The application of Virtual Reality systems in architectural design processes

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Abstract

This publication describes the development and the application of a Virtual Reality system for the architectural design process. It is based on the results of research into Virtual Reality technology and in particular into the possibilities of a natural interface between a designer and a design system. This description is also based on the development of a laboratory set up for a "full immersive" and a "partially immersive" Virtual Reality application. This application offers a designer the possibility of modifying and assessing a 3D design model in "Virtual Reality" and is used in the course of several case studies. One of these case studies was the making of a presentation of a house design to possibly interested parties. The other case study was the use of Virtual Reality in the course of a design process. Finally this publication includes the description of some future and anticipated developments. The research problem is mainly posed by the questions regarding the ways in which the design process changes under the influence of amongst other factors the Virtual Reality technology. Other questions concern the ways in which the interface between a designer and a design system can be made as natural as possible, the way in which a design model can behave as autonomous as possible, and the way in which a representation can be made as realistic as possible. With regard to these the starting points were respectively the use of sensors, the definition of behaviour characteristics and the use of illumination simulations.

1 Presentation media and virtual reality at the Calibre Institute

From 1985 onwards, one of the main research areas of the Calibre Institute has been research and development relating to presentation media and Virtual Reality. The Calibre Institute is an institute for research and development in the area of information technology and automation in construction. Work has been carried out on presentation media and Virtual Reality but also on product and process models and in addition on the development of information systems and technology. By media, for the rest, is understood the means for the transfer of information and by technology is understood the operations of the equipment items which bring about a result.

1.1 Presentation media

The multi-functionality of 3D digital design models has been a focuspoint in research. This research, and the development work resulting from it, was angled on the use of as many different relevant presentation media as possible on the basis of a single design model. In the current situation at the Calibre Institute it is possible to use computer-generated (stereo) images, photo montages, (stereo) animation, holograms and Virtual Reality for design presentation. (Smeltzer, 1993), (Smeltzer, Roelen and Maver, 1992). With the research special consideration was given to the user-friendliness of the interface between the user and the computer system, to the modelling with the aid of components, to the 3-dimensional character of the design models, to the simulation of attributes of the model (such as material and colour), to the quality of the generated images and to the use of mono media (see figure 1 and table 1).

Figure 1: Media for design presentations

Table 1: Overview of media for design presentations

Medium	Basis	Addition	Presentation
Design sketch	geographic data	contract	reproduced

Medium	Basis	Addition	Presentation
Design drawing	geographic data design sketch	location and scale measure and scale	plot
Design model	geographic data design sketch design drawings	geometry attributes	computer screen
Design representation	design model	eyepoint, focuspoint, field of view, lighting	computer screen print

Medium	Basis	Addition	Presentation
Image Stereo-image	design representation	lay-out, format stereoscopic perception	computer screen print, slide, photo stereo viewer
Design drawing (generated)	design representation	drawing data (dimensioning, hatching)	computer screen plot, print
Scale model	design drawing or design representation	materials	touchable photo or video enthescope
Photo montage	geographic data design representation	photo- or video calibration data	computer screen print, slide of photo
Animation Stereo-animation	design representation	script, dynamics audio stereoscopic perception	computer screen videotape stereo viewer

Medium	Basis	Addition	Presentation
Hologram	scale model stereo images or stereo animation	holographic data number and size of strips number and location of viewpoints	holographic set-up

1.2 Virtual Reality

From 1991 work has been carried out in research into Virtual Reality, specifically on known Virtual Reality technologies such as sensors, head mounted displays, joysticks, control systems, computer-generated stereo animation and transputer-based computer systems. With this research special consideration is given to an interface which is as natural as possible, to modelling with objects, to design models which are as autonomous as possible, to the simulation of operations on objects, to representations of the model which are as realistic as possible and to the use of stereo media.

The big difference between presentation media and Virtual Reality is determined by the use of the representation. Presentation media can reproduce a design model with the aid of a representation which has been worked out beforehand, whilst Virtual Reality can be used in order to perceive the model oneself by means of a representation which is worked out on the spot and at once (in real time). With the use of presentation techniques the emphasis is on the presentation of a design while in the case of Virtual Reality the emphasis can be placed on the evaluation of the design. This is why presentation techniques are discussed in terms of a target and a targeted group whereas of Virtual Reality is discussed in terms of a result, the design model in Virtual Reality, and a user.

1.3 Virtual Reality in construction

In relation to the research into Virtual Reality the assumption was that this technology should be able to make a contribution to the construction industry. Through the use of a simulation of the behaviour of a design model, replacing for example rules of thumb, the problem-solving capacity of the designer can be increased. This must be able to lead to an improvement in the quality of an architectural design. The use of 3D design models, for an efficient exchange of data during the design process, must lead to a reduction in the route to a satisfactory design. This means that a contribution can be made to the improvement of productivity in relation to the architectural design process. The use of a simple user interface, such as is possible in the case of Virtual Reality, should contribute to the quality of the design, the productivity of the design process and also to an improvement in working conditions. (Smeltzer, 1994)

The research into the use of Virtual Reality in construction should also be able to make a contribution to an improvement of the theories, technology and applications of Virtual Reality. Here the construction industry has quite specific requirements. With regard to the subject of interfaces, the construction industry has quite specific requirements because those involved in construction range from lay people (principals, consumers) to specialists. With regard to the use of models, digital models of buildings are of great importance owing to the lack of other types of prototypes. Finally, with reference to the representation of these models specific requirements are set because construction is so close to everyday reality for everyone.

Owing to the importance of the interface, the model, and the representation, these subjects have gradually become included within the research into a Virtual Reality system concept. This concept, the technologies which are used, the applications which have been developed and the influence on the architectural design process have been researched in the course various case studies. These case studies resulted in an example of an architectural Virtual Reality demonstration. This demonstration makes it clear that Virtual Reality is already able to play an important role within the construction industry.

Before proceeding to a description of the demonstration, first consideration has to be given to the content of the Asterisk I project, the system concept which has been developed, the case studies and the current situation with regard to the Asterisk Virtual Reality system.

2 The Asterisk I project

The Asterisk I project includes research into the applicability of Virtual Reality or multimedia 3D real time simulation technology, within the architectural design process. The aim is to be able to use this technology to arrive at a "natural" interface between a user and a design system. The project thus tries to make a contribution to the realisation of a (virtual) bridge between the information technology and the construction.

For this project use is made of literature, participation in conferences and fairs, experiments and the system components and documentation from the participants Autodesk and Sun Microsystems.

2.1 Setting of Target

The final target was to arrive at a laboratory set-up for a Virtual Reality application. This set-up should be used for follow-up research into the practical applicability of the technology in the design process and into the psychological, ergonomic, economic and technical feasibility of an application of this type. Within the overall context of the research this feasibility research should be followed by the development of a prototype for a Virtual Reality application which is to be finally developed. It must be possible to use this prototype for demonstrations and a market introduction.

The following targets were set for the first research and development project: the development of a laboratory set-up and the application of Virtual Reality technology, the development of modelling possibilities for use in a Virtual Reality environment, the development of a (real time) simulation with a (photo)realistic representation of the design model.

