VR MODELLING IN BUILT & ENVIRONMENT
SOME EXPERIENCES AND DIRECTIONS IN SITE OPERATIONS

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SUMMARY

In this paper, we will share our experiences of producing a Virtual Reality (VR) model of a large and complex building, and indicate some areas where this can be implemented in the normal planning and construction process. The approach will be applied in an actual project – the building of a new hotel and office block in Gothenburg, Sweden. The relevance of the VR model created in this study was investigated and reported separately (Woksepp, 2002).

The VR concept used in this study can briefly be described as: Firstly, a 3D model was created from traditional paper and 2D/3D CAD drawings. Then, the 3D model was imported into a rendering program where mapping coordinates, textures and additional objects were added. The complete model was then converted to a suitable VR format. Finally, the model was imported to a VR visualisation tool where additional user oriented features were added.

Although the method used to produce the VR model described in this paper by no means represents the optimal course of action, we can nevertheless conclude that the investment required to create a VR model is low, while offering extensive potential. Our on-site research demonstrated widespread agreement that the VR model enhanced understanding of the building for all involved. This study relates not only the experiences gained from producing the VR model and the new directions this has opened up, but also certain new issues of interest for future studies.

INTRODUCTION

Visualisation is a way of making best use of data. It can assist in understanding concepts, interpreting data and also communicating them (Ganah *et.al*., 2001). Virtual reality (VR) is an emerging technology that enables interactive real-time viewing of three-dimensional data (Swann, 2001; UK VR-Forum, 2000; Whyte, 2001). VR has become a familiar concept and is currently being evaluated for practical use in various industrial fields including computer graphics, CAD, CAM, CIM, robotics, medical/health care, multi-media, games (Ellis, 1991; Helsel and Roth, 1991; Laurel, 1991; Sheridan, 1992; Nomura, 1999). To date, the benefits of VR applications in the construction industry have been investigated for almost a decade. However, the practical implementation of VR in the construction industry has yet to reach maturity owing to technical constraints (Bouchlaghem *et al.*, 2000). The rapid progress within IT is constantly generating new and improved VR solutions. This considerably widens the prospects for fostering more effective working methods in the construction industry in the near future.

The construction industry is slowly adopting the use of modern computer techniques for many different purposes. Today, 2D drawings are almost always produced using some sort of CAD system. Common programs are AutoCAD and Microstation. Very few companies or projects employ 3D models and even fewer attempt to utilise VR for enhancing communications between all parties involved in the construction process. However, as previous work, such as the European Union funded ESPRIT CICC project, indicates, efficiency gains of up to 30 percent can be achieved by using VR and other techniques to improve communications in the construction process (Hobbs *et al.,* 1999).

In a recent article, Whyte (2000) described three different practical modeling approaches for VR applications. The approaches were investigated in the context of house building. The approaches described included a library-based approach – where a library of components is archived for reuse within the VR environment, a straightforward translation approach – where complete CAD models are used to generate VR models, and a database approach – utilising a central database to control

component characteristics, with both CAD and VR as graphical interfaces to the database. The VR model is created in the central database, allowing the model to be updated using both CAD and VR. Whyte concludes that the library-based approach was found to be best suited to this application of VR. The straightforward translation method, used in the "Centralhuset" project, was considered appropriate for the creation of this type of unique and complex structure.
Telenor, the leading telecom and media company in Norway, used a 3D "vis" (visualisation) paradigm when creating a VR model illustrating the structure and surroundings of its new 140,000 square-meter headquarters at the old Oslo Fornebu airport. A 3D model was created, based on the data (AutoCAD) gathered from the architects involved, in 3D Studio MAX/VIZ. Textures and the like were added to the 3D model, after which the 3D model was converted into VR (dVMockup). The VR model was used during the design phase to review different design solutions so that modifications and corrections could be implemented before construction work began. This approach was considered suitable in the context of VR utilisation during the design phase. The design layout underwent few changes during the initial process and the VR model was created quite rapidly. Gathering information in 3D Studio allowed high-quality images and animations to be created for marketing and similar purposes (Telenor, 2002).

