INTEGRATION OF VIRTUAL REALITY WITHIN THE BUILT ENVIRONMENT CURRICULUM

SUBMITTED: July 2005
REVISED: December 2005
PUBLISHED: May 2006 at http://itcon.org/2006/23/
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SUMMARY: *Virtual Reality (VR) technology is still perceived by many as being inaccessible and cost prohibitive with VR applications considered expensive to develop as well as challenging to operate. This paper reflects on current developments in VR technologies and describes an approach adopted for its phased integration into the academic curriculum of built environment students. The process and end results of implementing the integration are discussed and the paper illustrates the challenges of introducing VR, including the acceptance of the technology by academic staff and students, interest from industry, and issues pertaining to model development. It sets out to show that fairly sophisticated VR models can now be created by non-VR specialists using commercially available software and advocates that the implementation of VR will increase alongside industry's adoption of these tools and the emergence of a new generation of students with VR skills. The study shows that current VR technologies, if integrated appropriately within built environment academic programmes, demonstrate clear promise to provide a foundation for more widespread collaborative working environments.*

KEYWORDS*: virtual reality, built environment, integration, academic curriculum.*

1. INTRODUCTION

Students entering higher education are increasingly computer literate. Growing up in an age of digital media, students have expectations that they will be introduced to appropriate information technology (IT) skills required by their profession. This poses a great challenge to academics who have to consider how to respect this expectation yet balance it with the demands of carefully designed curricula to meet the requirements of industry. Since the advent of computer aided design (CAD) into academic programmes in the early 1990s we have seen an ongoing debate and concern for appropriate integration (Ahmed et al, 2004). Whilst there have been many advances over recent years, CAD for many still means electronic drafting – ie a new tool for an existing skill, with 80% of drawings still done in 2D (CIRIA, 2005).

Virtual Reality adds to the heterogeneity of techniques now available for architectural design, representation and beyond (Giddings and Horne, 2001). The history of VR can be traced back to the 1950's with early applications developed for the military and engineering industries. Within the AEC industry, whilst some argue that it has been architectural design which has been the main driving force for developments in three-dimensional modelling and Virtual Reality (Bouchlaghem et al, 2005), substantial research has been conducted into the simulation of the construction process and has been directed towards exploring the potential of 4D/VR technologies (Dawood et al, 2002). The use of Virtual Reality for design and wider involvement is not widely diffused throughout the built environment industry (Whyte, 2002) and many architectural practices are sceptical. Additionally it is estimated that only about 3% of universities worldwide teach VR today (Darken et al, 2004), and those concerned with the state of VR education are searching for the reasons for this low level of integration.

The School of the Built Environment at Northumbria University is one of the largest providers of Built Environment education in the UK. In 1998 the School introduced an undergraduate degree in Architectural Technology (AT) in response to a growing need for specialists to bridge the gap between design and construction: specialists having the skills to resolve design and technical issues and ensure optimum building

performance and efficiency. An architectural technologist 'will be able to analyse, synthesise and evaluate design factors in order to produce design solutions, which will satisfy performance, production and procurement criteria' (CIAT, 2005). CAD and VR are key subjects for the architectural technologist who needs to visualise and analyse new technologies and communicate options to various design teams and clients. CAD and VR, whilst resulting from the spectacular evolution of computer animation (Thalmann and Thalmann, 1992), are perceived to be extensions of the traditional forms of representation, which are still respected and introduced to students throughout the School. During the past decade industry has been forecasting that as the price of technology decreases, VR will become more widespread in its application as software will be able to describe the look, sound and feel of an artificial world, down to the smallest detail (Gates, 1996). The rapidly developing computer games industry is a major contributor to decreasing prices, and is also offering architects lessons in the creation of artificial worlds (Richens and Trinder, 1999). Leading executives of the CAD industry, attempting to predict likely developments in the 21st century, forecast an increase in the acceptance of three-dimensional modelling and the possibility of working in a 3D environment from the beginning of the design process (Smith, 1999).

