USING VIRTUAL REALITY IN A LARGE-SCALE INDUSTRY PROJECT

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EDITOR: B-C Björk

Stefan Woksepp, PhD Candidate
eBygg – Center for Information Technology in Construction, Department of Civil & Environmental Engineering, Luleå University of Technology, and NCC Construction Sverige AB, SE
email: Stefan.Woksepp@ncc.se, http://construction.project.ltu.se/~ebygg

Thomas Olofsson, Professor
eBygg – Center for Information Technology in Construction, Department of Civil & Environmental Engineering, Luleå University of Technology, SE
email: Thomas.Olofsson@ltu.se, http://construction.project.ltu.se/~ebygg

SUMMARY*: The Swedish state-owned mining company LKAB has recently initiated the process of building a new pelletizing plant (MK3) in Malmberget, northern Sweden. The total expenditure will amount to €280 million and the new plant is expected to be operational around the turn of the year 2006-2007. Contractors are expected to employ a workforce of about 250 in connection with the construction of the plant, while some 150 consultants and engineers are engaged in the design phase. Since time to market is a crucial factor for LKAB, the contractual agreements for cooperation in the project support collaborative working methods such as concurrent engineering, open information flow and introduction of innovations in the design process. The complexity of the project, the number of actors involved and the desire to involve the client and the end-users, such as industrial workers responsible for the future plant operations, in the design work makes Virtual Reality (VR) an excellent enriched source of communications. This paper describes findings from a case study that sought to explore and document the practical work and experiences achieved, including some good examples, from using VR in the design and planning process.*

KEYWORDS*: client requirements, construction planning, construction project, design process, virtual reality.*

1. INTRODUCTION

A great number of papers and reports emphasize the need for change in order to increase the effectiveness of the construction industry (e.g. Egan 1998, Koskela et al 2003 and Kunz et al 2005). Changing the industry does not necessarily depend on the introduction of new advanced information technology (IT) tools; however, many of these aids have proven to be very efficient in other sectors. For example, results from the EC project ESPRIT CICC (1999) indicates that an efficiency increase of 30 % is possible by exploiting the possibilities of different IT tools.

Even though the introduction of new IT tools in the construction industry has changed the way we work, the full potential on project level is yet to be reached. The pragmatic communication in construction today is often based on traditional media where the breakdown of the project and its presentation can only provide some basic information transfer between the stakeholders of the project (Kähkönen 2003). To be able to act as a facilitator and to provide new opportunities these tools have to be adapted to the business processes (Björnsson 2003 and Lindfors 2003). However, today's processes are constructed to support an information flow mainly based on documents and 2D drawings.

Several European Information Society Technology (IST) projects have taken the challenge to introduce new IT tools and model-based working methods in the construction industry, e.g. Manubuild, OSMOS, eConstruct, Divercity, ISTforCE, eLegal, GLOBEMEM, et cetera. The results from the ICCI project (ICCI 2004), where one of the objectives was to improve the co-ordination between these IST projects, revealed that there is a need to overcome business, social and technical barriers before model based working methods can be introduced.

It is also vital to find enough incentives in order to justify the introduction of new IT tools and model-based working methods. The report “Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry” (NIST GCR 04-867 2004) by the National Institute of Standards and Technology (NIST) indicates that the cost for only for the inadequate interoperability in the U.S. Capital Facilities ran up to $15.8 billion annually. This report contributes to creating an increased awareness about interoperability-related issues, not only for owners and operators in the capital facility industries, but also for the construction industry at large. This is not believed to be a technical issue but rather a consequence of the reluctance to share information and knowledge between the stakeholders in a construction project. Basically the lack of trust, and also the lack of adequate tools for communication are the two most important factors for information losses in traditional construction projects (Blokpoel 2003 and Blokpoel et al 2004).

Virtual Reality (VR) models are one way to improve information handling, communication and understanding in construction projects. VR offers a natural medium for the users providing a three-dimensional view that can be manipulated in real-time and used collaboratively to explore design options and simulations of the construction process (Bouchlaghem et al 2005). Already during its introduction in the construction industry in the 1990s VR was considered to have a great potential in construction providing new possibilities for improving the construction processes (e.g. Retik 1997 and Cochrane 1997). However, it is only recently that VR have started to be used in construction projects as tool to support the design and construction process. Although, the proper use of VR models in the different phases in a construction project is still not clear (Westerdahl et al 2006). This paper describes a case study of the use of VR in a real construction project and will hopefully contribute to the understanding on how VR can be utilized for improving the construction process.

2. RESEARCH OBJECTIVES AND METHODOLOGY

The case study was launched to explore and document the use of VR in a construction project by providing values achieved and good examples from how the client, design teams and planning teams have been using VR models as a complementary source of information to 3D CAD models and 2D CAD drawings in the construction of a large-scale pelletizing plant (MK3) in northern Sweden. The research objective was to provide new insights and knowledge about the values of using VR models in a construction projects with focus on the design and planning process.

A qualitative research methodology was used. The study is based on field investigations and informal interviews with 12 respondents involved in the design and planning process in the construction project. The interviews were mostly conducted on a one-to-one basis in conjunction to the participants’ everyday work. This informal method helped us to map out the working process as well as to obtain a deeper knowledge of the experience of using VR in a more systematic way throughout the design and construction process. Since the project is still on-going the possible impacts on overall targets in the project have not been evaluated.

The paper is organized as follows: The next section provides the reader with some background and review of the use of VR in construction projects. The case study project, MK3, where VR has been used in the design and planning process, is then presented followed by a description of working methods and some examples of benefits found the in the design and planning process. Finally, the uses of VR in the MK 3 project are discussed and some conclusions are made regarding the prerequisites and benefits of using VR in construction projects.

3. CURRENT RESEARCH ON VR IN CONSTRUCTION

Applications of VR have clearly been an area of increasing research and development activities in architecture and construction (Kähkonen 2003). Below are some examples of research on the use of VR models in construction projects. The examples are structured in reversed chronological order.