Simultaneous with these developments, achievement of the following was sought after: the integrated use of digital (audio-visual) information, the possibility of simultaneous usage by several participants in the design process, open architecture, which is required for the integration of new information technology, generic results by means of the use of application-dependent functions and a separation of structure and data.

2.2 Statement of problems

The research problem is mainly posed by the questions regarding the ways in which the design process changes under the influence of Virtual Reality technology. Other questions concern the ways in which the interface between a designer and a design system can be made as natural as possible, the way in which a design model can behave as autonomous as possible, and the way in which a representation can be made as realistic as possible. With regard to these the starting points were respectively the use of sensors, the definition of behaviour characteristics and the use of illumination simulations.

The development problem is posed by the question regarding the way in which a laboratory set-up, in co-operation with a national establishment of a supplier of hardware (Sun Microsystems Nederland BV) and a supplier of software (Autodesk Benelux BV), can be developed. In order to do this, use has to be made of their system components, such as workstations and CAD software. Another problem for the development of the laboratory set-up is the way in which the Virtual Reality project could be enabled to use technology which was still not yet generally available.

2.3 Approach

The project consisted of a research and a development component. During the project the emphasis came to lie more clearly on the development and on the practical applicability of the results. The project began in January 1993 and is completed in May 1994 and it consisted of the following main sections:

2.3.1 Reference design process

The description of a reference design process (modelling process) in relation to Virtual Reality technology and the formulation of the functional requirements for the design system;

2.3.2 Functional characteristics

The defining of specific functional characteristics of system components, such as software and (peripheral) hardware for the design system and for the subsystems. The emphasis here is on the answering of the question of what can be possible;

2.3.3 Subsystems

The defining and the development of subsystems consisting of an interface (ergonomics, participants in the design process and design systems), software (programming technology), hardware (visualisation techniques) and data bases (the design model, design presentation);

2.3.4 The programme of requirements

The determining (and evaluation) of a functional and technical program of requirements for the laboratory set-up and for the subsystems which belong with it. Here the emphasis is on the answering of the question of what has to be possible;

2.3.5 Laboratory set-up

The realisation and integration of a working laboratory set-up, on the basis of available hardware, software and data bases. This set-up is to be used for possible case studies and for follow-up research into the feasibility of a similar design system.

2.4 Results

The result of the Asterisk I project consists of a description of a reference design process in relation to new technology. The result of the Asterisk I project furthermore consists of three subsystems. The first subsystem, DynaCAD, is a system for the modelling of architectural designs. The second system, Rayder, is a system for the simulation of illumination situations. The third system, CALView is finally a system for the perception of these results. This system can, as appropriate and in combination with DynaCAD also be used for the modification of the design model. These subsystems are in the end integrated into a laboratory set-up on the basis of a programme of requirements.

2.4.1 Description of a reference design process in relation to new technology

The reference design process in relation to new technology is in the current project defined by three main characteristics.

The first characteristic is the cyclic and iterative nature of the design process with respect to the design activities analysis, synthesis, evaluation and presentation (Lawson 1990, Boekholt 1984). This aspect imposes the desirability for the following possibilities with respect to new technology:

- the integration of ascertainments from a design problem analysis in design algorithms
- the generation of several relevant design variants in a short time span, if relevant, based on design algorithms
- evaluation of design variants on several qualitative (e.g. illumination effects) and quantitative aspects (e.g. volume, costs)
- presentation of 3D design models based on ascertainments from previous design activities.

To attain an efficient design cycle, results from each design activity must be passed on to successive activities without loss of relevant information.

Related to the use of design algorithms in design activities is the primary generator. The primary generator is related to the use of design algorithms in design activities. Rowe (Rowe 1987) describes the use of a primary generator as follows: "..several distinct lines of reasoning can be identified, often involving the a priori use of an organising principle or model to direct the decision making process". From this point of view, primary generators can play a key factor in the design decision making and are worth investigating in relation to the applicability in new design media. They could be used for an automated generation of design variants based on design knowledge, design constraints or, for example, random generators, thus establishing the possibility to perform creative sessions, comparable to brainstorming.

The second characteristic is the increasing level of detail of the design concepts as the design process evolves. This characteristic should be integrated in the design system by allowing the user to perform design activities with a variable level of detail. Design algorithms can be used to manifest this characteristic. Making the level of detail of design activities variable has the advantage that design variants with too much detail are avoided with respect to the stage of the design process, thus contributing to the optimalisation of the evaluation of design variants.

The third characteristic is related to the use of design media for presenting and expressing design concepts. Where the design problem has a strong spatial nature, traditional media, like pencil and paper, lack this spatial nature. New technology can contribute to the development of design media that reflect the spatial nature of the design problem and successively improve the evaluation of design decisions with respect to the perception of space and shape.

Sketching as a way to express design concepts has proven to be a powerful technique (Scrivener et al. 1994, Porter 1978, Oxman 1990, Oxman et al 1992). In the development of new design media, the application of the technique of sketching should therefore be strived for. In order to achieve a design medium with a spatial nature, the technique of solid modelling and the related Boolean operations is another item that preferably needs to be applied in new design media. The technique of solid modelling is an optimal method for defining spatial objects. With this technique spatial objects can be defined by surface and by volume, offering all necessary information needed for an optimal perception of space and shape. Further, the related Boolean operations have a strong analogy with operations using spatial 'real world' media, like clay and wood. Therefore the use of Boolean operations can contribute in the awareness of the user with respect to his modelling activities and contribute to the development of user-friendly design tools and interfaces.

The development of new design media in which the techniques of sketching, solid modelling and the use of Boolean operations, design algorithms and primary generators are applied and integrated, will combine the qualities of both traditional media and new technology.

2.4.2 The DynaCAD subsystem

The DynaCAD subsystem contains a number of tools with which 3D design models can be modelled. The 3D design models can be prepared for multimedia presentations in DynaCAD itself, illumination simulations and representation in Rayder, and for perception and model modifications in CALView.

The interface of DynaCAD reflects the reference design process. This has resulted in a menu structure in which the design tools are grouped based on the analysis-synthesis-evaluation-presentation design process model.

The development of the modelling tools has focused on attaining a natural, dynamic and intuitive interface. This is done by applying certain metaphors and analogies with real world situations, combining different modelling operations in a single tool (e.g. combining moving, rotating and copying), and combining drafting and modelling techniques, like sketching, solid modelling and modelling using design algorithms, in a single operation.

The dynamic characteristic of the modelling tools is attained by applying event loops. These event loops offer the possibility to generate a continuous flow of data that is used for giving a continuous feed back to the user and for a continuous evaluation of the outcome of the modelling operation. Further, event loops offer the possibility to modify modelling parameters continuously during modelling operations, which enables the user to generate and evaluate various variants in a short period of time.

DynaCAD contains various tools to prepare the 3D design model for Rayder and CALView. These tools allow the user to:

- define multiple and overlapping parent-sibling-child relationships between geometrical components of the 3D model (CALView)
- attach attributes to components of the 3D model, like gravity, translation and rotation constraints, collision detection and collision sounds (CALView)
- define walkthrough paths (CALView)
- define material properties of components of the 3D model (Rayder, CALView)
- define lightsources (Rayder, CALView)
- export the 3D model to Rayder and CALView, inclusive all non-geometrical data stored in the 3D design model

The system components on which DynaCAD is based, are AutoCAD R12 for Solaris 2.3 and Sun SPARCstation, and the programming environments AutoLISP and ADS.