In anticipation of these changes, in 2003 it was decided to introduce VR into the School of the Built Environment, initially for students of Architectural Technology as an aid to visualising design and construction, but longer term for staff and students of other AEC disciplines. This paper reviews current developments in VR technologies and issues pertaining to its introduction. The study offers a case study of the integration of VR into a design project of final-year Architectural Technology students. The approach adopted for this integration is examined alongside an analysis of the process and end results of VR implementation. Conclusions are drawn relating to value of adopting an integrated approach for students' learning and the potential of the technology to be introduced to students of other AEC disciplines to further collaborative working within the School of the Built Environment.

2. DEVELOPMENTS IN VIRTUAL REALITY

Virtual Reality is the name of the interactive computer technology that attempts to create a completely convincing illusion of being immersed in an artificial world that exists only inside a computer (Rheingold, 1991). VR adds the dimensions of *immersion* and *interactivity* to three-dimensional computer generated models. It enables the exploration of designs and the consideration of alternative options not offered by any other form of traditional representation. However the technology is still perceived by many as being inaccessible and cost prohibitive. Expectations from the highly publicised VR 'centres of excellence' several years ago were not fulfilled, and VR applications proved time-consuming and expensive to develop as well as challenging to operate. Specialist centres were set up to help companies assess the potential of VR without investing in expensive and easily outdated computer hardware and software (Stone, 1994). This process has now changed and some of the factors leading to this change are reviewed by discussing the VR systems currently available.

2.1 VR Systems

Virtual Reality can be of a type known as '*full sensory immersion*' where the user wears headsets and maybe gloves to gain a total immersive feeling of 'being' in a simulated environment. Applications of immersive VR have been seen in the fields of aeronautics, medicine and military applications – developed often at high cost by those whose need for a prototype was justified. To enable more participants to experience a simulated environment, a type of '*semi-immersive VR*' describes small cinema-like studios where audiences can share the feeling of being in a scene, although the navigation is usually in the hands of an experienced operator. CAVE installations can also be described as '*semi-immersive*' as the participants can be surrounded on three sides by screens onto which are projected images of a scene (Shiratuddin et al, 2004). A third type of VR is becoming known as '*desktop VR*' and the increasing power of PCs and graphics cards is making the technology accessible to those with computers typical of those found in many offices.

The performance of the computer hardware selected for VR has to be such that simulated scenes can be navigated in real-time and that users' exploration is not hampered by hardware limitations. Hardware needs to be compatible with software already in use and software planned to be used, and configurable to display the scene on a large screen system.

Whilst considerable advances have been made in CAD software and architectural design programs such as AutoCAD, ArchiCAD, Revit, MicroStation and SketchUP, commercial software developers have as yet paid

little attention to the prospect of immersive virtual environments for design (Anderson et al, 2003). However VR software is capable of producing visual interpretations in real time which can enable the exploration of ideas and scenarios. There are have been a number of PC-based VR systems, including Superscape, VRML and World Tool Kit, tried for their suitability for use in the AEC sector. Some products are also being developed which offer VR as an 'add on' to CAD packages already widely used by the industry. As in the early days of CAD, software selection and implementation is far from straightforward as users are faced with many choices. A key criterion for selection is usually 'ease of use' which can be facilitated by choosing familiar computing environments and tried and tested commercial applications wherever possible. (Otto et al, 2003).

2.2 Users of VR Systems

Successful implementation of VR begins by considering *who* will be the users of the facility and *how* it will be used. The participation of end users in the adoption process can assist in better defining needs explicitly and increasing the opportunities of having successful technology adoption (Fernandes et al, 2004). This will drive the various design decisions that need to be made when considering a VR facility. The financial and human resource investment in implementing VR has to be balanced against the returns on any investment in computer hardware, software and space requirements for the VR facility.

The requirements of the users will also determine the location of a VR facility. Whilst a single mounted headset display may be the most appropriate type of VR simulation for flight simulation, in the AEC industry it is likely that VR will be used for collaborative purposes and the space and location should be designed with this in mind. The integration of hardware and software within the VR facility still remains in the hands of the VR specialists, but advances in computer PC hardware and software are resulting in more affordable systems which can be used by non-computer specialists.