A study by Westerdahl et al (2006) investigated how employees of a company experienced a VR model of their yet-to-be-built workplace. The use context for the VR model was the late stage of the architectural planning process. The results indicated that the employees provided them a good understanding of their future workplace and that the VR model helped them in the decision-making process of the design.

Bouchlaghem et al (2005) reviewed the applications and benefits of visualisation in construction projects from three research projects covering collaborative working and design in the conceptual design stage, marketing process in the house building sector and modelling of design details in the construction stage. The paper concluded that visualisation applications are becoming more available and accessible to construction professionals largely because of the continuous decreasing cost of software and hardware and leading construction firms now have invested large resources realizing its business benefits.

Ganah et al (2005) presented a research project with the aim to develop a visualisations system for graphical communication of constructability information between design and construction teams. The objective was to improve the lack of communication between design and construction using visualisation tools.

Janols (2005) studied how 3D visualisation can be used for improving timber construction by communicating the aesthetical properties. The results showed that structural complexity, intended viewer and current building phase influence the benefits of the visualisation and that the need for 3D visualisations with high realism and high level of detail is higher for external communication compared to internal communication between professionals.

Woksepp et al (2004) investigating how a VR model was experienced and assessed by the users in the construction of a large hotel and office building, and the extent to which such model could complement the 2D CAD drawings that are mainly employed in such a context. The operational use of VR at the building site was of primary concern. The study involved a total of 93 participants all involved in the building project. It was concluded that the VR model in question was realistic, a majority of the participants being positive regarding use of VR in their profession. The participants also were of the opinion that the information flow at the building site is insufficient and that use of VR models would be beneficiary for the communication and coordination at the building site.

The use of VR in the construction of a new lecture hall in Helsinki was studied by Savioja et al (2003). The study described the process starting from a relative simple VR model for presentation of the concept and layout. The model was further detailed until a photo realistic model of the building could be presented and used for detailed studies of the design. All participants, especially the design team and the end users, were enthusiastic over the possibilities the VR model could bring to the project. Some technical problems were reported, especially when the complexity of the model increased. One conclusion worth mentioning was the necessity of early planning of the model structure, especially when realistic VR models are going to be created.

The use of 4D/VR in the construction of a high-rise apartment and commercial store building project in South Korea is described in Kim et al (2001). The biggest gain from using 4D/VR models was achieved from improving communication between managers and workers which led to reducing the construction time from 43 months to 39 months.

Calderon et al (2000) studied the use of VR as a communication medium for building design. A review of the literature showed there to be a lack of adequate research and there being relatively few practical applications there thus far.

To conclude, research has indicated that VR at the present time has become more accessible and available as well as appreciated and accepted by the stakeholders in the construction process. Knowledge of benefits and method of application in the construction process is relatively good, especially the use of VR for communication of design intents to the client. New VR applications such as visualisation of the erection process (4D) (e.g. Fischer et al 2004 and Jongeling et al 2004) are starting to be introduced in the construction sector. Westerdahl et al (2006) suggest that there is a demand for further research on the use and value of VR in the design and construction process; especially since the construction industry is starting the transition from a traditional document supported process using 2D drawings to a model based supported design and construction process.

4. THE MK3 PROJECT CASE STUDY

4.1 Background

The Swedish state owned mining company LKAB has recently initiated the building of a new pelletizing plant (MK3) in Malmberget, in the north of Sweden, which will be complementary to an existing pelletizing plant for the purpose of increasing the production capacity. The total expenditure will amount to €280 million and the new plant is expected to be operational in October 2006. Contractors are expected to employ about 250 persons in connection with the construction of the plant, while some 150 consultants and engineers are engaged in the design. Since time to market is a crucial factor for LKAB, the contractual agreements for cooperation, partnering, in the project support collaborative working methods such as concurrent engineering, open information flow and introduction of innovations in the design and construction process. The Center for Information Technology in Construction (eBygg) at Luleå University of Technology is closely monitoring and studying the design, planning and the construction process of the plant as it involves the application of advanced IT systems, such as process-plant design software and VR walkthrough environments.

The client's three key goals in the MK3 project are to obtain a plant with required *Capacity* in *Time* within the *Investment frame*.

The 12 interviewees, all men, represented the client (LKAB) and a number of subcontractors with responsibilities within project management and planning, design coordination, business management and development (representing the client), technical engineering and VR modeling. All but one, the VR consultant, had several years of experience from similar construction projects. Also, the VR consultant was the only one that had some experience of working with VR models. Everyone uses computers frequently and agreed that the amount of information in construction projects is probably enough but needed to be more structured and easier to communicate to the different stakeholders in the project.

4.2 Project characteristics

Discussions about whether a construction project can be classified as unique or not often leads to different standpoints. Nevertheless, one can certainly assert that the MK3 project is carried through based on a combination of conditions that all together have an effect on the project performance in a way that separates this project from other similar projects. For example, the time period from the decision of investing in the construction of a new pelletizing plant to its completion is limited to two years. This put great demands on the project organisation and project performance. The conceptual stage of the project, the base for the investment decision (business conditions, manufacturing process and preliminary layout of the plant), was carried out during a very short period of time.

Normally, the spatial needs govern the preliminary plan in a construction project. However, the design of the plant in the MK3 project is affected by the following parameters:

1. The design of the manufacturing process,
2. The plant layout (the plant and its surroundings),
3. The construction of the plant.

This leads to a situation where the focus is on the assembling and functionality of the machinery in the plant instead of the actual building. All separate design processes including construction, HVAC, electrical installations, process, et cetera, occur simultaneously in a concurrent design approach. The project has employed a number of retired local staff who has experience from the existing pelletizing plant constructed during the 1970s. Otherwise, lack of local competence could have been a problem considering that the plant is being built in a remote and sparsely populated place.

