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Use of Virtual Reality in Scheduling and Design of Construction Projects

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Abstract

This paper outlines some of the potential applications of Virtual Reality to a variety of construction problems. It is envisaged that the main role of VR will be to provide a more natural interface to the data being manipulated by computer software. For example, the ability to visualise the state of a building at different times during the construction programme would be invaluable to planners concerned with the problems associated with coordinating the labour, machinery and materials resources on site at any given time. Also, the evaluation of different structural systems would be a good application for a VR system. Lastly, the use of a networked VR system allows the possibility of having conferences with people who are geographically remote from each other.

1.0 Introduction

The popular image of the construction industry in the United Kingdom is one of an unsophisticated industry which resists any changes to its archaic working practices. However, it is fair to say that there has been a cautious shift in attitude towards the use of computers in recent years [1]. In general, the industry seeks to use technology which is already established elsewhere in either the manufacturing, automotive or aerospace industries. It should come as no surprise, therefore, to discover that the use of Virtual Reality (VR) in construction is almost unknown [2]. Some of the potential application areas for VR systems are summarised in Table 1 and include many aspects of site work, design activity and so on. This paper will describe the applications of VR technology to two construction problems and will go on to show that there is potential for further research in this area.

The field of Virtual Reality has developed out of experience gained in computer graphics and human-computer interaction. The basic concept is that of the *immersion* of the operator in a computer-generated world such that the sensory information conveyed reinforces the

Table 1 **Potential Applications of VR in Construction**

Area	Potential Applications
Site Operations	Rehearsing erection sequences Planning lifting operations Progress and monitoring Communications Inspection and maintenance Safety training and skills
Office Automation	Tele-conferences Project review and evaluation Project documentation Marketing
Design Phases	Preliminary and detailed design Lighting and ventilation simulations Data exchange Fire/safety/access assessments Scheduling and progress reviews
Special Areas	Nuclear industry Subsea inspections and work Near space operations Micro inspection and testing

impression that the model or synthetic world is real [3]. The virtual world is generated by a specialised computing platform and is conveyed to the operator using the human sensory input channels. At the same time, extraneous impressions of the real world are excluded. VR tools for simulating construction processes and site environments fall into the two categories of immersive and non-immersive VR systems.

Immersive VR systems are where a user dons a headset and gloves in order to take an active part in the virtual domain maintained by the computer. In this way, the user can simulate the behaviour of a tower crane operator or participate in a training session. The other approach is called non-immersive VR and is where a user is outside the virtual world maintained by the computer. In general, the user looks at a flat screen and comprehends the virtual world from outside. This approach is also called Projection VR.

Typically, an immersive VR system comprises a sophisticated computer system to maintain the synthetic world for the user, a headset with displays which are matched to the eyesight of the operator, a means of interacting with the synthetic world such as a hand-held wand, glove or speech recognition system, a pair of headphones for supplying auditory information and a method for tracking the body of the user so that the position and orientation of the

Figure 1 **Head-Mounted Display**

sensory channels of the operator may be determined. A photograph of such a system is shown in Figure 1. By swathing the eyes and ears of the operator, much extraneous information from the local environment is blocked out which reinforces the experience of immersion for the operator.

A simple calculation shows that a computer capable of over ten thousand million floating point operations per second (10 GFLOPS) is required in order to generate a flow of synthetic images which exceeds the capacity of the human eye to distinguish individual frames. Comparable levels of computing power are required in order to synthesise the effects of a sound source that appears to move in space around the operator [4]. While these numbers are beyond the reach of desktop machines at the present time, price versus performance statistics suggest that computers with this processing power will be available within the next ten years.

2.0 A building design system using virtual reality

In order to demonstrate the feasibility of using Virtual Reality for building design and visualisation purposes, two complementary computer systems were integrated using a local-area network. A computer-aided building design system was modified to allow its results to be visualised using an immersive VR system produced by researchers at Reading University. The Master Project Coordinating Program (MPCP) was developed to design highly-serviced buildings usually found on business parks, a typical example of which is shown in Figure 2. Such buildings are generally either two or three floors in height and have simple layouts on plan [5].