2.4.3 The Rayder subsystem

The Rayder subsystem is used for generating a 3D illumination simulations model based on a 3D design model. The illumination simulation model can be perceived in real time with the subsystem CALView , thus attaining a realistic representation of a 3D design model.

Rayder offers the possibility to import 3D design models created with DynaCAD and all other 3D models in DXF-format. Once imported, the user can modify and prepare the 3D model for illumination simulation using tools with which the user can modify the geometry (move, rotate, delete, scale, etc.), change the face normal direction of planes, define and modify light source definitions and material properties, and increase the vertex density in the model via meshing or discretisation.

The illumination simulation algorithm is based on a combination of beam tracking, radiosity and ray trace techniques (Kirk, 1989, Kok, 1991), and results in a realistic representation of the 3D design model. In defining the simulation process model, emphasis has been placed on finding a balance between the level of realism of the representation and the duration of the simulation calculation, thus enabling the user to generate illumination simulation models in a reasonable time span, depending on the complexity of the 3D design model.

The illumination simulation model can be stored in a special data format, that describes the geometry, non-geometrical attributes and the illumination characteristics generated by the illumination simulation. This data format can be imported in the subsystems DynaCAD and CALView.

A second possibility to store the result of the illumination simulation is via bitmaps. Rayder offers tools to render the 3D model and store the result in the bitmap format Targa, TIFF, GIF or Postscript.

Rayder is based on the illumination simulation program DIM, developed by Abacus (University of Strathclyde, Glasgow), LIDAC (Philips Eindhoven) and Calibre (Eindhoven University of Technology) and developed for Solaris 2.3 and Sun SPARCstation, and as a MS Windows application for PC's, both in programmer's language C.

2.4.4 The CALView subsystem

The CALView subsystem is used for three purposes.

- The first purpose is to attain a real time stereoscopic perception of the representation of a 3D design model created by DynaCAD and Rayder.
- The second purpose is to offer the user a natural and user-friendly interface for interaction with the 3D design model, e.g. walkthroughs.
- The third purpose is to offer the user possibilities to perform model modifications in the 3D design model via a natural and user-friendly interface.

One of the main features of CALView is the possibility to perceive real time an illumination simulation model created by the subsystem Rayder. Because illumination characteristics are stored per vertex of the 3D design model, it is possible to view the model from any point of view without having to recalculate the illumination effects on the surfaces of the model. This enables real time interaction with the simulation model.

Besides rendering of the 3D design model using vertex colours, rendering can also take place using facet colours. This offers the possibility to perceive different representations of the 3D design model and allows to perceive 3D design model without the necessity to perform an illumination simulation calculation in a situation where the emphasis of the evaluation of the 3D design model lies on the form, more than on illumination effects. Therefore, a 3D design model created by DynaCAD can be imported and perceived directly, skipping the Rayder operations and using the material and light properties defined in DynaCAD.

Another feature of CALView is the possibility to perform model modifications, like repositioning, scaling, moving and rotating model components. The awareness of the user of his operations is supported by real time visual feedback and auditive feedback (e.g. collision sounds). The 3D design model, modified within CALView, can be stored and exported to Rayder and DynaCAD, thus attaining an full integration of the three subsystem in the laboratory set-up.

The quality of the perception of the 3D design model is determined by the completeness of the design model and the representation, with respect to the level of detail and realism and correctness of behaviour. In order to achieve a high quality perception, CALView is able to process real time illumination simulation models with a high level of geometrical detail and with various behavioural characteristics defined in DynaCAD, like gravity and collision sounds.

The ergonomics and user-friendliness of the interface of CALView are crucial for optimal perception of the 3D design model. All input and output devices therefore have to support the real time aspect of the design environment, the 3D nature of it, the strive for realism and the multimedia characteristics.

The development of the interface of CALView has taken place in two system configurations which can be specified as partial immersive Virtual Reality and immersive Virtual Reality.

Partial immersive Virtual Reality uses true colour stereo images that can be perceived using shutter glasses and are projected on a monitor screen or large screen.

Besides visual output, high quality auditive output is possible using integrated audio facilities like speakers and headphones.

Input devices used in stereo Virtual Reality enable the user to manipulate eye or camera properties (position, direction and the field of view) and to perform model modifications. Integrated in the subsystem are two 6DOF input devices to support these operations and can be used simultaneously using both hands. This offers the possibility to walk through the model and modify the model at the same time (e.g. carry model components around).

Partial immersive Virtual Reality is especially effective if the emphasis is on the design objects and high visual quality is desired. Therefore, a comparison can be made with working with scale models or mock-ups. Immersive Virtual Reality systems also make use of true colour stereo images, but these images can be perceived using a head mounted display (HMD). Via stereo headphones, that are integrated in the HMD, the visual output can be supported using high quality auditive output. Input of data for manipulation of position and orientation of eye and hand is done using sensors on HMD and 6D joystick. Via a Polhemus tracking device, the sensor on the HMD is used to determine the position and direction of the eye, the sensor in the 6D joystick to determine the position and orientation of the user's hand. Both manipulations can be performed simultaneously, also giving the possibility to walk around and perform model modifications at the same time. Immersive Virtual Reality is especially useful in situations where the emphasis is on presentations and less on visual quality, comparable with working with a 1:1 model or prototype. CALView is based on two sets of system components.

The first set is based on the full immersive Virtual Reality system Division ProVision 200, which uses Divisions 6D joystick, a Head Mounted Display from Virtual Research and Polhemus tracking devices.

The second set is based on a Sun SPARCstation 20 with ZX Graphics Accelerator from Sun Microsystems, and further CrystalEyes StereoGraphics shutterglasses, a Logitec 3D Mouse and a Space Mouse from Space Control, establishing a partial immersive Virtual Reality system or stereo Virtual Reality system.

2.4.5 The Asterisk 1 System

What is referred to as the Asterisk I system is in fact an architectural Virtual Reality application which has been developed on a certain platform. This development is based on results of earlier research, such as a description of a reference design process, developed subsystems, a system concept, the use of these subsystems in several case studies and a program of requirements. In the main the development of the system consisted of two phases which were realised more or less in parallel. What is involved here is the setting up of an integrated program of requirements and the realisation of a final laboratory set-up.

2.4.5.1 Programme of requirements for the laboratory set-up

The programme of requirements for the laboratory set-up is determined by the functional and technical specifications of DynaCAD, Rayder and CALView and the integration of the subsystems in the laboratory set-up.

DynaCAD must enable the user to create effectively usable 3D design models and should contain tools with which the user can model a 3D geometry in a dynamical and user-friendly manner. These tools should, if possible, be based on event loops, thus attaining a possibility to create dynamic tools in which different operations can be combined. These operations should be based on a sketch approach, solid modelling techniques (Boolean operations) and design algorithms, preferably in combination. Where possible, multimedia feedback should be applied in the interface design.