Due to the complexity and the time pressure in the project the contract was based on incentives to meet the client's requirements in function, time and costs. This contractual form is called Partnering and is used to form an open collaborative project environment. Partnering facilitates problem solving and shift focus from the individual goals for the involved partners to the overall project goals. Also, changes in the design beneficiary for the project can be implemented without renegotiation of the contract. Partnering often involves cost reimbursable forms (transparent) for remuneration with incentives for reaching project goals. The incentive is often based upon sharing savings and overflows of the target price. In the MK3 project the incentives are based on a combination of the three project goals to make all major stakeholders focused on the overall project performance. The project management introduced a number of team building activities in order to improve the working climate and trust between the different parties. Early in the project the decision to use 3D CAD and VR was taken by the Partnering group. The project management foresaw the difficulties of gathering, coordinating and easily communicating comprehensible multi-disciplinary information to all stakeholders in the project.

4.3 The VR system

The VR system used in the MK3 project is a low-cost approach that consists of commercial software, PC computers, servers and projectors. Walkinside™, which was selected as VR platform in the project, can import most of the major CAD formats. An independent VR consultant is especially appointed to work full-time managing the VR models and the information that is passing through.

4.4 Creating and displaying the VR models

Most of the information that makes up the VR models of the plant originates from 3D CAD models developed by groups of multidisciplinary design teams. The only exception in the project is the electrical installations that were modelled only in 2D. However, the cabling was later remodelled in Microstation as 3D CAD objects to show the location of the cable ladders in the plant. The design was carried out using a number of 3D CAD applications such as: Solidworks, AutoCAD, Tekla Structures, Microstation (where most of the mapping of material and textures is done) and Intergraph's PDM system. Apart from the use in creation of VR models, most 2D CAD shop drawings are directly generated from the 3D models.

The different design teams responsible for the development of steel, concrete, machinery, ventilation, et cetera, extract chosen parts of the 3D models to be included in the VR models. These are then transferred into a common FTP server that works as a hub for exchanging and storing design information. The common exchange format used is DWG. Each design team has a dedicated folder with a given assigned authorization to facilitate the exchange administration and to secure those parts of the information that is protected by patent. The design teams are responsible that the latest updated version should always be available on the FTP server.

The VR consultant converts the uploaded 3D models into VR format. Larger 3D models, consisting of many objects, are first converted and optimised separately to reduce the size of the VR model. Smaller models are converted and optimised in groups before the complete VR model is put together. The aim was that to produce updated versions every week. However, in reality this occurs every two weeks or when a large design change has been made. To facilitate the process of integration, all 3D CAD models uses the same coordinate system. Also, during the course of the project the design become more detailed and objects describing smaller parts of the machinery such as bolts or similar that has less significance for the visualisations are filtered out in the DWG exchange file before they are uploaded to the FTP server.

The total amount of information describing the VR models of the pelletizing plant is extensive, and includes the construction (prefabricated and cast in place concrete, and the steel structure), the installations (machinery, HVAC, electrical installations, et cetera) and its surroundings. The VR models are considered to be reliable because they directly origin from the different 3D CAD models and are not re-constructed from supporting 2D CAD drawings.

After the transfer, storing, converting and optimising have been completed, the VR consultant then produces different VR models for different purposes, e.g. design reviews, construction site planning, production, mounting, working environment for safety and maintenance et cetera. After the VR models have been produced they are transferred back to the to the FTP server.

All presentations of the VR models are done with computer monitors or projectors (2D). Screen-shots and movies are also produced and distributed via the FTP server. Besides overview and detail examining, the VR software is also used for ocular clash detection (automatic clash detection is being carried out in the 3D CAD software by the design teams themselves), distance measuring, user positioning (XYZ coordinates or on an overview, updated in real-time), turning on/off objects layers, gravity, impenetrable objects, avatars, et cetera. An especially practical functionality of the VR software is that the user can mark locations in the VR model and write notes. These notes are connected to the marked location and logged in a separate text file. The description and its connection to the location can be retrieved by clicking on the note symbol in the VR model. A number of people can also interact collaboratively in the VR models over the network. A typical example of a VR model of the plant can be seen in Fig. 1 - showing an avatar inside one of the main facilities in the pelletizing plant.

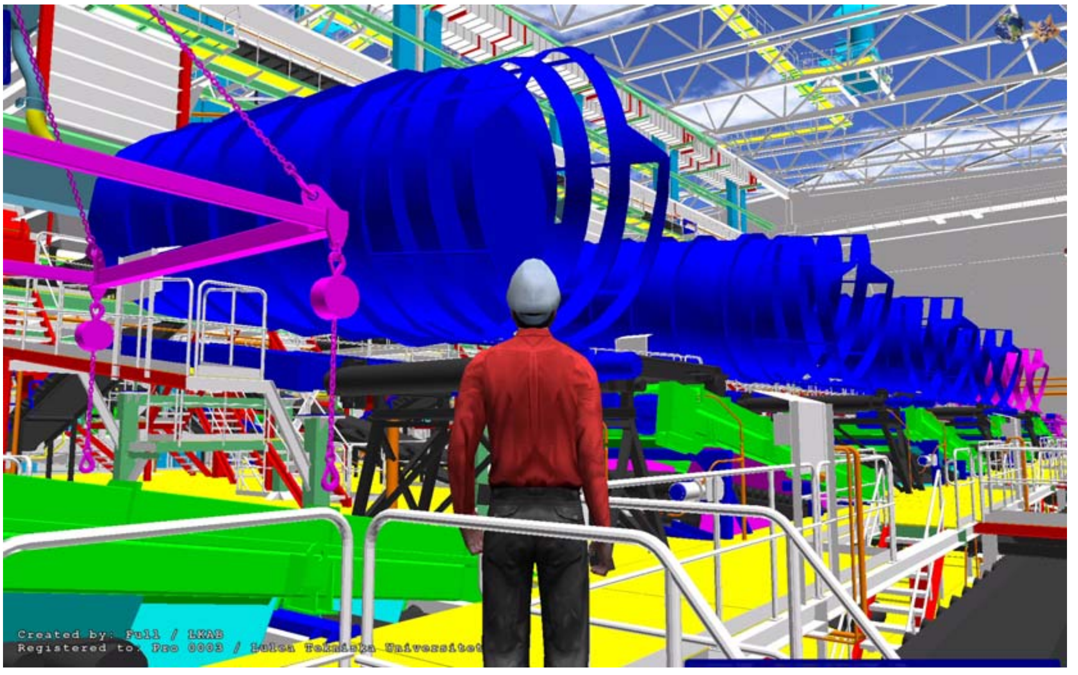

FIG. 1: A screenshot extracted from a VR model showing an avatar inside one of the main facilities in the pelletizing plant.