A modular, industrialised building system was developed which took advantage of manufacturing automation and on-site robotics. At the same time, a general building model was developed using an object-oriented representation scheme. A Blackboard shell was used to filter the changes that were requested by the designers. The architecture of the MPCP is shown in Figure 3. In practice, the designers used a copy of the building model and were allowed to work on it providing that no-one else was changing the model. The needs of different designers were accommodated by translating the 3D model of the building into a form that was relevant to their particular activity [6].

The VR system developed at the University of Reading is based on a home computer

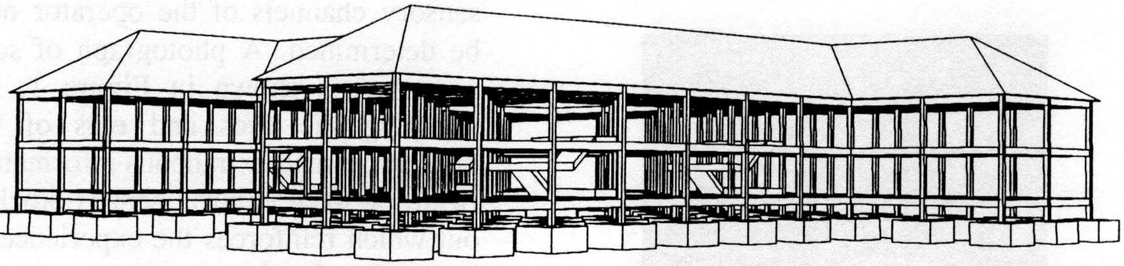


Figure 2 Typical Building Frame

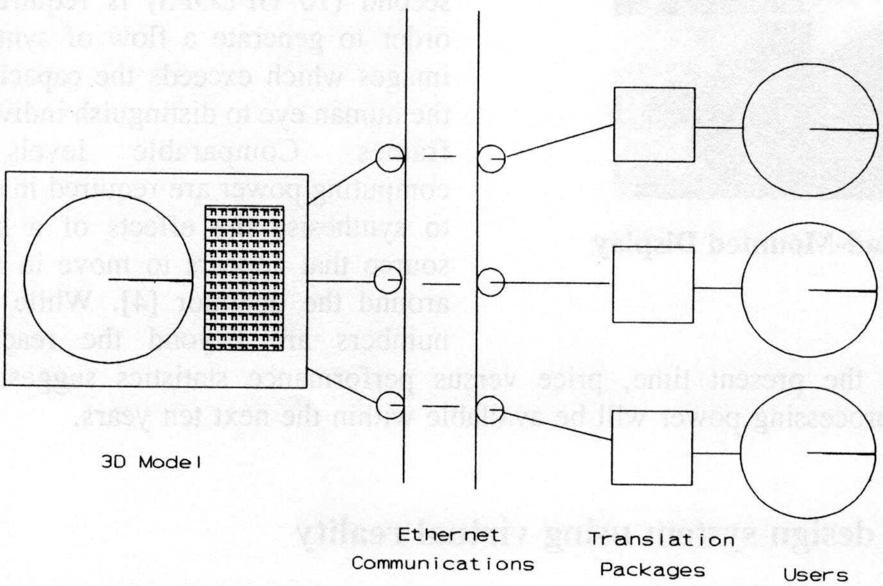
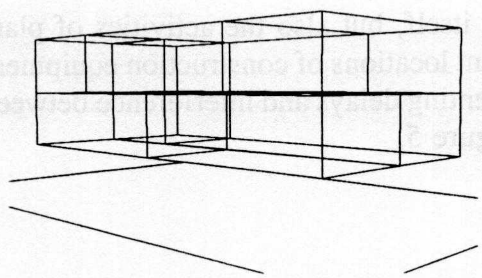
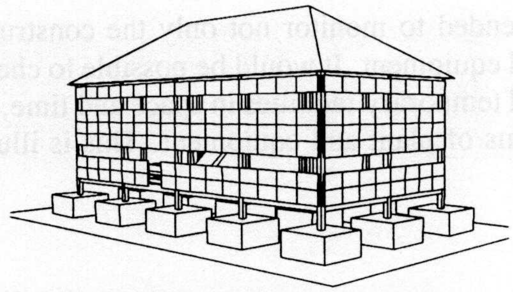