Further, DynaCAD must contain tools to add non-geometrical data to the 3D design model. This non-geometrical data is necessary to prepare and extend the 3D design model for usage in Rayder and CALView and for usage as a multimedia presentation model. Therefore, non-geometrical data should define the following features:

- multiple and overlapping parent-sibling-child relationships for usage in CALView
- behaviour attributes like gravity and collision sounds for usage in CALView
- material and light source definitions for usage in Rayder and CALView

To attain an optimal integration, DynaCAD must be able to store the model in data files that can be processed by Rayder and CALView and that contains both geometrical and non-geometrical data. DynaCAD also must have the possibility to read these data files to attain a bi-directional linkage with the other subsystems.

Following the composition of the project team and the strive for integration, the development of DynaCAD will be based the system components AutoCAD R12 for Sun SPARCstation 10 and Solaris 2.x and the programmers environments AutoLISP and ADS.

Rayder must enable the user to generate a realistic representation of a 3D design model via illumination simulation. Rayder must contain tools that enable the user to import 3D design models created by DynaCAD, define and modify material and light source definitions, and generate an illumination simulation model using a combination of beam tracking, radiosity and ray trace techniques that is a photo-realistic representation of the 3D design model.

Integration with DynaCAD and CALView should be achieved by the possibility to store the illumination simulation model in a data file that can be processed by the other subsystems.

Rayder must be based on the system components Sun SPARCstation 10 and Solaris 2.x and the programmer's language C.

CALView must offer the possibility to attain an interactive perception of the 3D design model created by DynaCAD and the illumination simulation model created by Rayder. Further, CALView must enable the user to perform model modifications within a real time 3D environment. These operations must be performed via an interface that is as natural and user-friendly as possible. This must be attained by using multimedia feedback, 3D/6D input devices and by avoiding the usage of keyboards and 2D mice. Input of non-data via voice recognition applications is preferred.

To attain a high quality perception, CALView must be able to process 3D models with a high level of detail and be able to generate a minimum of 10 true colour stereo images per second with a resolution of at least 640 by 480 pixels.

Model modifications should be possible by performing moving, rotating, erasing and scaling operations on model components and should be supported by real time visual and auditive feedback and behavioural characteristics to attain an optimal awareness of the user with respect to his operations. CALView must be able to store the model modifications in data files that can be processed by the other subsystems and recall older design concepts.

By touching design model components, CALView must be able to process external multimedia reference data using the links defined in the subsystem DynaCAD. Therefore, software to process multimedia data must be integrated in CALView.

Following the composition of the project team and the strive for integration, CALView will be based on the system components Sun SPARCstation 10 and Solaris 2.x, the graphical function library XGL and the programmers language C. Further, the interface will be based on the system components CrystalEyes StereoGraphics shutterglasses, a Logitec 3D Mouse and a Space Mouse from Space Control. The projection of the stereo images must take place using a true colour high frequency monitor or a large screen and a high frequency video projector. Together these components will result in a partial immersive Virtual Reality system.

2.4.5.2 Realisation of laboratory set-up

In order to be able to perform the operations modelling, simulation and perception using 3D design models and illumination simulation models within a single laboratory set-up of a design system, DynaCAD, CALView and Rayder have been integrated in the workstation Sun SPARCstation 10. For the optimal exchange of results of the subsystems, a special data file format has been developed, called the CAL-format which can contain geometrical and all non-geometrical data specified in the three subsystems.

Integrated in the interface design there are links from one subsystem to the other, enabling an easy-to-use circulation of results and thus an efficient design cycle and quick evaluation operations of divergent nature.

The system components for input of data all support the 3D characteristics of the design environment and the strive for an ergonomic and user-friendly interface, allowing even inexperienced users to perform relevant operations.

In order to attain a relevant, easy to use demonstration of a design proposals, tools have been developed in DynaCAD, with which inexperienced users can model relevant 3D models of office interiors, using a 3D component library. The 3D design model contains automatically all relevant data, geometrical and non-geometrical, for an efficient illumination simulation by Rayder and an efficient perception by CALView. Together these operations will instruct the user in a short time span about the possibilities and limitations of Virtual Reality technology.

In the realisation of the laboratory set-up two significant problems can be distinguished.

The first major problem was lack of software for the integration of (a combination of) 6D input devices. Effort had to be put in establishing this integration, with a relative low effect on the progression of the development of the laboratory set-up itself.

The second major problem was the lack of an existing 3D real time simulation environment on top of which specific applications can be developed. The realisation of the laboratory set-up therefore had to start from scratch, resulting in a time consuming and extensive development of a basic 3D real time simulation environment in preparation of the development of the actual design system applications.

2.5 The Asterisk I Project; retrospective

The Asterisk I project has led to a number of clear results. The project includes, as has already been stated, research into the applicability of Virtual Reality simulation technology within the architectural design process in order to attain a natural interface between the user and the design system. Different aspects are then to be treated in succession.

In order to acquire a theoretical foundation for the functional requirements and the technical possibilities there has been research into the literature on the subject. This research has mainly concerned the design theories, methods and technology and the situation with reference to (multi)media, and in particular "Virtual Reality" technology. In order to attain an insight into the state of affairs several (inter)national specialist fairs and conferences have been attended.

An "incremental development approach" has been selected for the design and the development of the various components of the laboratory set-up which has to be produced. That is to say that a functional laboratory set-up was being worked towards with the aid of the integral design and development of various components. At the same time the actual development of the system components served as the mainspring of the obtaining of specific knowledge with reference to the designer as user, the use of (multi)media in design systems and the interface between the user and the design system. By means of various presentations and the carrying out of practically-oriented projects different situations of the system components have been demonstrated and tried out. Finally the research and development work has led to a theoretical system concept of, for example, the Virtual Reality applications which were under consideration.

With reference to the applicability of multimedia real time 3D simulation technology within Virtual Reality and the architectural design process, examination of this has been limited merely to the use of this technology by a designer during a design process. The emphasis is on the development of a design system with an interface between the user and the system which is as natural as possible. This design system strictly speaking has to be suitable for the generation of design situations, for the evaluation of these and for the presentation of the results. As per the specification of these possibilities dynamic modelling has been selected to be a part of the generation of design proposals. This has resulted in DynaCAD. In addition, the simulation of light and colour effects has been selected as a part of the evaluation of designs. This has resulted in Rayder. Finally the most interactive possible method of perception of design concepts has been selected. This resulted in CALView.

Multimedia technology is used for the simultaneous addressing of the different senses in order to intensify the perception of for example the design models. What is being attempted is the simultaneous use of audio and video, mono, stereo and immersive, 2D, 3D and 6D and also of buttons and sensors (for the registration of natural movements). In a subsequent project what will then be attempted will be distributed use. In that case the compression and the decompression of the design states or transitions will be of particular importance.

A Virtual Reality process requires a minimum of a 3D space and the possibility of defining 3D models. Other research was carried out into the temporal aspects of architectural design models. (Smeltzer, Dijkstra, 1993) (Smeltzer, Dijkstra, 1993). This research led to the possibility of associating both retrospective and prospective temporal aspects to model components and should lead to a first version of a truly 3D design system.