4.5 A concurrent design process

4.5.1 VR models in the design process

Fig. 2 outlines the iterative and concurrent design process in the MK3 project. The client is responsible for the overall design process while the design teams within Construction, Mechanics, HVAC, et cetera, are responsible for the design of the subsystems in the plant, i.e. process equipment, building structure, installations, et cetera. All design teams are also responsible for providing correct and updated input data to the "VR database". The VR consultant working for the client manages all the VR data and also makes updated and corrected VR models accessible for everyone involved in the design process.

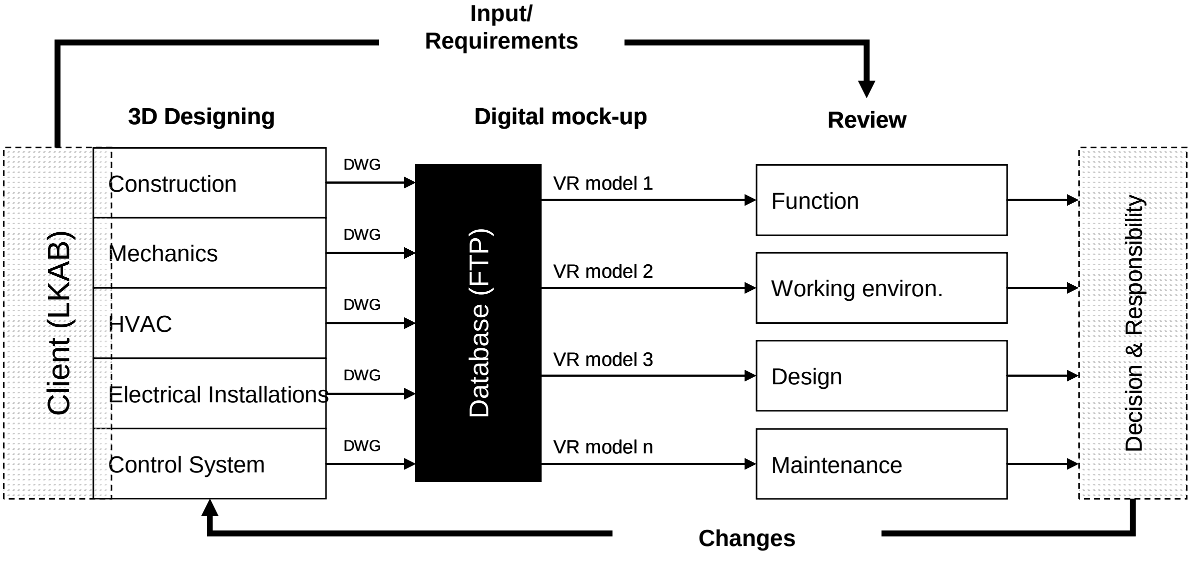

FIG. 2: An iterative design process with specified VR models in a concurrent and multi-disciplinary design situation.

The VR models, in Fig. 2 denoted VR model 1 to VR model n, provided the design teams with structured and easy-to-understand design information in a way that is not possible using a traditional design process using 2D CAD drawings. The stakeholders could analyse the design both from a perspicuous as well as detailed perspective by navigating freely in the VR models. Moreover, using VR models made it easier to explain and discuss different design solutions with a larger group of stake-holders with different knowledge and experience in interpretation of 2D design drawings. This facilitated the collecting of views from different perspectives that could be used get a better and more production adapted design. Also, a number of collisions and design errors could also be discovered and corrected in the design process.

The interviewees involved in the design process concluded that one of the major benefits was the increased level of understanding; especially within areas outside the scope of their own profession, or to quote one of the design managers: “I was sceptical at first but when I realized that by studying one VR model instead of spending time searching through piles of paper drawings could save me a lot of valuable time thus I could focus on what is important”. To illustrate his point, he mentioned how much easier it was to design the concrete foundations of the machinery when you get a clear picture from the VR model of how the mounting frames were designed.

Since a model based design process using VR had not previously been tested by the different design teams the design coordinator made sure that if the 3D design process should come to a dead end during the course of the project due to problems for the software to handle the amount of 3D data there was always the option to go back to the traditional way of working using 2D drawings. In the beginning of the project both fascination and scepticism over the VR technology was noted which was thought to effect the credibility of the VR models. However, these symptoms quickly vanished when the use of VR models become a natural part in the daily work.

4.5.2 Design review meetings

The VR models were extensively used in the reviews meetings that occurred every two weeks. Here, design solutions were examined from the different perspectives and requirements on function, work environment and maintenance. Clashes between the different design disciplines was also discussed and resolved. The use of VR made the review work much easier and minimised the risk for misinterpretations. This implies that more valuable time could be spent on finding solutions and opportunities.

The usability of any information is strongly connected to its trustworthiness, especially in a decision-making situation. Since the VR models was one of the main sources of information in the design review meetings the VR consultant put a lot of effort in making these models up to date.

However, one of the greatest advantages in design reviewing as well as in the individual design work was the increased understanding for the overall design. The design teams could, interactively, in a virtual environment, explore different alternatives by predicting, understanding and evaluating the impact on the project as a whole in order to come up with the best solutions. VR was especially valuable in the conceptual design of the plant layout and in the detailed design phase.

Much of the non-productive work during the production phase is generated in the design phase. Re-work caused by bad design or collisions between different objects, such as HVAC and the building construction, is mainly due to incomplete coordination and information flow between different design teams. The use of 3D and automatic collision detection can be a remedy to this problem, although this implies that all design teams should use the same CAD system. Furthermore, in large construction projects containing a huge amount of CAD objects the use of automatic collision detection generates in many cases too much collision information to be practicable. Instead, the technique including probing avatars was used to detect collisions in special areas of the plant. Since the major risk for collisions occurs in the interface between different design teams, e.g. mainly between installation and construction, a visual detection technique was used. For example, an avatar was made to crawl inside the ventilation system to detect colliding objects penetrating the ventilation shaft, (see Fig. 3). This example also shows how natural/visual interfaces to large data sets can inspire interaction with the VR model that mimics the strategy that would be taken in the real world.