3. INTEGRATION OF VR INTO THE ACADEMIC CURRICULUM

Increasingly it is becoming acknowledged that visualisation can assist all AEC professionals, from the presentation of an initial concept to the effective planning, management and maintenance of a project. The benefits and applications of VR for AEC have been investigated for over a decade (Bouchlaghem et al, 2000), but the relentless developments in computer hardware and software are making its practical implementation more possible. Given recent advancements in computer technology it is believed that four-dimensional CAD technology will have strong potentials and will impose significant impact on construction management practice (Chau et al, 2005).

3.1 Introduction to VR

The initial inclusion of computer-related subjects as stand-alone modules in the structure of academic programmes is an established technique within the School of the Built Environment. Once students and staff become more familiar and confident with a computer application, further integration into other subject areas evolves, and, to date, elements of IT appear in many modules throughout the School. The adoption of this approach has provided opportunities to assess the stability of new technologies and appraise potential applications for other subject areas. In a discussion of the role of today's technology in the architectural design studio (Thompson, 2005) reference is made to the premise that computing may not simply be a subject to be taught in its own right, but a component part of almost every other subject in the curriculum (Bridges, 1986).

The relatively new profession of the architectural technologist has a specific need to be able to simulate and interact with a model in order to resolve both design and technical issues and to ensure optimum building performance and efficiency. Students of architectural technology had an immediate requirement to apply VR to enhance buildability and performance in their design projects. However, to consider the longer-term possibilities of integrating VR within the broader curriculum, for all built environment students, it was decided to design a stand-alone module entitled VR for the Built Environment which was seen as progression from the introduction of CAD (Year 1), Building Information Modelling (Year 2), with VR strategically placed to be introduced to final year students. This module was designed to introduce students to the theoretical aspects of VR, including the planning, management, documentation and archiving of VR projects, as well as hands-on use of the software.

3.2 Model for Integration

An approach was adopted to implement the integration of the knowledge and skills acquired in this VR module with the undergraduate architectural technology students' final year design project (Fig. 1). This integrated approach was adopted to minimise the time pressures and risks on students, increase their motivation and encourage to them to apply the software to their discipline in a focused way.

The first group of twenty undergraduate architectural technology students to use VR did so from October 2004 to April 2005. Their degree is a 4 year modular programme structured around several core areas. IT provision had been introduced strategically alongside other modules, culminating in the integration of this knowledge and skills within their design project.