The real time character of the system has above all been associated with the simulation of light and colour effects, of the consequences of changes in the situation of the design model and of the effects of movements of the user. The efficient and effective use of the correct system components has meant that the deceleration which occurs in the representation of the design model when changes take place has been brought back to an acceptable level. Further investments in hardware are necessary in order to obtain true real time performances. In terms of the research this has been given a lower priority for the time being.

Simple visualisation programs are not adequate in order to attain the simulation of for example light and colour effects. Therefor, in consultation with Philip Lidac and on the basis of the DIM program of Abacus (University of Strathclyde, Glasgow), special software has been developed in order to attain an accurate simulation of these light and colour effects. The program has undergone further optimalisation in order to attain a real time simulation.

Above all, with reference to the nature and the extent of the test and demonstration models, in this project consideration has been given to construction as the area of application. The design models have still been limited to models for the establishment of the definitive design. More detailed models are, owing to the technical possibilities of the current set-up, not being researched nor are required. With reference to the design process, in which the design system finally has to be applied, the starting points are the dynamic character of the design process, of the design modelling and of the designer as the user of the system.

The indication "naturally" is above all used to designate the possibility of being able to give tasks to the design system with the aid of ordinary movements instead of complex commands. This above all concerns here the commands for the changing of image variables, such as viewpoint and/or eyepoint and for the manipulation of design objects, such as the location of an item of equipment or of the dimension of a wall. The use of speech (voice input) may be added to that of ordinary movements.

With reference to the interface what is being sought is the "overlapping" of the designer as the system user and the design system as the exponent of the design model. Virtual Reality technology provides this possibility in principal and for this reason serves as the point of departure for the laboratory set-up which is to be produced.

The designer does not play an active part in the picture until a later stage. Until this time a "user" will suffice. The design system is finally to be presented as a starting point for a prototype, or else as what is referred to as the laboratory set-up. This set-up is then to be used in order to research the feasibility of the design system which is finally envisaged.

3 Case studies

During the research work a relatively high level of consideration was paid to the technical aspects. In order also to be able to give due consideration to the application aspects grateful use was made of the projects which were being carried out at the Calibre Institute. Two representative projects will be discussed in the following as case studies.

3.1 Presentation of a design for a house

The first case study was the development of a Virtual Reality presentation of a housing project. This presentation was in the first instance aimed at people who had an interest in the project. Besides these naturally people who really only had an interest in Virtual Reality also came. The presentation was announced as being a first Virtual Open House. Every interested person was able to walk through the 3D design model and move the furniture and fittings. During this case study consideration has been given to the relationship between the interfaces which exist between the user and the system, the level of detail of the model and the speed of the representation.

On the basis of the usual design drawings, such as ground plans, facades and sections, a 3D computer model was produced with DynaCAD. Intensive consultation with the architect was necessary in order to determine the level of detail of the model, the colours and the textures of the materials which were to be used. First of all account had to be taken of the possible performance of the available full immersive Virtual Reality system. This performance can for example be measured in terms of the number of possible polygons (plane surfaces) in the model with respect to a minimum number of images per second. In order to attain a acceptable visual output for perception a minimum of 12 images per second is necessary. This performance could be attained for a maximum of 20,000 polygons.

After the model had been completely integrated the possibility existed of dividing the model up into several submodels. Within the final Virtual Reality application the users should also be able to make use of modelled special doors and staircases in order to go from submodel to submodel or from room to room. Through the use of these submodels and doors the different rooms could be provided with suitable furniture and fittings, without the performance of the system falling below the minimum level.

In consultation with the principal and the architect the representation based on a simulation with Rayder was assessed. After several adaptations to the model, the functionality of the system was tested before it was to be used by possible interested parties. Finally various illustrative sounds were linked to the design model which could be made audible in certain pre-programmed cases.

For the presentation of the design of the house the whole system was accommodated at a special location, which was in fact where it was supposed to be built in reality. There was great interest in the presentation which had been announced as a Virtual Open House. Part of this interest was naturally in the house itself, and part of it was in the new technology which was being demonstrated. Interested parties got the opportunity to look round the house which was standing around them with the aid of the head mounted display and also walk around it with the help of the 6DOF mouse. In order to make the presentation more attractive the users were able to move several items of furniture and also to pick up various articles.

The Virtual Reality application was delivered later than planned, due to design problems but especially due to several technical problems,. The presentation was however enthusiastically received and favourably judged by the principal (the Innovatiecentrum Alkmaar and Espeq training centre for construction), the designer (Architectenbureau Zeeman), interested parties, journalists and TV and radio.

3.2 Evaluation and presentation of a design

The second case study was the use of Virtual Reality during a design process. The system was used for the evaluation of visibility and safety aspects for another housing project. The use of the system was initially only aimed at the designer and the principal. Based on their evaluation of the design in the end different design modifications were effected. After this the system was also used for internal presentations, of applications as well as of technology. This application for the evaluation and presentation of an architectural design has been developed for a full immersive and a partial immersive system.

The problem which played a part during this study was first and foremost a design problem and a technical problem in the second instance.

On the basis of design drawings and a mock-up a 3D computer model of the building and their immediate environment was produced using DynaCAD. The emphasis here was on the exterior of the buildings and on the designed underground parking provision since the principal and the designer were to investigate some of the safety aspects of this parking provision. In doing this they wanted in particular to evaluate the possible visual monitoring of the parking provision area and of the path between the parking garage and the houses. This meant that consideration had to be given to the lighting of the open spaces and to the mass of the construction and to the facades of the buildings.

During the modelling these visual and safety aspects were taken into account as much as possible. Furthermore account was taken of the possibilities and the limitations of the Virtual Reality systems which were finally to be used. In doing this consideration had to be given to the possibility of looking at the model overall and also to the limitations with regard to the scope of the whole model. The exterior model could not, be divided up into several submodels owing to the lack of enclosed rooms with for example doors between these rooms.

The computer model was provided with colour, texture and lighting characteristics and was converted for use in the full immersive Virtual Reality system. The principal and the designer had control over the modelled design. This study led to the situation where several suspicions with regard to consequences of some design decisions were confirmed. On the basis of this, definite design modifications which had been made up until that point were implemented. The main point was that several independent areas for the storage of refuse containers which figured in the plan were moved so that they were further away. By experimenting with the technology and by means of chance several other discoveries resulted, which led to some changes of details during a design process. Virtual Reality had made a contribution to the quality of a design solution.

Following the use of Virtual Reality for the evaluation of design solutions, several more presentations were made for the employees and relations of the principal. For this, amongst other things, an interior for one of the houses was modelled and added. This meant that the new model was also converted for use within the partial immersive Virtual Reality system. This possibility of putting the two types of Virtual Reality system next to one another in practice for once raised interesting questions both for the research and for the presentation itself. The immersive system, with the head mounted display was compared with a maze and the partial immersive system, with the stereo image and the stereo glasses was compared with a (hologram of a) scale model. The full immersive Virtual Reality was required for the evaluation of the design without anything more. Partial immersive Virtual Reality appeared however to be already fully adequate for the presentation of the design, and thus for the application.