Figure 3 Architecture of the MPCP

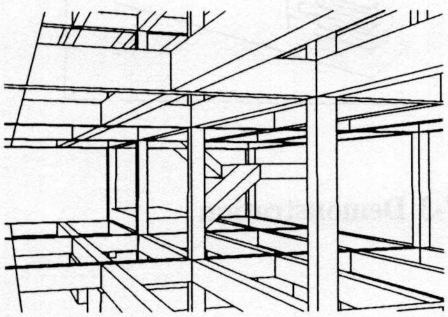
delivering stereo image pairs to a helmet-mounted display. Binaural sound is also available via a pair of speakers attached to the helmet. The orientation and position of the user's head is tracked using a magnetic tracking system incorporating three mutually-orthogonal coils. The VR system was attached to the existing MPCP infrastructure by adding it as another client and reading the 3D model into the VR world database. It was thus possible to wander through the CAD model of the building using the VR system. Sample output is shown in Figure 4 and were generated while the MPCP was connected to the VR system over an Ethernet network. Design changes were made to the building model by the MPCP and were immediately displayed by the VR system. In principle, there is no reason why many VR-based users could not have had equal access to the MPCP during a project meeting.



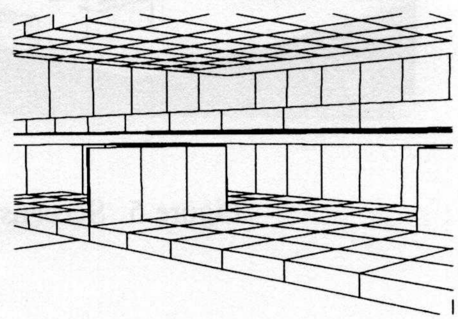
(a) **Volume Layout from MPCP**



(c) **Building with Cladding**



(b) **Structural Frame**



(d) **Wall and Floor Units**

Figure 4 **Sample output from the Reading VR system**

3.0 Visualising the construction process

The creation of a VR-based visual interface between a computer and user for a construction context would not only facilitate the validation and evaluation of the generated construction plan but would also support further decision making such as resource allocation and progress monitoring. Computer graphics development has already led to a variety of visualisation tools and simulation techniques for the construction planner. For example, methods exist for integrating computer graphics with artificial intelligence tools in civil engineering [7]. The problem is that existing computer-based design tools were originally developed for designers to deal with the design of a product. This meant producing drawings or models of a building or structure. By contrast, construction planning tasks such as scheduling are an example of process design.

The visualisation and simulation of a construction process may give a planner a better perception of the complexity of a project. In large scale projects, the approach can be extended to monitor not only the construction process itself, but also the activities of plant and equipment. It would be possible to check the different locations of construction equipment and temporary facilities in space and time, thereby preventing delays and interference between items of plant and equipment. This is illustrated in Figure 5.

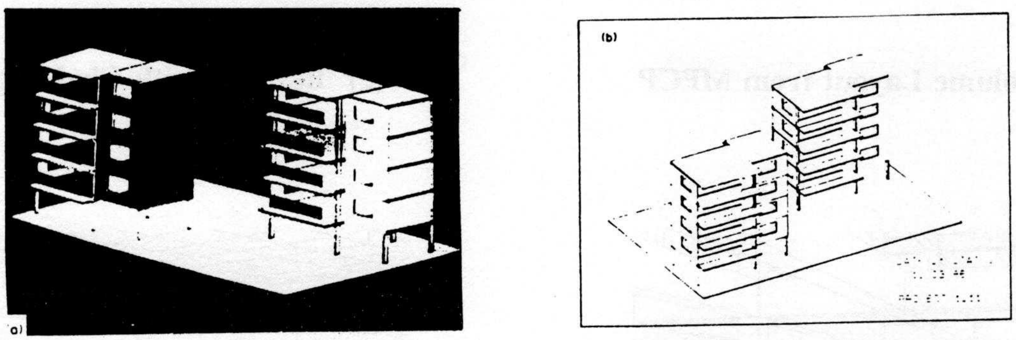


Figure 5 **Screenshot from VRT-3 Demonstration**

Currently, research work at the University of Strathclyde is investigating collaborative visual planning and simulation of the construction process using the medium of Virtual Reality. Interactive collaboration will be through the medium of the VR model of the site and will employ intelligent simulation of the construction process. The interface will also help the users verify and refine the construction schedule for on and off site work. This schedule will have been generated by a knowledge base of the system which integrates construction progress with on site activities and plant in a dynamic fashion.