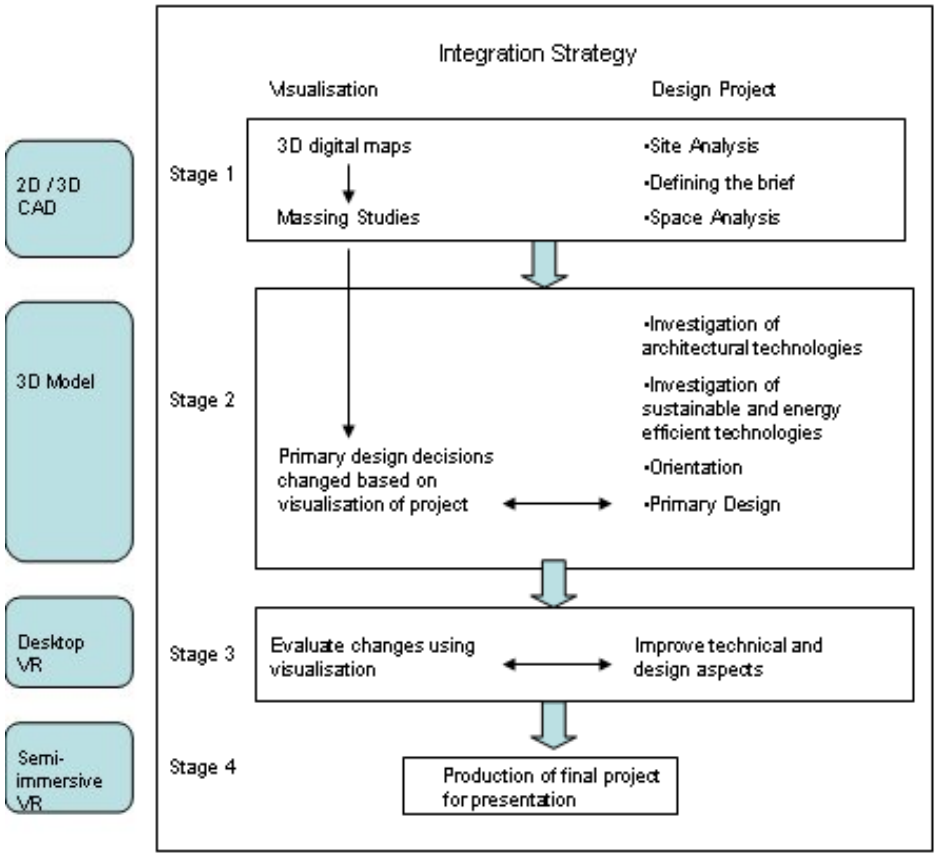

FIG.1: Integration Strategy of Visualisation into Architectural Technology Curriculum

3.3 Visualisation Software Selection

One of the criteria for software selection in the School is that the software is used by industry. For the purposes of visual communication the following process is adopted:

- **Year 1** 2D CAD (AutoCAD) - to provide accurate 2D representation of project design.
- **Year 2** Computer Aided Visualisation and 3D Modelling (Revit) – to provide credible 3D representation and enable spatial assessment.
- **Year 3** Year in industry – to see the actual position in practice.
- **Year 4** Virtual Reality (3dsMax, VR4Max, Stereoworks) – to enable interaction and depth perception when viewing design.

VR4Max was selected as being suitable for VR for AEC as its development is not only focused for the games industry, as is the case with some other VR software products. This strategic approach ensures that students have been introduced to the underlying theory in each subject area, as well as developing knowledge and skills in application of the software. Having acquired this knowledge, students are encouraged to apply it in other subject areas, and demonstrate appropriate integration into their modular programme. This approach requires staff in

other disciplines to keep abreast of software developments in order to understand the potential for integration into their subject areas. Students were introduced to VR using both desktop VR and semi-immersive VR.

Desktop VR facilities were introduced to provide access for up to thirty students. VR software (VR4Max) was chosen that could interface with the commercially available CAD and Visualisation software (AutoCAD and 3ds Max) already used in the School. This enabled the direct transfer of data from traditional CAD systems into VR. The VR software runs on Compaq D530, Pentium 4, 1gb ram workstations with Matrox Parhelia AGP 128mb graphics cards. In addition to the thirty licences of VR software provided by the School, students were also able to purchase their own student licences to run on their own PCs. This option greatly facilitated and enhanced students' learning. Students begin by importing 2D CAD data into 3dsMax where they build up their 3D model prior to export into the VR software.

3.4 Semi-Immersive Virtual Environment

In addition to desktop VR facilities, the School also implemented a semi-immersive Virtual Environment which has been located in a well-situated, central position to allow convenient access for students and staff. This facility consists of a single 244 x 183 cm passive stereoscopic, rear-projected display screen driven by a Dell PC with dual P4 Xeon processors and NVIDIA Quadro FX 3400 graphics cards. Passive stereo projection is handled by Stereoworks (Engineering Talk, 2005), a range of software systems launched by Virtalis in 2003, and a left eye and right eye image is projected by two Christie Digital DS 3000 lumen projectors. The projected images are precisely overlapped onto the screen and passive stereo viewing is enabled by the use of inexpensive polarized plastic glasses, practical and affordable for student use and occasional large audiences. The facility can be used by groups of up to thirty participants and allows students to view their designs in stereoscopic format, from multiple viewpoints, and to navigate through space in real time. A cordless mouse allows user interaction with the system and a wireless control panel enables projectors, mono / stereo display, lights and sound to be controlled from one convenient source. The familiar Windows desktop environment resulted in an immediate confidence by users to operate the system and encouraged other academics in the School to consider that the technology was not as 'out of reach' as they had perceived. The implementation of the semi-immersive Virtual Environment included the additional installation of six workstations to be used by students and staff specifically for 3D modelling and visualisation. This was seen as an important inclusion in order to maximise the use of the facility from the outset, to promote possibilities of collaboration, and to demonstrate potential applications of VR to projects.