3.3 Other possibilities

Virtual Reality is however not only to be used for the evaluation or the presentation of for example architectural designs. It can for example also be used for the equipping of an office. After an area for an office has been modelled and a selection of certain equipment items has been made it is possible for example to investigate different variations relating to this equipment. Virtual Reality should eventually also be able to serve as a substitute for and an improvement of showrooms where it is only possible to show and set up a limited number of bathrooms, kitchens, or cars. Virtual Reality can also play an important part in the researching of guiding systems for buildings or of the layout of a shopping centre.

4 Description of a virtual reality concept

On the basis of the results of the Asterisk I project and on the basis of different presentations and demonstrations a concept has arisen for a(n) (architectural) Virtual Reality system. This system concept has turned out to be of importance in the treatment of Virtual Reality. The concept brings together the various components and possibilities of a Virtual Reality system. In this concept the different stages of the development are brought together at the same time (figure 2).

Figure 2: Concept of a Virtual Reality system

The system concept consists of the following components:

- an interface between a person and the computer for modelling of a design;
- possibilities for modelling of a design
- a design model;
- possibilities for simulation of a design model;
- a representation of the results of the simulation;
- possibilities for the perception of the representation;
- an interface for the perception.

Hereinafter these different components will be looked at in more detail. On the one hand there will be a brief mention of the most important items which constitute an outside influence on the component. On the other hand the characteristics will be named which are typical for one of the development stages. Other aspects which are regarded as being relevant will finally also be added to the description of the components.

4.1 Interface

Here what is involved is the interface between a user and the computer system. The user can be for example a principal, an architect or consultant. A computer system consists of (peripheral) hardware, software and data bases. For the use of this, it is above all the possibilities of the peripheral hardware and the software which are of importance. The interface has to operate within the system concept as well with the modelling as with the perception aspects.

4.1.1 Modelling interface

Various actors can be incorporated for the modelling. Here it is being assumed that the modelling is effected in the first place with the hands. For this, use can be made of a traditional keyboard or of a normal mouse. A Virtual Reality system offers in place of this a mouse, joystick or spaceball with a minimum of 3 (3D) but better with 6 (6DOF) degrees of freedom. In combination with sensors, which can measure all translations (3) and rotations (3) of the hands and individual function buttons it is possible to manipulate the individual model components. With what is referred to as a data glove it is possible to replace the function keys with gestures or actions. The voice may also be used for modelling. With the aid of spoken commands (voice input) certain commands can be given and in some cases the entry of data is also possible. The use of the eye for the manipulation of a design model appears to be unreal. Various military applications in fact already make use of what is referred to as eyeball tracking, or else the measurement of the direction of the eyes. With this measurement data it should for example be possible to move or to displace certain model components.

4.1.2 Perception interface

Various sense organs can be used for the perception process. Here it is being assumed that perception takes place in the first instance with the eyes, that is to say by means of sight. For this it is possible to make use of a traditional screen. A Virtual Reality system offers in place of this a minimum of a stereo screen, what is referred to as a head mounted display or a stereo-large screen projection in for example a dome (or a cave). By means of sensors, which here too can measure 3 translations and 3 rotations, it is possible to perceive a representation of a design model. If the sensor is for example fixed to the head mounted display then all movements of the head can be measured and at almost the same time the corresponding representations can be worked out. Naturally it is also possible to use the ears or hearing for perception. With the aid of acoustic simulations, background sound for the purposes of illustration or spoken commentary a representation can be noticeably improved. Sound can, for example in an immersive system, also be used in order to improve the orientation of the user. The use of for example the hands, or of touch, for the perception of a representation has already been applied in combination with a data glove. This possibility is in general designated with the terms tactile feedback or force feedback.

4.1.3 Interface for modelling and perception

The design for and the realisation of an interface is dependent on the form of communication between the system and the user and mutually between the users. In addition to a definition of the form of communication a definition in terms of the model (process model) of the process in which the system is to participate is also necessary. It must be possible to develop an interface on the basis of these two things.

The character of the interface is also developing itself still further. Until recently, and this still applies for presentation media, user-friendliness was an important characteristic feature of a computer system. In a Virtual Reality system the interface has rather to be as natural as possible. This is, amongst other ways, attained by means of sensors for the head and hands. At the same time the interface is progressing from being interactive, with a sequential connection between question and answer or between measurement and regulation, to acting in real time, with a connection which is as good as being parallel (or dynamic) between these.

4.2 Modelling

Here this concerns the modelling of a design model where the emphasis is clearly on the generation of a design. The modelling characteristics are dependent on the phase in which the construction process or the design process finds itself and on the design methods or systems which may be available. The aim of modelling using Virtual Reality is in particular the reduction of the design time and thus the increase in productivity of the design process. During the modelling attention must be paid above all to the consistency of the model. At the same time consideration has to be given to the temporal aspects of the model components.

4.2.1 Modelling of design models

The design for and the development of the modelling components of a Virtual Reality system are to a great extent determined by the available technology for this.

For modelling, the current starting point is the modelling of elements of buildings based on components. These components can be found in a component library. From then on they may be used in the composition of the design model. Due to the possibilities of the Virtual Reality systems the components which have geometry and attributes have to be replaced by objects. Objects are in this case a sort of component but they have hierarchical relationships and individual operation which describe their behaviour under certain circumstances. Finally certain states of the objects have to be used for the composition of a design state.

4.3 Model

This concerns a model of a design (object), in a situation (space), at a certain moment (time). The geometry and the attributes of the entities are given from the design or the object. In the case of construction the objects can be divided up in terms of area, construction and construction element levels. Geographical and topological relationships between the entities can be established in the situation or the space. Taking into account the time aspects, the operations on certain objects can be established in a retrospective, current or prospective sense. Through this several versions of the states of these objects can be generated.

4.3.1 Design model

The design for and the realisation of a design model is dependent on the form of the exchange of data between the different systems. In addition to a definition of the form of the exchange a definition of the product in model terms (product model) is also necessary.

The character of the design model is also still undergoing further development. Until recently, and this still applies for presentation media, if a model was 3D this was an important characteristic feature. In a Virtual Reality system the model has rather to be as autonomous (independent) as possible. This is, amongst other things, attained by the use of objects with operations instead of components with attributes. At the same time the design model is progressing from being integrated with a sequential connection between different aspects to acting in real time, with a parallel connection between these.

4.4 Simulation

Here this concerns the simulation of certain aspects of the design model. The emphasis here is on the evaluation of a design. The form of this is dependent on the architectural aspects such as lighting, which have to be simulated.

The aim of the simulation in Virtual Reality is in particular the increase in the capacity for the finding of a solution and thus of the quality of a design. During simulation attention must above all be paid to the correctness of the result. At the same time consideration has to be given to new developments in the area of for example concurrent engineering.

4.4.1 Simulation of design aspects

The design for and the development of the simulation components of a Virtual Reality system are to a great extent determined by the systems which are available for this.

In the case of simulation, the starting point at the current time is the simulation of the attributes of design components, such as colour and texture. Due to the possibilities of the Virtual Reality system the simulation of component attributes has to be replaced with the simulation of operations of objects. Finally transitions of model states have to be simulated.

