the world view, the 2D polygons created for the plan view, are used to position 3D CAD objects. A 'height' attribute is used to define the height of CAD geometry (figure 8). The CAD objects are linked to the original GIS shapes using a separate table in SDE. In this table, the CAD model as well as its orientation and scale parameters are stored.

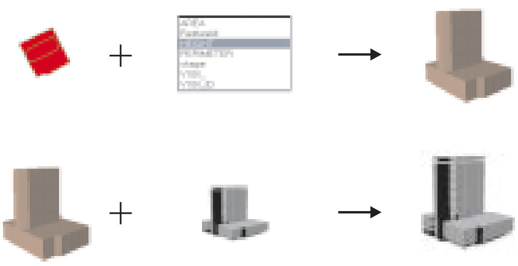


Figure 8. Creation of 2_D geometries from 2D geometries and an attribute value (top), and adjusting a CAD object's scale to match the generated 2_D model (bottom).

The different geometries needed for the views are stored in a single scene graph (section 3.2.2). Each shape is represented by a level-of-detail (LOD) node, which is used to cluster the 2D, 2_D and 3D geometry models (figure 9). The LOD node contains the shape's database key, and the center of its 2D geographic coordinates. The database key is necessary to enable both Karma and SDE to uniquely identify objects when communicating queries and results. Each of the geometry models is centered at the geographic coordinates stored at the LOD node. When moving one of the models, these coordinates are updated, thereby moving all models in real time. This way, simultaneously displayed views remain consistent at all times.

It is often the case that only a single CAD object is available, which represents multiple shapes in the GIS. Cutting up this object or making independent CAD models for each of the shapes is impractical. Therefore, CAD models can be shared by a number of different shapes. The CAD model is linked to each of these shapes in the database. The model's center is calculated by averaging the center coordinates stored in the LOD nodes of the shapes.

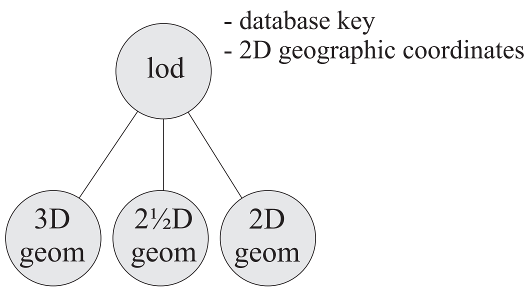


Figure 9. A Level-Of-Detail (LOD) node is used to cluster the different geometric representations of a shape.

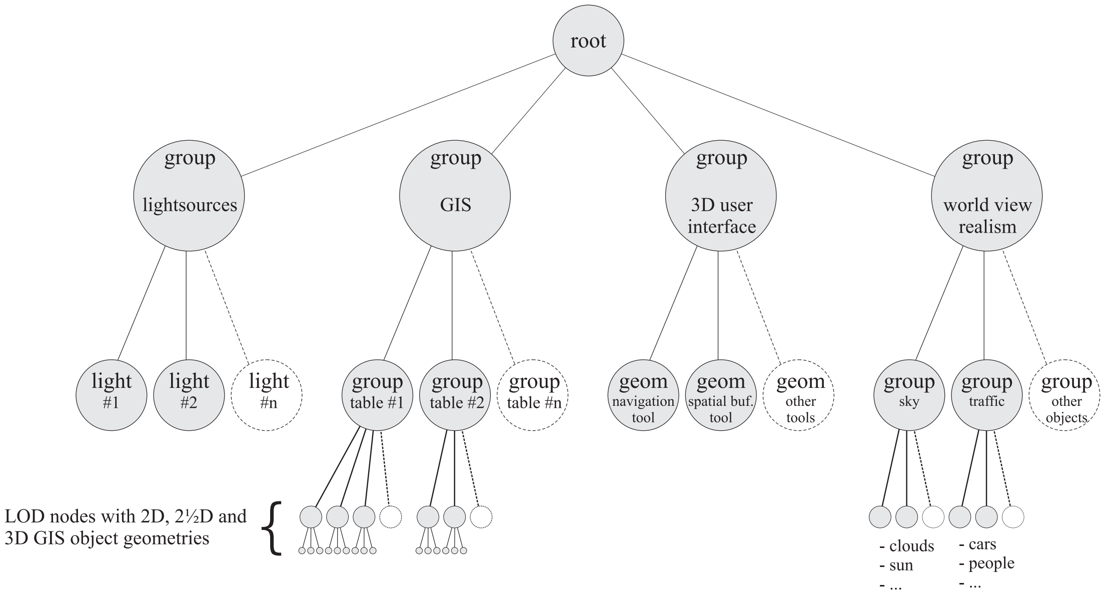


Figure 10. Basic structure of the scene graph used in Karma VI.

Finally, we will describe the basic structure of the Karma scene graph (figure 10). The root node of the scene graph is split up into four subtrees or groups, each having their own functionality within Karma. The 'GIS' group contains all loaded GIS tables, which in turn contain the LOD nodes with the three geometric representations. Next to the GIS data, several other items needed for visualization and user interaction are stored in the scene graph. First, one or more global light sources are added to adequately lighten the scene (contained in the lightsources group). In the near future, we will add a `3D user interface' group. This group will contain the 3D widgets to support virtual reality user interfaces on Virtual Workbench and CAVE systems, and to some extent also on desktop systems. To enhance the world view, some additional non-GIS related objects will have to be added to the scene graph, like clouds, people, traffic and vegetation. Some of these objects will have to be animated (e.g. clouds and traffic). Finally, some objects will have to produce sound (e.g. cars) to be convincingly realistic. These world view-specific objects are stored in the `World View Realism' group.