The use of 3D graphic models of buildings and structures will be used to visualise the basic activities of the construction processes, as detailed elsewhere [8]. The planner will be able to observe the progress of the simulated project using different scenarios, or at various stages of execution. Deviation from a planned schedule may be shown using different colours. As a result, the planner will see not only that a delay has occurred, but also its location. Moreover, an expert system can be incorporated into the managerial part of the system to advise on what actions may be taken to rectify such situations.

In order to use such a dynamic visual status of the project activities during the construction process, it is necessary to present a comprehensive picture of the project including new structures, landscape development and site organisation with plant and facilities. This is illustrated in Figure 6. The visual status of construction work progress related to the site organisation is very important to project planners and managers as it gives them the ability to compare and validate several alternatives for plant and facilities location on site. It is hoped that improved information will help the planner to arrive at better solutions.
Different levels of detail are needed during the project simulation compared to the

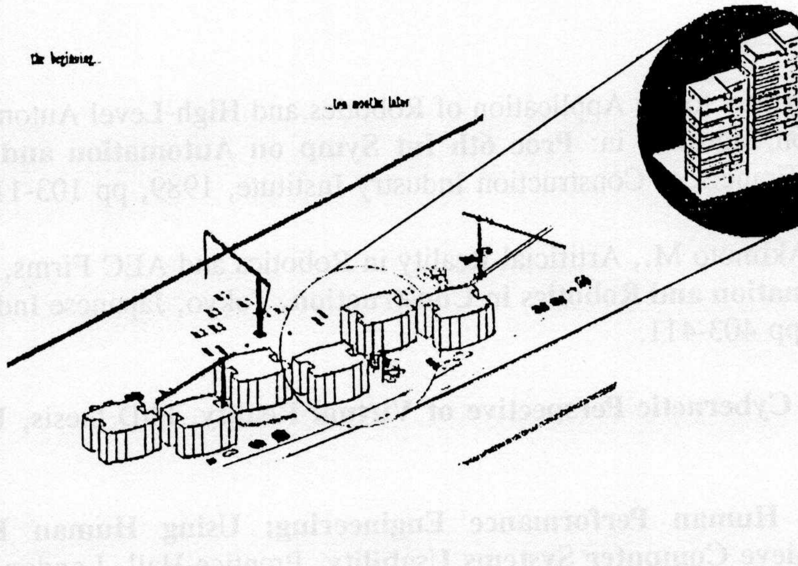


Figure 6 **Screen-Shot from Scheduling Demonstration**

construction phases. Each building may be presented by work elements or segments, examples of which might be a structural assembly or finishing works. Every segment is associated with a group of activities requird to complete the segment. As a result, each segment may be represented by its constituent activities, the activities of each of its major trades, or the activities of its various responsibility groups. Each of these sub-activities needs to be monitored separately for its actual versus planned status. Three hierarchical levels have been identified as sufficient for planning and monitoring tasks [9]. The use of VR visualisation techniques will dramatically improve the presentation of the relevant information.

4.0 Conclusions

This paper has demonstrated that there is potential for the application of VR technology to several areas in the building and construction industry. Initial research conducted by the authors has shown that it is possible to interface a VR workstation to separate scheduling and design systems and thence display the results of construction-oriented activity. It has also been shown that the different users need not be at the same site, but can be spread geographically over a large area. Furthermore, it is conceivable that data interchange and site meetings will be conducted through the medium of a 3D model of the building maintained by the VR system. These changes to current working practice promise improved productivity and may lead to more information-intensive design and scheduling methods as the technology becomes more widely accepted by the industry. Other potential application areas for VR have been identified and will become the subject of research in the near future [10].

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