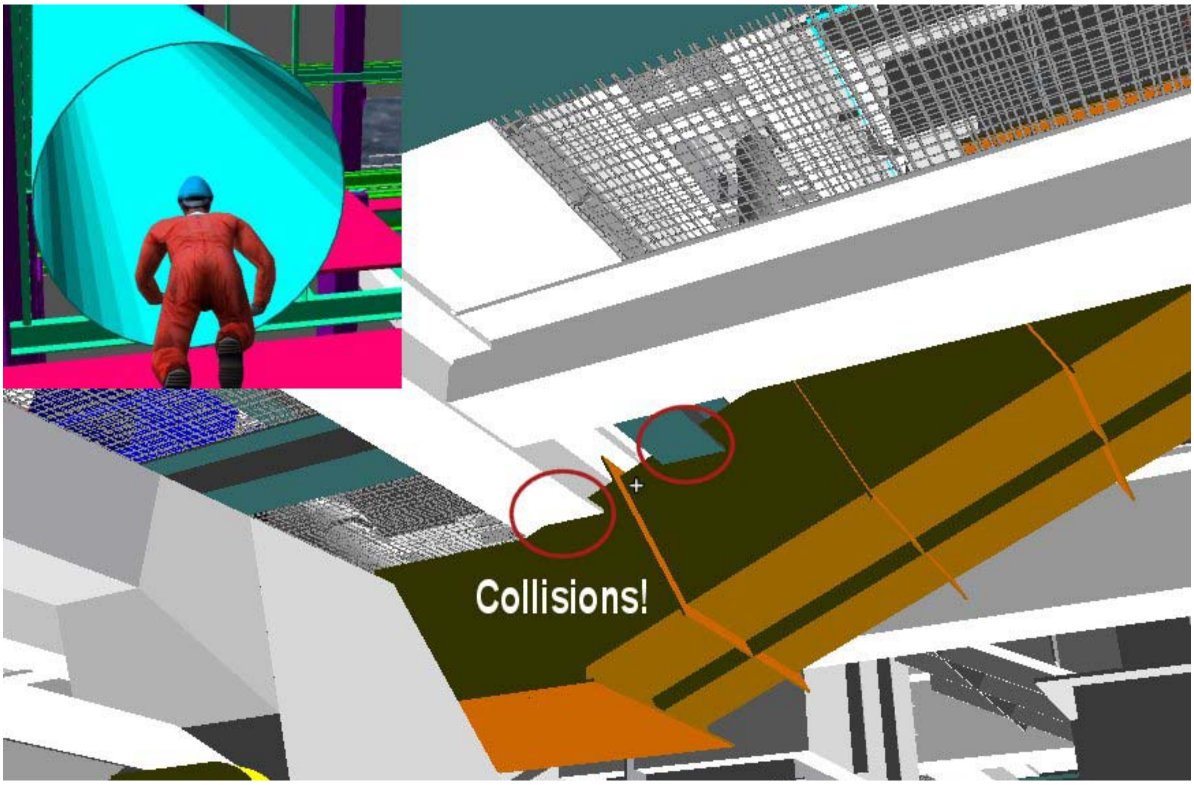

FIG. 3: Screenshots extracted from a VR model showing a detected clash between the ventilation system and the structural system. These types of clashes are much easier to detect from the inside of the ventilation system.

Fig. 4 shows a detected bad design solution where the process water outlets were placed in such a way that would have hindered the access to the area. These types of errors are often costly to take care of in the production phase. They will also affect the production rate generating delays in the production schedule and re-planning of activities.

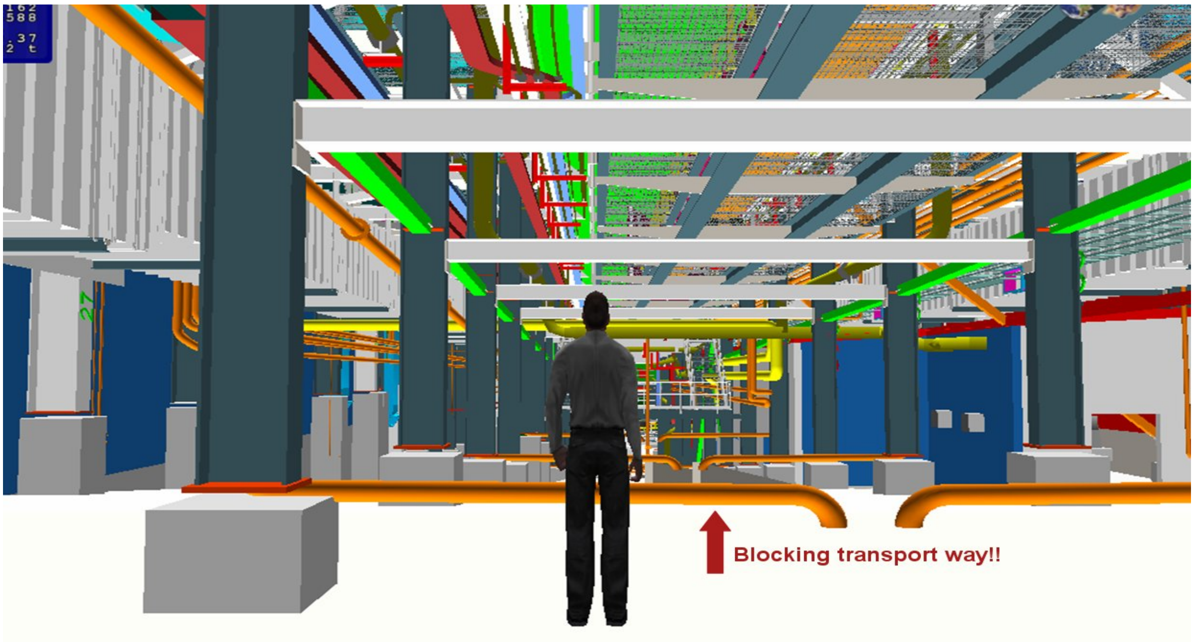

FIG. 4: Screenshots extracted from a VR model showing a design solution that would have blocked the access.