The current paper reports on experiences gained from the production of a VR model to support planning and construction work on "Centralhuset," a new hotel and office block in Gothenburg, Sweden. The production, implementation and utilisation of the VR model constitute a pilot project (the Centralhuset Project), which aims to investigate the extent to which the VR model can be used as a tool for communicating complex information at the building site. Basic requirements for the VR model included a moderate level of detailing and a high degree of credibility. The method used in the creation of the VR model has been a 3D "vis" paradigm. We will comment on the procedures employed, beginning with 2D modeling, continuing to a 3D model, the methods for adding textures in a visualisation program, and then progressing to VR. Our efforts in producing this report lead us to ask whether a VR model truly can provide important information on the construction phase, and how we can streamline the process of transferring data from 2D CAD, 3D CAD and other drawings into VR. Several trials have been carried out in order to achieve a pragmatic approach to the research issues.

This work is part of a larger project called Applied Virtual Reality for Large and Complex Buildings (VRlcb) (http://vrlcb.sm.chalmers.se/). The project outline is based on two fundamental questions:

- How can VR be used in the construction and analysis of large and complex buildings?
- Can VR be used as the main modeling paradigm?

VRlcb is part of the IT Construction & Real Estate 2002 (ITBOF 2002) programme (project number 99503), which is a sector-wide program for implementing IT in construction and facilities management. In order to promote such development, the program's aim is to create a common IT platform for the sector. This will be achieved through research and development efforts, standardisation and implementation.

AIM AND SCOPE

Underlying this work is the vision of using a VR model in the planning and construction of large and complex buildings. The aim here is to share our experiences of creating a VR model and to provide some indications of direction in selecting the appropriate approach. In order to establish and compare different methods for different purposes, the method employed in the current study will be discussed and evaluated in comparison with alternative approaches.

The documentation of the work carried out in producing the VR model of "Centralhuset," along with various literature studies, provided us with the necessary information.

THE CENTRALHUSET PROJECT

General

"Centralhuset," the new 34,000 square-meter building at the bus and rail station in Gothenburg, will be constructed between the spring of 2001 and the autumn of 2003. Up to 230 people will be employed at the site. The construction cost is estimated at approximately EUR 55 M. The building will include a hotel block, an office block and commercial and restaurant premises. The rail area will be partly rebuilt and aligned with the design of the new building. Situated in central Gothenburg, immediately adjacent to the rail and bus station, in an area of dense commercial activity, the construction process will cause many additional problems of logistics, security and so forth.

The Virtual Reality model

The VR prototype of "Centralhuset" includes the adjacent surroundings, excavations, the cast-in-place basement, piles and pile footings, prefabricated and cast-in-place supporting structure (steel and concrete), prefabricated and cast-in-place floors, parts of the façade, rail area (platforms, railway tracks, etc.), site office, and a moving crane. The exact details, locations and angles of all 347 cohesion pilings were also described. VR equipment managed by personnel from Chalmers and NCC AB were installed at the building site. During construction, the VR model was maintained and updated with vital information. Approximately 300 working hours have gone into modeling the 10,000-object VR model. Although the complete VR model, illustrated on a 1:1 scale, is very extensive, the files total no more than 80 Megabytes, which is just a fraction of the size of the 3D "vis" model files.

PROCEDURE AND FINAL RESULT

Modeling procedure – the 3D "vis" paradigm

All initial data and information regarding the design and construction of "Centralhuset" were gathered from 2D paper, 2D CAD and 3D CAD drawings, supplied by the architects, constructors and other subcontractors. Additional sources detailing the surroundings, such as ortophotos and photos of building exteriors, were purchased from the National Land Survey of Sweden (LMV) or produced using a digital camera. Based on data from the CAD and paper drawings, a 3D CAD model was created. All objects describing the building were oriented according to the building layout, and the model was saved using the STL file format. When using the STL file format, each object is represented by one specific file. All files, describing the objects' characteristics and their respective orientations in the structure (x, y and z-values), are gathered in a comprehensive catalogue, facilitating export to other modeling or visualisation packages.

The 3D CAD model was then exported to a 3D modeling and rendering software (stl–3ds) by using a script that also enabled the objects to retain their orientation in the structure. Additional features and objects, such as textures, ortophotos, the construction crane, site office, rail area, and existing rail station, were subsequently added. The complete 3D "vis" model was then oriented to the correct location in the city center district using an ortophoto (aerial photograph).