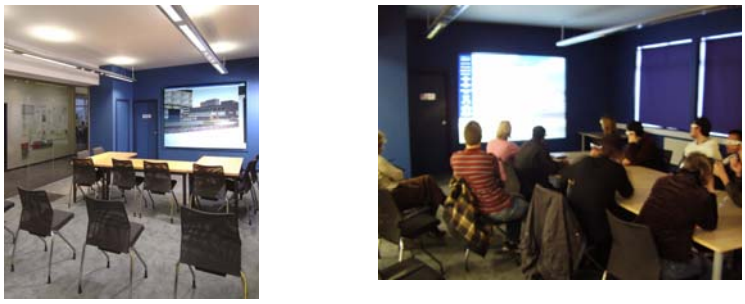

FIG. 2: Collaborative Virtual Environment

4. STUDENT PROJECTS

4.1 The Process

Students were requested to examine the available VR technologies and to select and apply appropriate approaches for the development of an interactive simulated environment. They were asked to focus on the building they had designed for their final year design project and to produce end results which would enable an interactive exploration of the building.

The majority of students developed their visualisation project from CAD plan drawings, massing and contour maps, which had been submitted for their design project. These design projects were imported into 3dsMax and used as the basis for the 3D model, developed by creating objects using a combination of simple primitives, Boolean operations, spline extrusions and AEC objects for walls, compound objects and pre-defined objects such as doors, windows and foliage.