Errors discovered during the design review meetings were immediately delegated to the design teams concerned. All errors that were attended to were logged and later confirmed in the next meeting. Decisions on major changes in the design were taken after conducting a risk analysis on the three goals in the project, i.e. *Capacity*, *Time* and *Investment frame*. These decisions were always taken in the risk management group consisting of the client and the main subcontractors in the Partnering contract.

'Informal' design review meetings were also conducted continuously throughout the design process. The main objectives of these informal meetings were to function as a complement to the formal meetings and to speed up the design process. One of the drawbacks of using VR as a communication platform in the project has been the limited access to enough computing power to handle and visualise the increasingly larger VR models. Therefore most of the information in these informal meetings has been based on 3D models, extracted 2D paper drawings and screen shots from the VR models communicated through emails and telephone meetings. However, the lack of VR has not impacted the information sharing since these informal meetings occur between the regular design reviews where the coordinated VR models are displayed. The partners in the Partnering group have encouraged these informal meetings between the different design teams and sharing of information.

4.5.3 Capturing the client's needs and requirements in the design process

The most important task for the client in the MK3 project was to ensure to that needs and requirements of the pelletizing plant were implemented in the design. The time-pressure in the MK3 project and the use of Partnering as a stimulus to enhance the collaboration between the stakeholders, resulted in a concurrent design process where the VR models been used to coordinate and communicate the design to the client. Besides making it easier for the client to make crucial decisions; the VR models have also involved the client in the everyday design work. Being able to quickly sort out the information that is relevant for the moment and present it in an easy and comprehensible way have enabled the client to collect opinions from a wider audience, such as the plant operating and maintenance staff, and to concentrate on the actual decision making.

Decision-making in the MK3 project is a delicate procedure, especially for the client where the decisions in the project will have a long-term impact on the opportunity to make revenue on the invested capital. The decision-making and the design sequencing can affect the design process negatively. To reduce the risk for negative design iterations Ballard (2000) suggests among other measures: team problem solving, the share of incomplete information and concurrent engineering. These measures were encouraged by the Partnering group.

Decisions made early in the design process have a great impact on the final outcome. Therefore, by focusing on the preliminary design stage, the greater are the chances to achieve a positive effect on the final costs and quality. This applies to this project as well as to most construction projects. In view of the wide range of technical inputs, the client and the designers must be provided with information that can be assimilated into decision criteria's regarding, e.g. risks, costs and milestones.

There are several examples in the MK3 project where the VR models have been used to facilitate the client's decision-making in the design process. For example, due of the tight time schedule, the client and the different design teams needed to take quick internal decisions often without consulting the other design teams on a regular design review meeting. The VR models have helped them to better understand the multi-disciplinary consequences of a decision. From the client's perspective, the impact of the decision on the manufacturing processes has the highest priority. All other decisions regarding for example construction, HVAC, et cetera, are of subordinate significance. Therefore, when the client had chosen the plant process and the machinery to produce the required capacity, the spatial needs can be defined. These needs were described to the construction design teams using a VR model of the plant process design. The construction design teams could then begin to plan the layout of the construction and select technical solutions to be discussed, followed up and evaluated in the succeeding design review meetings.

As mentioned above, the use of VR models in the MK3 project have facilitated the client and the design teams to become more actively involved in all of the different designs of the plant. This has promoted coordination and fostered a common view on the overall project goals. However, it is difficult to give an overall estimation of the value added and the waste saved caused by the use of VR. Here, we will give the reader a few examples on how VR has been utilized to add value to the final design and to minimize the waste in the production phase:

In the analysis of the plant working environment and safety a specially designed avatar of ample size (210 cm of height) was allowed to mimic the behaviour of the operational and maintenance staff. This was primarily a spatial analysis where working spaces, escape routes and risky areas in the plant were investigated. The result of the analysis was forwarded to the involved design teams for redesign of the problematic areas in question.

The second example also concerns a spatial analysis but with a totally different purpose. The operation of a highly automated industrial process is to a large extent dependent on the maintainability of the process equipment. Measures to prevent production losses have high priority in such facilities due to the economical consequences. Therefore, to make sure that maintenance could be conducted, the maintenance personnel were asked to participate in a spatial analysis using avatars and VR models of the process machinery and layout. Problematic areas from a maintenance point of view could as a result be taken care of in the design phase, see Fig. 5.