4.5 Representation

This concerns here a representation of a design model or else the result of a simulation of one. A representation can be graphic (for example audio/video), alphabetic (for example text) and/or numerical (for example tables) in nature. What happens in most cases is that the representation of a design, in Virtual Reality, is able to make use of light, sound and touch.

4.5.1 Representation of design

The design for and the realisation of a design representation depends on the form of presentation to various users or interested parties. In addition to a definition of the content of the presentation a definition in model terms (presentation model) of the required or necessary presentation is also required.

The character of the representation is still undergoing further development. Until recently, and this still applies for presentation media, representations were generated on the basis of e.g. ray tracing algorithms. In a Virtual Reality system the representation has rather to be as realistic as possible. This is, amongst other things, attained by the use of radiosity or ray tracking algorithms. (Kirk, 1989, Kok, 1991). At the same time the design representation is progressing from being iterative (repetitive), with a sequential connection between changes and representations, to acting in real time, with a connection which is as good as being parallel between these.

4.6 Perception

Here this concerns the perception of the representation. The emphasis here is on the analysis of a design (or a design states) The form of this is dependent upon the (detail) level in which the design model (and the representation) is to be found and the relevant elementary geometry aspects. The aim of the perception in Virtual Reality is in particular the improvement of the "conditions of work" for, by way of example, the principal, the designer and the adviser. During perception attention must above all be paid to the completeness of the design model and the representation. At the same time consideration has to be given to new developments in the area of distributed data bases.

4.6.1 Perception of design presentation

The design for and the development of the perception in a Virtual Reality system is to a great extent determined by the available media.

In the case of perception, the starting point at the current time is the perception in the form of a mono image and sound. Owing to the possibilities of Virtual Reality systems the perception in mono has to be replaced with perception in stereo, which applies for both the image and the sound. Finally it must be possible to perceive design presentations with satisfactory quality and speed by means of immersion.

4.7 Stage of development

With the aid of system concept components it is as a result possible to describe the situation with reference to the development of presentation media into Virtual Reality. Here it is being assumed that Virtual Reality actually stems from presentation media. The most important difference between the two media is once again the fact that in the case of presentation media the emphasis is on the presentation of a representation of a design model whilst in the case of Virtual Reality the emphasis is on the (self) perception of this. Another difference is that in the case of presentation media there is a mutual interface between people and that in the case of Virtual Reality the interface is between the person and the computer system.

4.7.1 Presentation media

The situation with regard to presentation media can be demonstrated by means of the following characteristics:

- user-friendly interface
- modelling with components
- 3D model
- simulation of attributes
- rendered representation
- representation in mono (as appropriate also in stereo)

4.7.2 Virtual Reality

With reference to Virtual Reality systems a difference is made between Partial Immersive or Stereo Virtual Reality systems and Immersive Virtual Reality systems. The situation with regard to these systems can also be demonstrated by means of the system concept.

4.7.3 Stereo Virtual Reality

This designation refers to the use of stereo images and the possibility of perception with stereo glasses (polarised glasses or shatter glasses). These systems are also designated partial immersive Virtual Reality systems or Virtual Holography systems. In their application the emphasis is on the design objects. In this way a comparison may be made with working with a scale model or a mock-up.

The situation with regard to stereo Virtual Reality can be demonstrated by means of the following characteristics:

- natural interface (with sensors)
- modelling with objects
- autonomous design models
- simulation of operations
- realistic representation
- perception in stereo

4.7.4 Immersive Virtual Reality

This designation refers to the use of immersive images and the perception possibilities with head mounted displays or stereo data projection in domes (caves). These systems are also designated as full immersive Virtual Reality systems or virtual environment systems. In their application the emphasis is on the presentation. In this way a comparison may be made with working with a 1:1 model or prototype.

The situation with regard to immersive Virtual Reality can be demonstrated by means of the following characteristics:

- interactive interface
- modelling of states
- integrated model
- simulation of transitions
- iterative representation
- perception with immersion (head mounted display, dome)

5 Demonstration of the virtual reality application

The sayings "A picture paints a 1000 words" and "The proof of the pudding is in the eating" point to the fact that perhaps the laboratory set-up and the Virtual Reality concept would be better demonstrated than described. The starting point of this demonstration would be one of the aims for the follow-up work on the Asterisk I project. This aim was the development of a laboratory set-up for demonstrations in the Office of the Future. This demonstration must in its turn be able to make a contribution to the research into the feasibility of Virtual Reality applications in practice. The main point being that the content of the demonstration should be determined by the design and presentation of an office. In the case of the design the emphasis is to lie on the generation and evaluation of design variants. In the case of the presentation the emphasis is to be on the simulation of the illumination situation.

5.1 Demonstration set-up

The aim of the demonstration itself is to be able to allow those with an interest in this to become acquainted with an application of Virtual

Reality technology. The application should be in the area of the development of products, in this case of a part of a building. Those with an interest may or may not be involved in the actual building process. Those involved can look at the demonstration through their own eyes, those who are not builders can look at the demonstration through the eyes of a principal. In connection with making everyone acquainted with the use of this new medium we are interested in reactions and comments on the demonstrated application and/or the technology used. These reactions are to be collected with the aid of a survey and/or of interviews.

Prior to the demonstrations the parties with an interest can receive explanations regarding the different system components. In doing this consideration should be given to the computer system, the peripheral hardware and the software, in relation to which in the case of the latter the emphasis should be placed on the interface between the system and the user. The difference between full immersive and partial immersive should be explained, as well as the global operation of the sensors and of the peripheral hardware such as 3D and 6D model and representation manipulators.

The description of the demonstration is based on the Virtual Reality system concept. The demonstration should discuss the Virtual Reality aspects which have been named here in as brief a manner as possible. On the other hand it may be the case that during a simulated design process these aspects may in fact have to be discussed several times. The initial assumption for the demonstration should be that the user is not an architect, and it should start from a model which does not yet exist and a limited number of modelling possibilities. The 3D design model must be able to exist in a limited form before the demonstration and the simulation. The simulation and the representation should only refer to visual aspects and the perception of the representation is to be as interactive as possible.

5.2 The demonstration content

5.2.1 The project

The owner of a consultancy company has plans to construct a new building. He lets an architect produce a design and now he wants to have a look at it himself so he can make his own evaluation. He wants to see whether the empty spaces are spacious enough, and whether the office areas have in fact been given the right dimensions and whether the colours and materials, which have been chosen, fit well with his company image. Strictly speaking should he want to be able to equip his office and should he want to be able to assess the illumination plan, he thus only has to ask.

5.2.2 The design model

In the first place the 3D design model must be built up digitally. This can take place in a number of ways:

On the basis of design drawings a 3D model is constructed by a colleague. A digitizer tablet and a database with 3D models of architectural objects, such as wall elements and doors may be used for this.

In another case the architect has perhaps himself taken a 3D digital design model with him. This model will then probably just have to be translated into a Virtual Reality model, so that it can be read through the Virtual Reality system.