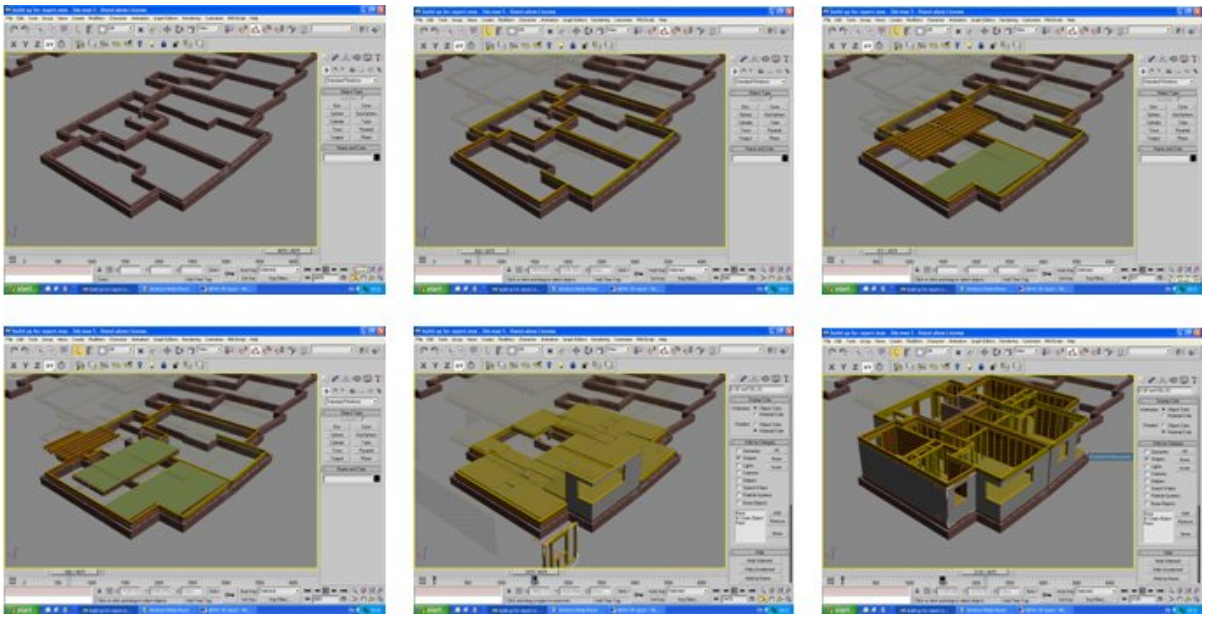

FIG. 3: *Process of 3D Model Construction (Student: Peter Jones)*

All students modelled both the interior and exterior of their building and mapped appropriate materials and textures onto faces of the geometry. Many material libraries are now available in commercially available software and also via the Internet, although some students preferred to avoid excessive use of materials so as not to detract from the actual design of the building itself. Students added lights and cameras to their 3dsMax model and included aspects of the site landscape. Surrounding buildings were simply massed from available 2D site plans. Prior to exporting the 3D model into VR4Max students learnt how to define helpers within 3dsMax which were used to match views to specific cameras and then attach key-board presses to these views. This achieves a user-friendly way for participants to view the model and examine important issues which may influence design decisions. Helpers (Fig. 9) were also defined to enable on-screen toolbars, simple key-board presses or mouse clicks to control behaviours of the model within the interactive environment of the VR world.

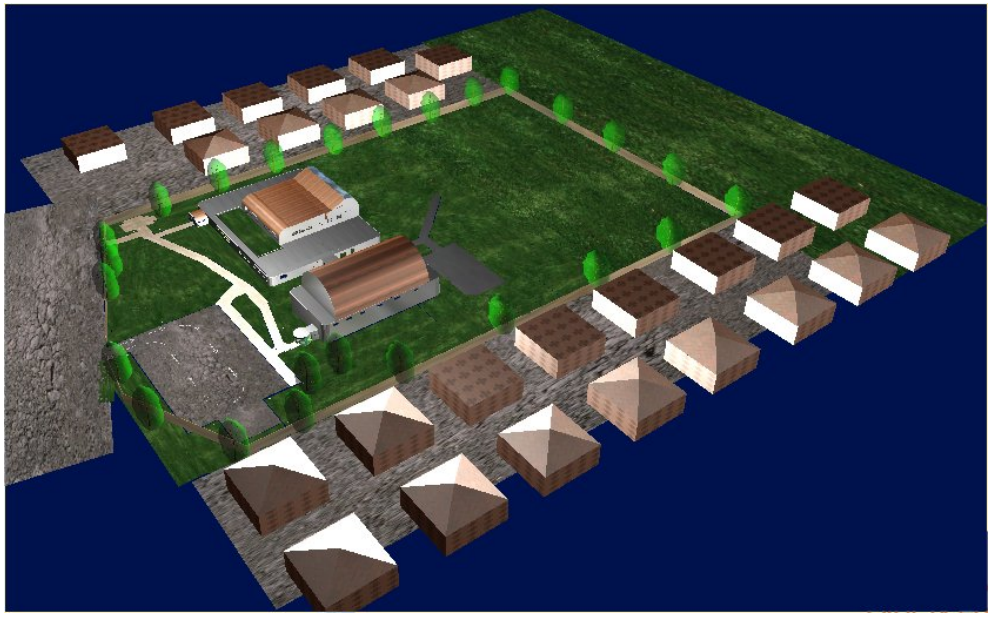

FIG. 4: Massing Studies (Student: Garry Bothwell)

The final 3ds file was translated into vmx file format and imported into VR4Max software which enabled navigation through the model. Students planned their requirements of pre-programmed animations within the interactive model by making use of storyboards, which helped develop a systematic, logical approach and

consideration of the required level of detail (Bartlett et al, 2003). As familiarity with the software improved, students were able to use it for casual exploration of design options and quick massing studies, focusing on the design itself rather than the operation of the software.

4.2 End Results

Student projects demonstrated a concern for applying the technology appropriately for the needs of their profession. All twenty students were able to develop a model which enabled real-time interaction, with users being able to fly freely around and through a building prototype. All students developed a model which enabled the user, by pressing a key on the keyboard, to cycle through various views of their building and within their building. Fourteen students incorporated a representation of the site and analysis of the external influences on their proposed building design.