Exporting the 3D "vis" model to VR using either the 3ds or stl file format (3ds-vdi alt. stl-vdi) (vdi is the top-level representation (ASCII text file) of the assemblies in the Division Mockup VR software) achieved a successful result, while exporting to vrml disintegrated the object structure. Visualised in the VR software, certain additional features, such as the sky and motion, were eventually added to the VR model in order to enhance the sense of authenticity

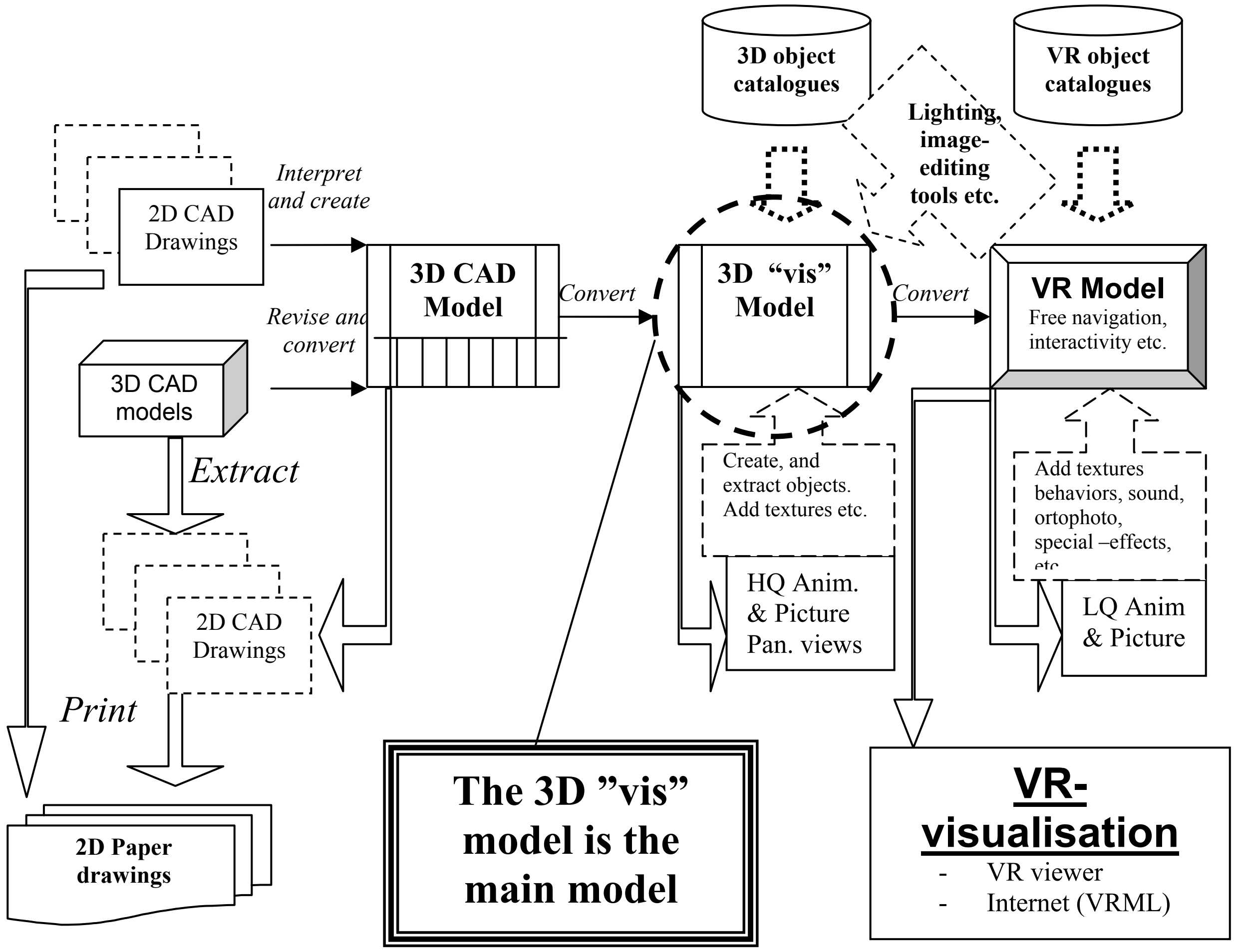

Figure 1 The 3D "vis" paradigm

Using constructors for 3D modeling as well as 3D and VR visualisation was considered to be inefficient. Instead, a special expert group of one 3D modeler, one VR specialist and one co-coordinator was appointed to handle those tasks, allowing the constructors, who are not usually trained in visualisation and VR, to concentrate on constructing and supporting site personnel. Although, during 3D modelling close contact between both groups were maintained in order to solve any technical problems that arose. This solution was regarded optimal for obtaining the best possible result. A data coordinator supplied the expert group with data and managed and maintained the resulting 3D and VR models. 3D Studio MAX was used as the principal application software where all objects and features were assembled and oriented – the 3D "vis" paradigm.