3.3 Functionality

Research (Verzijl, 1998) showed that specific functionality is required in the different stages of a design project. Therefore, each view mode has specific interaction possibilities, which are apt -but not necessarily limited to each view. Table 1 gives an overview of the three 'views' and the corresponding model representations and types of visualization and interaction.

3.3.1 Manipulation of GIS data

An important feature of the system is the support for manipulation and editing of GIS data from within the VR environment. Within Karma VI, several functions have been developed to be able to manipulate, model or analyse the 2D/2_D data directly via the different VR interfaces. The actual manipulation, modelling and analyses take place in SDE while the setting of manipulation / modelling / analysis parameters takes place in the VR environment. For example, when the user translates and rotates an object in the model view, only the transformation parameters are sent to SDE where the original data are updated. Since we are using a client / server architecture, it is also possible to edit and analyse the data with external GIS applications.

Until now, the geometry manipulation and modelling functionality has been kept simple and the development effort was focused on the total system design and the data exchange between the different modules (see fig. 4).

	Model	Visualisation	Manipulation	Selection	Analysis	Navigation
2D Plan	2D-GIS - topography - attributes	Cartographic	Create Remove Position Orientate	Query Position Distance Attribute	Buffer Overlay Network Neighbour	Pan and zoom Scale Specify position Scroll
2 1/2 D Model	2D-GIS *-topography* *-attributes* ***(extrusion)*** multi-TIN surfaces Relations	3D scale model Symbolic representation Handles References	Position Translate Scale Rotate Define relations	Relation Layer Group	Line-of-sight Contours Volumes Distance Shadow	View-point Centre of interest Zoom
3D World	3D-CAD polygons Textures Video	Immersive Realism Level-of-detail	Options Variants	Info Data Detail	Impact Sound Sight	Walk-through Move Pointing

Table 1. Functionality of the Karma VI system

3.3.2 Graphic Performance

Since geographic datasets tend to be quite large, problems arise when visualizing GIS data. Next to GIS data, even more detailed CAD data have to be visualized. Therefore, some optimization techniques have been implemented to ensure high graphic performance of our 3D-GIS & VR system. These optimization techniques include:

- Level of Detail
  This technique (which is directly supported by WTK) uses several geometries, which differ in the level of detail they provide. The geometries all represent the same object, but only one of them is displayed at any given time. Whenever a viewer gets closer to the object (and is able to see more detail), a geometry with a higher level of detail is selected. A lower 'level of detail' geometry consists of less polygons, and will therefore need less calculation time than a more detailed geometry.

- Dynamic Object Loading
  When detailed GIS or CAD objects are not visible (e.g. behind or very far away from the viewer), they are only taking up memory and valuable processor time. To minimize memory usage, these objects should be loaded into memory only when the viewer is close enough to see them.

  Additionally, leaving out (detailed) objects will also speed up graphic calculations.

4 Future developments

At this moment, a prototype of our 3D-GIS & VR system is operational on PC, Virtual Workbench and the CAVE. Basic geometry manipulation of the GIS data like translation and rotation is possible from within a virtual environment as well as basic GIS functionality like 'identify', 'spatial buffering' and 'query based selection'. In the near future, we will further explore 3D GIS functionality like 3D network analysis, 3D buffering and volume calculations. For the geometric manipulations and conversions, we will develop a constraint-based model to support 'intelligent' geometric manipulation.

Furthermore, we will continue to explore new optimization techniques like 'horizon mapping' to ensure high graphic performance of Karma VI. This technique uses 'horizon maps' (based on impostors (Schaufler, 1995)), which capture the horizon part of one frame, and re-use this part in consecutive frames. In a 3D virtual environment, objects that are far away show little detail, and have the same orientation towards the viewer during a certain number of successive frames. Furthermore, the relative screen distances (pixels) and sizes of objects near the horizon can be considered constant (because they are far away from the viewer) during several frames. When the user's orientation or position invalidates the current horizon map, a new map must be created. By replacing a (possibly large) set of objects by a small set of texture mapped polygons (one for desktop systems, more for CAVE systems), we can increase graphic performance.

Next to optimizing graphic performance, we will also have to further develop the user interface. The interface needs to be easy-to-use and intuitive. While this is not a big problem on desktop systems, on true VR systems like the Virtual Workbench or the CAVE, it is difficult to develop an intuitive (thus usable) interface. For example, in a CAVE, the use of a keyboard for text input is not possible. We may have to introduce speech recognition enable spoken commands, and develop a way to let users specify queries using a point-and-click interface. Furthermore, displaying alphanumeric results of a query in a 3D environment will be a problem, especially when a lot of information is returned. This information must be presented to the user in such a way, that the user does not loose his/her sense of immersion. This means that the information must only fill a small part of the user's field of view, or that the information is integrated into the 3D world (e.g. projected onto the walls of a virtual building). On the other hand, the information must be presented to the users in a clear way. Apart from textual in- and output, visual tools (3D widgets) will have to be developed to let users access the GIS functionality (e.g. 3D analyses, manipulation) of the system.

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