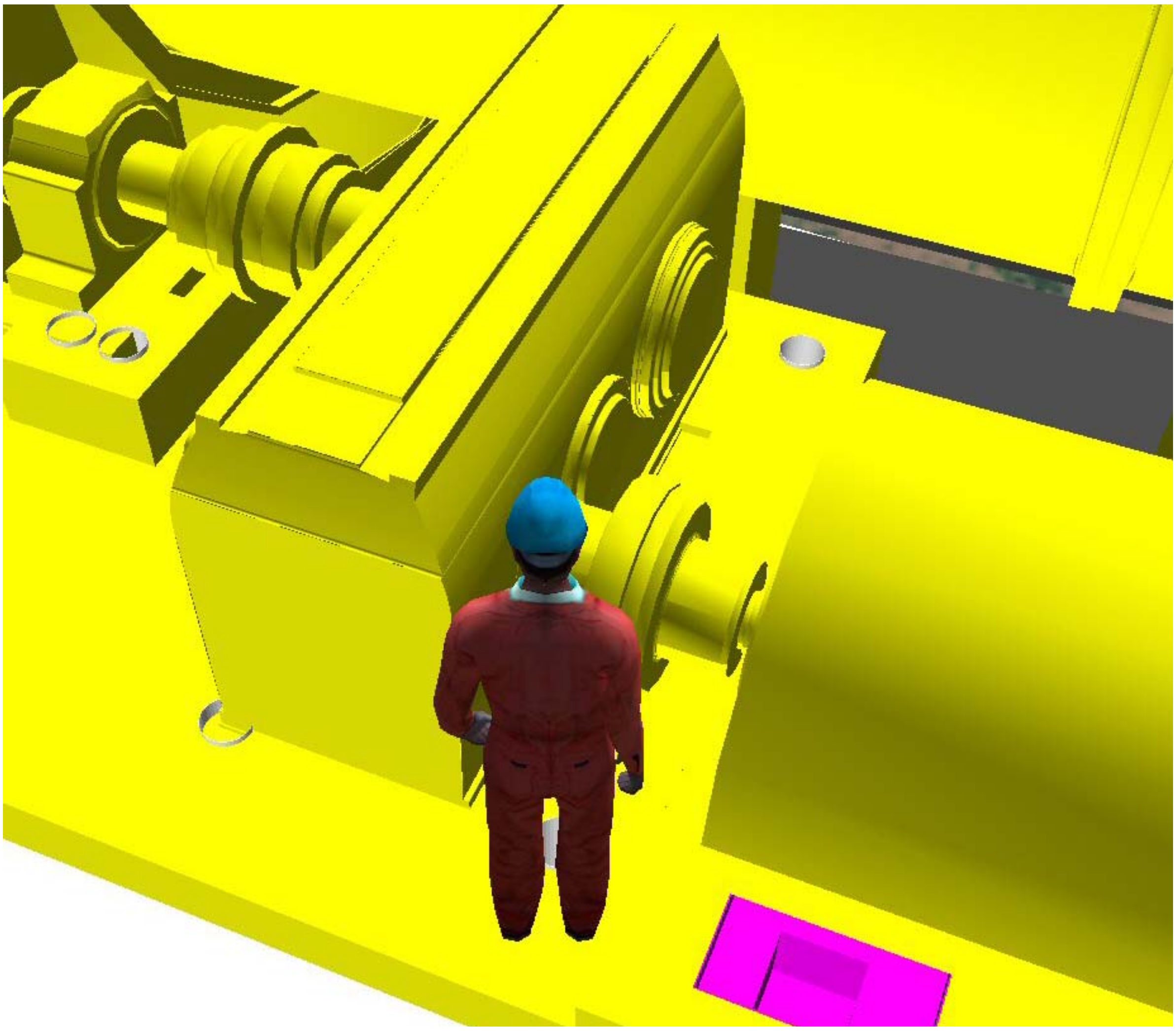

FIG. 5: A screenshot showing the use of avatars for investigating the maintainability of the process machinery in the dressing plant.

The design of the new plant process could also be exemplified in an early stage of the project, where alternative solutions from a production capacity point of view and the impact on the layout and logistics could be visualised for the client. These layouts were also part of the information on which the board of LKAB took the decision to invest in the MK3 project.

Currently the VR models are used to speed up the CE-marking procedure of the plant and to get an earlier production start. The CE-marking procedure is normally carried out when the plant is finished. Also, the VR models are planned to be used to train operational and maintenance workers.

The client and the involved design teams are very positive to the use of VR in the MK3 project. Several respondents argued that the use of VR will probably increase in future project and that more built-in intelligence in the VR model will extend its use in planning (4D) and process simulation. Some preliminary investigations of the use of 4D in the MK3 project have been conducted by Jongeling et al (2006) and Woksepp et al (2005).

4.6 The planning process

Effective planning throughout the construction project is essential for achieving a high level of quality and profitability. A comprehensive and parallel information exchange process characterises the multi-disciplinary and concurrent project planning process in the MK3 project. Traditionally, as well as in the MK3 project; this is a document-oriented process where the planners rely on conventional planning tools (e.g. Gantt charts), 2D CAD drawings, paper documents and personal meetings. This work process puts great demands on the planners, because they have to determine whether the accessible information is reliable or not besides performing the actual planning work. A consequence of this procedure as described by one planner participating in the study was that he had considerable difficulty in achieving an overall picture and understanding of the project. The lack of a continuous and structured information flow in construction projects is traditionally accepted as a natural part of the process and problems are dealt with on the construction site as they arise.

In this study we have focused on the preconstruction stage. Waly et al (2002) describe this stage as the macro planning process, which involves selecting major strategies, reviewing the design for constructability improvement, site planning for major operations and construction path, and arranging for the primary means, methods and resources required for the execution of the work packages. Our hypothesis is that this process can be facilitated by the use of VR models.

According to the planners, the biggest value from using VR models to support the planning process was obtained from including the setting-out grid (created as “VR solids”) in the VR models. The setting-out grid provided the planning teams reference positions from where distances to the construction parts could be measured. This created a common frame of reference and a better spatial understanding. The VR models also facilitated the structuring and handling of the massive amount of information in the planning process. This took some of the work load off the planners.

VR models were also utilised to support planning and decision-making of prefabrication. For example, to speed up the production it was decided that larger parts of the belt conveyor system could be assembled off-site after it was checked in the VR model that these preassembled belt conveyor parts could safely be lifted in the plant.

Even though the planners considered the VR models to be reliable and well-structured most of the planning work was nevertheless done using traditional methods. The two main reasons for this are believed to be that the traditional way of working is still firmly established and that the “right” VR models often were inaccessible when much of the planning work was conducted. There was simply not enough time to produce and present production adapted VR models to the planning team.

5. DISCUSSION AND CONCLUSION

The design and planning process in a multi-disciplinary and concurrent large-scale project such as the MK3 project is a complex and difficult process to manage. However, the uses of VR models have provided the potential to increase the performance and reliability of the information according to the several informal interviews performed on the construction site. By comparison to the traditionally-used 2D and document-based working methods the designers and planners have obtained a higher degree of spatial understanding and a better understanding of how and when the construction is going to be built from the VR demonstrations. As a result the designers and planners have been able to foresee future consequences from different decisions and test and evaluate different solutions, further develop exchange of experience, and plan and manage the time schedules.

The reliability of the information has been obtained by continuously updating the VR models using the different design teams’ 3D CAD production models. In the MK3 project, one person was appointed to manage all information that was exchanged between all project participants. This proved to be a good investment. As a consequence, the rich information environment has facilitated the users to focus on ‘priority of consideration’.