Basic modeling data and software

The 3D "vis" model constitutes the "main model," that is, the model where all data detailing the objects, surroundings and so on, are gathered and arranged, although these data were derived from various sources:

- The concrete structure – paper and 2D CAD drawings
- The steel structure – 3D CAD
- The piling – 2D CAD
- Façades, interiors etc. – architects' description
- Adjacent surroundings – from old maps and real-life conditions
- Ortophoto (aerial photo) – purchased from the National Land Survey of Sweden (LMV)

All software used in this study was PC-based, industrial-standard design and VR tools:

- 2D CAD – AutoCAD (AutoDesk);
- 3D CAD – Xsteel (Tekla) and SolidWorks (SolidWorks);
- 3D modeling and rendering – 3D Studio MAX (AutoDesk, Discreet) and PhotoShop (Adobe); and
- VR visualisation – Division Mockup (PTC).

Results

The VR model could be structured in an assembly manager with hierarchical and parent-child relations (tree-structure). This made it possible to break down the VR model into modules or "sub-VR models" ("termed libraries"), depending on requirements. Dividing the VR model into these libraries allowed us to establish VR-object catalogues and to distribute (via LAN, Internet, CD etc.) streamlined VR models for different purposes. A questionnaire study, reported separately (Woksepp, 2002), investigated how the VR model was experienced and assessed by personnel working with the construction project, and also the basic information flow requirements at the building site. The study concluded that the VR model was realistic, a majority of the participants being positive regarding use of it in their profession. The participants also considered information flow at the building site to be insufficient and felt that use of a VR model would benefit cooperation there.

Pictures and animations produced in the VR application are of low quality compared to the ones created in professional visualisation programs, such as 3D Studio MAX. On the other hand, they crave a considerable less rendering time (around 1:50). For construction purposes, these low-quality pictures and animations were sufficient, that is, in illustrating the layout and structure of the building.

To facilitate the distribution of information, the expert group set up a local website to enhance communication with the data coordinator for up/downloading. This website also served as a meeting place where pictures and animations could be studied and downloaded.

Useful VR application functions

Using the functions in the VR application for load/unload and enabling/disabling of objects or sub-assemblies in the tree structure, in order to visualise specific areas of interest in the virtual environment, allowed users to optimise rendering and navigation performance. Furthermore, utilising the assembly manager allowed us to define the VR model hierarchy and object names in a concept familiar to the users.

Ideally, BSAB or Uniclass classification systems would be chosen as the object naming convention, which should made coupling to other systems more easy. However, in this project we structured and named the objects according to real-time conditions and areas of interest – house numbers, supporting structure and so on. Additional useful functions included the ability to "jump" quickly from one place to another using predefined landmarks, and the ability to measure exact distances in the VR model. Remote collaboration via the Internet was possible in the VR software, although this was not utilised during the project. Another function not taken advantage of was the possibility of using the arrow keys or a joystick to improve the user's navigational control, although this has been tested in other VR pilot projects with very promising results.

DISCUSSION

Different modelling approaches

We could describe the current approach as a **2D CAD paradigm** or, to be critical, a **2D paper-drawing paradigm**, since the only reliable documentation is provided by the paper drawings – updated in the CAD-system, printed, copied, and distributed regularly. Some projects are beginning to use "CAD-pools" on the Internet – an idea introduced as early as in the 1980s – but at that time distributed via corporate networks or slow modems.

Many attempts have been made to create 3D models inside a CAD model. Computer power and graphics are still unable to handle this smoothly. In spite of this, many modern CAD programs, for example Revit, Architectural Desktop and Microstation Triforma, are aiming to incorporate that method. This could be called the **3D CAD paradigm**. In this paradigm, the complete model is a 3D CAD model from which 2D CAD and paper drawings can be derived and edited. However, there is a risk of the 3D CAD model "dying" when the planning procedure has been completed. This is often the case of designs in manufacturing industry. Databases can easily be coupled to the objects.