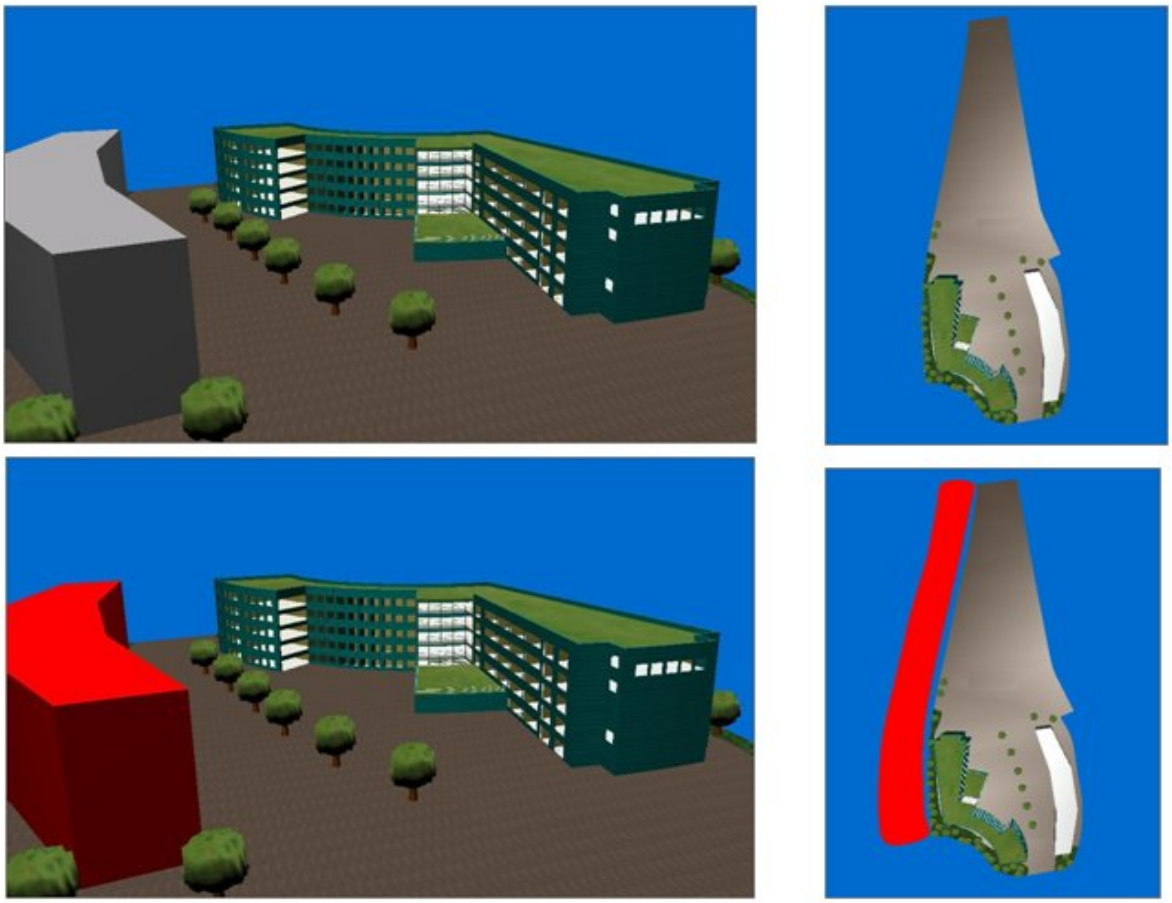

FIG. 5: VR model of new campus building highlighting external influence on design (Student: Ryan Bird).

Fifteen (out of twenty) students incorporated interactive behaviours, that can be switched on or off via the keyboard, and these enabled the:

- opening and closing of doors,
- opening and closing of roof to view interior layout of building,
- site analysis considerations,
- movement up and down stairs,
- exploration of external material cladding options,
- exploration of internal door and wall materials,
- exploration of roofing materials,
- movement of elevators,
- movement of vehicles,
- commencement of walk through the building to illustrate use of internal space and
- commencement of fly over the building to illustrate context within the site