5.2.3 First design evaluation and adaptations

Simple "wire frame" representations of the design model can be made automatically by the system. These can for example be in the form of isometric projections. These representations can be used in order to check the model and for the defining of the necessary adaptations or improvements. In order to select and adapt certain design model components in a three dimensional model the architect can use the 6D mouse or joystick and the stereoscopic images of the model, which can be offered through the partial immersive Virtual Reality system. The commands may be selected from a menu and they can be "spoken in" (voice input). The adaptations may for example relate to the form, the dimensions or the position of certain components.

5.2.4 Colour, material and behaviour characteristics

The architect can also allocate colour and material characteristics to the design model components. After a model component has been selected these characteristics can be interactively selected and associated with it from for example a type of book in the form of a stall. For this it is possible for example to use barcodes in the book, which is an interactive computer system or a CD-I application.

In Virtual Reality models the behaviour of a component can also be represented. For example weight can be ascribed to certain components. By means of this, these components can fall onto a ground surface under the influence of a simulated gravity. To other components behaviour may be linked which for example means that they are only able to be moved on one surface, or turn on one axis or so that a certain message is heard as soon as they are selected. The behaviour can be represented by a Virtual Reality system in a type of stereo animation.

In order to attain a quicker representation of the model, for the principal and/or for the architect the Virtual Reality model can be divided up into different enclosed spaces. Once the user is present in one of the rooms or submodels then, by means of the use of for example special doors, the space or the submodel can be changed.

5.2.5 Second design evaluation and adaptation

Now automatic images of the design model can be generated in stereo and they can almost be reproduced in real time by the partial as well as by the full immersive Virtual Reality system. The selection of one of the two possibilities depends on the number of people involved and of the desired or necessary image quality. The representation of the design model ensures that different design aspects can already be evaluated. Naturally, on the basis of this certain design modifications can be introduced and comparisons made.

5.2.6 Equipment and lighting

In order to be able to make a better assessment of for example the available space and the dimensions of this the principal and the architect are offered a catalogue with furniture and other equipment elements, such as plants and pictures. In the same way as before, when selections are made with regard to the colours and the textures of the materials, it is now also possible to select equipment and fittings. The partial immersive system can be used for the positioning of furniture and items of equipment, by means of which the catalogue and the model can be depicted at the same time. If the full immersive system is used then the elements have to be selected separately and they have to be positioned somewhere in the model or in a designated space. The principal can now, as appropriate in consultation with the architect, place the elements in their correct positions with the aid of the full immersive system.

As appropriate the architect can also select and locate lighting equipment. With this the representation of that can be noticeably improved. In order to be able to let the principal and the architect themselves determine what they want to look at then the representation of the lighting effects has to be worked out for the whole model in one go. Depending on the complexity of the model more or less less time is needed for this, but there is enough time in any case for a pause.

5.2.7 Third design evaluation and adaptation

The design model is now integrated, colour and material characteristics have been added, the behaviour of certain components in the model have been defined, the model has been divided up into submodels, the spaces have been equipped and provided with lighting and the representation has been computed.

With the aid of the head mounted display the principal or the architect can study the design. If at the same time they want to be able to move through the design then either several head mounted displays are necessary or instead of these several pairs of stereo glasses.

As appropriate there is also the possibility of a partial environmental immersion by means of making use of large screen video projection.

Naturally the defined model data can be modified until the design complies with the requirements which have been set when viewed objectively. For the purposes of the demonstration may be considered in relation to this the displacing of a wall, the adding of a door, the changing of a material selection, the replacement of an item of furniture and the removal of a light fitting. In order to ensure a representation which is as realistic as possible the illumination aspects of the model have be simulated anew each time.

6 Conclusion

The modelling of design models and the perception of representations of these has been simplified and improved with the use of the Virtual Reality system. In this case one can talk about a new interface between users and the system. Through this it should be possible to replace drawings and the use of drawings for the analysis, generation and evaluation of design concepts by the modelling with and the use of Virtual Reality systems. These systems are opening up the way to a "paperless" design office.

Virtual Reality makes it possible to perceive representations of changes made to design objects almost at once. The design information for this must be established in the design model in an integrated form. Owing to the possibilities or rather the limitations of Virtual Reality systems one has to try to limit the amount of information which has to be established as much as possible, and one has to try to establish this information at as late a stage in the design process as possible. With this Virtual Reality stimulates the conversion of an information explosion into an information implosion.

Virtual Reality set high requirements with regard to the performance of the computer system which is to be used. The performance of the system can for example be measured according to the speed in terms of a certain number of images per second, or the resolution or the reality value of an image. From various demonstrations and presentations it has become clear that the performance of a system, such as the Virtual Reality system seems to become less important if the goal which is aimed at is clearer and the users are more specialised.

Research in the area of Virtual Reality should within a short time become directed at the functional difference between the use of a joystick or a data glove for the modelling. At the same time there will have to be research into the possibility of associating the researched design system with a production and control system.

The associating of Virtual Reality systems also poses questions in the area of communications technology. These questions are sure to be looked at in the near future. Virtual Reality should go on to play an important part in information technology through a combination of computer and communications technology.

7 The future

Within a short time the developments with reference to the expansion of the interface should be completed. Here this concerns an expansion in order to attain the facilities of modelling and perception. With regard to modelling the use of the 3D/6D spaceball/joystick should be expanded upon with the use of audio/voice input. The use of eyeball tracking, for example the "looking at" of an object in a model is not yet envisaged. With regard to perception the use of 3D/6D (head) mounted displays and sound for illustration and orientation can be expanded upon with the use of tactile feedback. By means of this, the three, in this case, most important sense organs should be able to be used for modelling and perception.

In the near future further work should be carried out on the ultimate Virtual Reality system. Here what is to be attempted is the creation of a real time computer and communication system. This system should offer possibilities for an interactive interface, for the modelling of model states, for integrated design models, for the simulation of state transitions of the model, for iterative representations and for the perception of these representations with immersive (surround) media.

In the near future the research project, the Asterisk project, should become directed to the research and development of possibilities for the simultaneous use of the same Virtual Reality system by several users (multi user) and for the simultaneous use of the same design model at several locations (multi site). This research is to be followed by the development of a prototype Virtual Reality system for the architectural design process. This prototype is intended for presentations and demonstrations in general and within the construction industry in particular. The Asterisk II project is to be carried out in 1994. The working title of this project is "Virtual Reality and architectural designs: the future reality ?". It is a feasibility study into the practical applicability of Virtual Reality within the architectural design process. Virtual Reality is here also described as an integrated multimedia real time simulation technology. The project above all concerns an expansion of the functionality of the result of Asterisk I with possibilities for multi-user and multi-site use.

In 1995 the research and development work is to be continued with the Asterisk III project: "Virtual Reality and architectural design in a telematic environment: fantasy or reality ?". This project may definitely be pointed out as being a pilot project concerning the possibilities to be arrived at with regard to the introduction onto the market of Virtual Reality systems in a telematic environment in which work is being effected on an architectural design.

The expectation for the near future is that the interface of Virtual Reality systems should become more interactive. The model be made integrated in character and the representation should be more iterative. Finally it should be possible to process the interface, the model and the representation in real time. These important system components should thus imperceptibly overlap with one another.

Because the current situation is already designated with the term Virtual Reality perhaps the situation in which the different system components merge in with one another should be designated with the term Artificial Ontology.

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