If we want to produce visually attractive images and animations, we need to convert the model to some kind of visualisation program, such as 3D Studio, Maya or Lightwave3D, to render the images and animations. Producing high quality images and animations, with sophisticated materials and renderings, such as correct shadows and reflections, requires a great deal of processing time. A two minute long animation can take more than 100hrs of rendering. This often means that many computers must be used in parallel ("render farm"), which can be an expensive business in a project involving constant changes, unless routines are optimised. The 3D "vis" model is created by importing a 3D CAD model as a whole or as separate parts, or modelled directly in the 3D modelling software. Not all objects need to be 3D objects. Some can simply be surfaces with attached textures. Using the **3D "vis" paradigm** produces high-quality images and animations. It is not possible to extract 2D CAD and 2D paper drawings from the 3D "vis" model. Updating is a difficult procedure, although, if the design or construction layout were fixed, this paradigm would constitute an effective approach. Converting and importing 3D CAD objects from 3D modelling or CAD software can create a VR model. All object and assembly data are gathered and structured within the VR software – the **VR paradigm**. The problem is how the texture should be added to the objects. If we use basic textures and employ a smart naming convention, changes in the geometry will not cause any problems – the objects will still look "good." However, when extremely realistic looking objects are required (created by radiosity calculations), a problem arises. The 3D "vis" model must be recalculated and the new textures cut out by hand and imported to the VR model. This loop is time consuming. However, if we exclude this and use only basic textures, we can form a loop within which we proceed rapidly from 3D to VR, or even from 2D to VR. Put briefly, in order to create VR models effectively, it is essential to establish an efficient modeling algorithm.

Credibility of VR models

In order to make the images and animations of the visualisation look appealing, a number of objects often need to be added, which are not part of the building itself (trees, flowers, people, vehicles and so on). Orientation in the precise location will enhance users' ability to understand the impact of the appearance of the planned building on the area in question. The degree of detail depends greatly on the purpose for which the VR model is to be used. Creating a VR model si mply for reviewing construction aspects would not necessarily require any texturing at all, whereas using the VR model for design purposes would more likely require a more detailed visual description of building's component surfaces with several textures and maybe an ortophoto background.

DIRECTIONS AND RECOMMENDATIONS

The creation of a VR model for construction purposes is associated with a number of difficulties. For example, constant revisions of the construction impel modelers to continuously update the VR model. The choice of modeling paradigm must be suited to the purpose. Using the 3D "vis" paradigm in the Centralhuset project was not a poor choice, although using the VR paradigm instead would have streamlined the modeling procedure even further. Also, the VR model's purpose was to visualise the construction and to support site-related activities and high quality images and animations were therefore not required. For this purpose, the VR paradigm is recommended.

Also recommended is the use of a separate modeling and visualisation expert group – internal or external, remote or on-site – which allows constructors to concentrate on construction matters. The number of files needed in creating a VR model describing a large and complex construction grows rapidly. To deal with the consequent problems, the coordinator and expert group must establish strict guidelines for efficient information management. Using classification systems, such as BSAB or Uniclass, supports efficient information management.

CONCLUSIONS

The investment required to create a VR model is small compared to the impact this can have on the final quality and financial result when building a large and complex structure. Given that a suitable approach for creating and managing the VR model is adopted for the planning and initial construction phases, and given that the level of detail is kept low, the total cost would be about a tenth of one percent of the total construction costs (author's note: this has not been scientifically established, but is based on experiences accrued from various pilot projects).

PROPOSED FUTURE STUDIES

Considering the high additional costs and extended schedules caused by mistakes in the planning procedure and installation process, further studies regarding the use of VR in such contexts would indeed be called for. Creating a VR model illustrating the supporting structure and selected parts of the HVAC system would increase costs in comparison with the VR model created for the Centralhuset project, but might still improve the final financial result.

In addition, we recommend further research aimed at improving (simplifying, atomise) the handling of files and information. How can we streamline the process of transferring data from 2D/3D CAD etc. into VR? It is important to establish whether or not VR models really can provide important information for use in planning and construction. Another goal is to investigate the possibility to use one VR model through the whole life cycle of the building, or if it is more efficient to make smaller, more dedicated, models in each phase.

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