The team that has been coordinating the design claims that VR has really facilitated the design coordination in the project. It gives better quality and communication and compared with traditional design methods lower costs for design coordination. The number of people involved in the design coordination has been reduced by 50% in this project compared with a similar project 10 years ago where all design was made in 2D.

Neither realistic VR models (lighting, texture, et cetera) nor the experience of presence was considered to be essential in the design and planning process. Computer monitors and projectors (2D) were believed to be sufficient for the VR presentations.

The technical integration between the different design teams and planners has not been an obstacle despite the variety of CAD systems used in the project. The propriety format DWG provided ‘enough’ integration for the users in this project. The technical integration has been identified as one of the main barriers in several research projects conducted over the last decade. Instead the project management focused on selecting the best designers available using the CAD software of their choice. The integration was then a technical matter of selecting the common format and overcoming some of the spurious errors that occurred in the exchange of the DWG files to the VR models. Most of these exchange errors could easily be detected, see a typical example in Fig. 6.

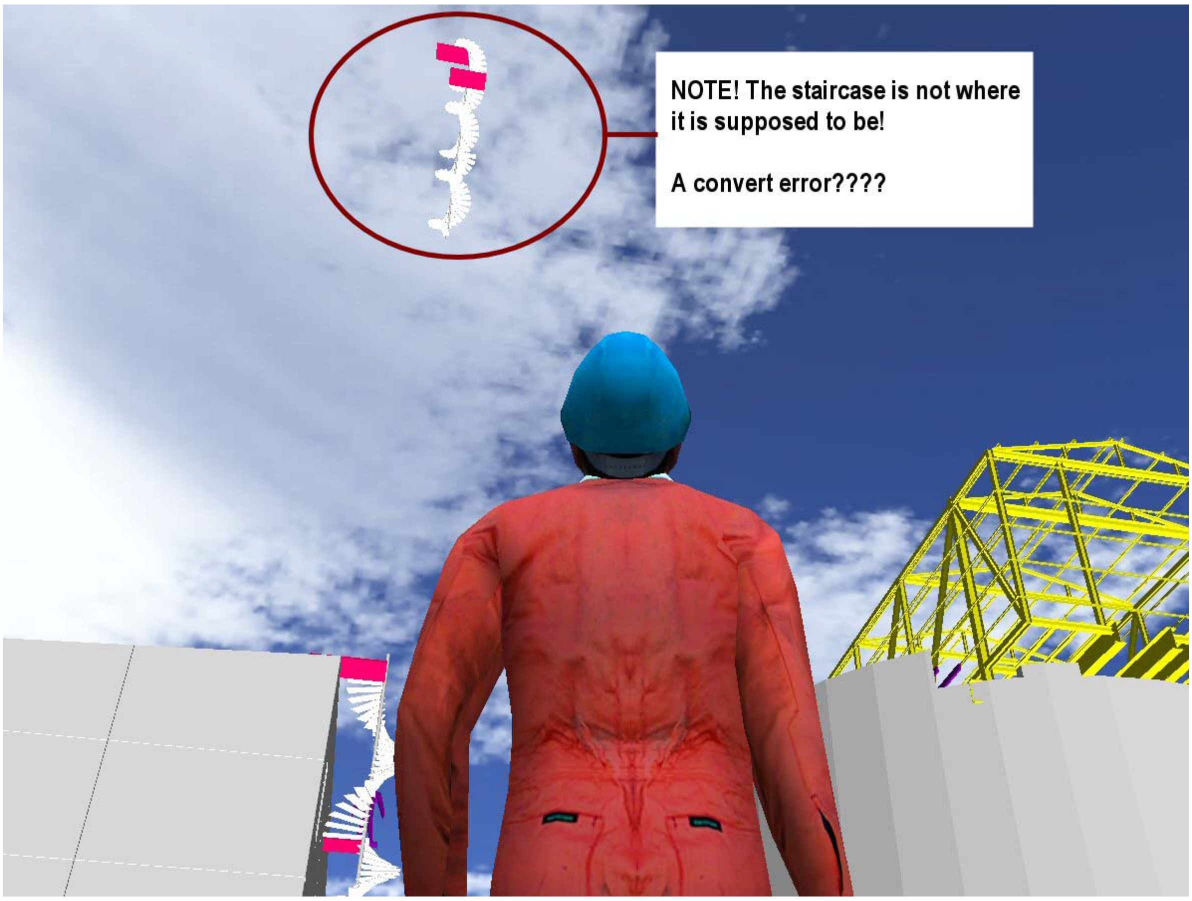

FIG. 6: An example of exchange error that occurred between the CAD and the VR software used in the project.

The reluctance to share information is also a major identified barrier in the construction sector. Even though the Partnering contract facilitates the cooperation between the different stakeholders by trust, the main cause for the intense information flow and willingness to share has been the time pressure forcing the different design teams to act concurrently.

In conclusion:

- VR has been used throughout the project and has been integrated in the design process and to some extent used in the planning process.
- The use of VR has facilitated the concurrent design process in the MK3 project. Especially in the design coordination process, the design review process and the capturing of client requirements on the final design.
- Most value has been derived in the use of VR as a decision support in the conceptual design of the plant layout and in detecting collisions in the detailed design phase.
- The VR models were considered reliable because they directly origin from the different 3D CAD models.
- Computer monitors and projectors (2D) were considered to be sufficient for displaying the VR models.

- Using VR has had a positive effect on the final project costs and quality. A rough estimate based on previous experience from a similar project using 2D drawings by the design coordinator showed that the cost of using VR is much less compared with the savings in design coordination alone. The staff devoted to design coordination was halved (from 15 to 7 designers) compared to the 2D design project. Still, the quality of the design coordination was deemed to be higher in the MK3 project.

Based on the experience from the MK3 project, the client LKAB has decided to use the same contractual concept and working method provided by VR in the next project – the construction of a new pelletizing plant in Kiruna, Sweden, twice the size of MK3. Also, the use of 4D CAD technology is also discussed to improve the production coordination of the new project.

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