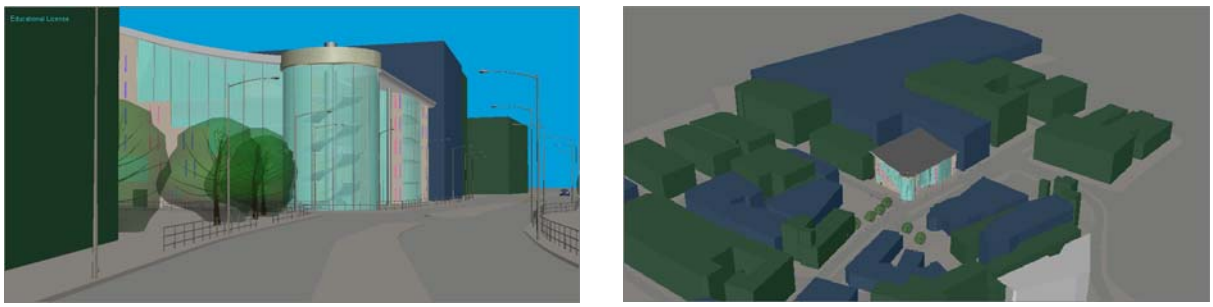

FIG 6: VR model showing context of building within surrounding site (Student: Andrew Forbes)

Students incorporated screen menus to enable the exploration of material design options very simply, via one mouse click, by a user.

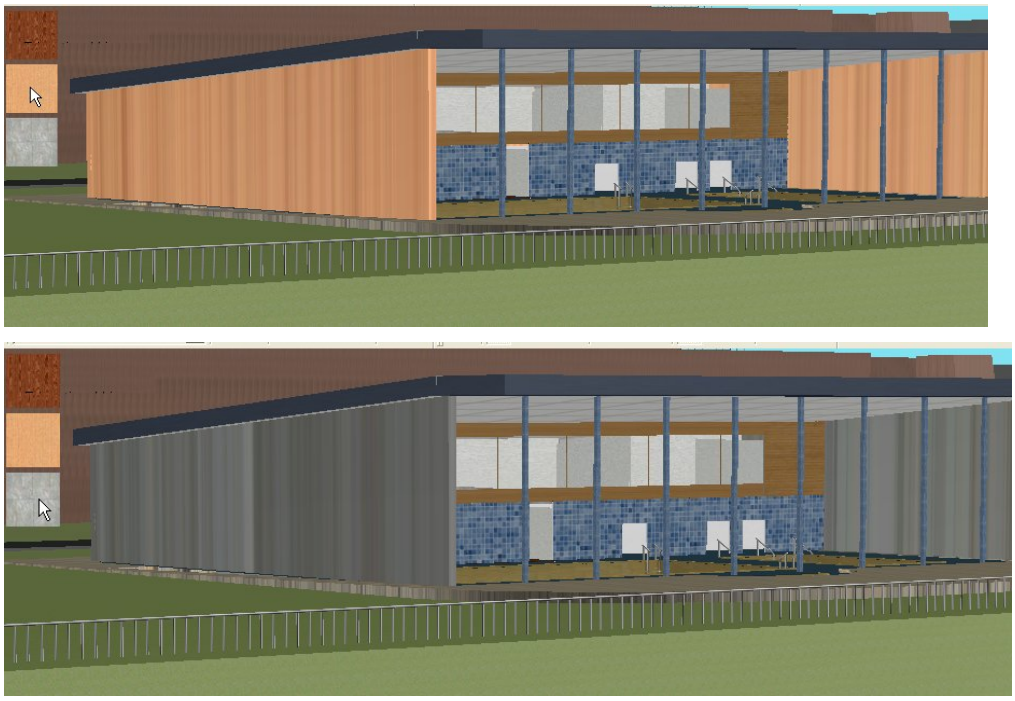

FIG. 7: Sports Centre showing screen menu to enable exploration of material options (Student: Rowena Rowell)

One student had identified an emerging requirement from the timber framed house industry to have 3D interactive models of such constructions in order to explore the technology for the timber frame, steel elements and roof structure. Consideration on appropriate level of detail and computer real time performance was given throughout this project. Materials were assigned to all the areas where highly detailed geometry would have been the other alternative solution, for example in the representation of brick and block-work, roofing tiles etc. Texture maps were used to add to the realistic representation of insulation materials, plastics and soil. Timber components were simply assigned a standard colour rather than attempting to represent the grain of the wood. The end result enabled the interactive exploration of the building and representation of the technology and materials through cut-away sections of the various components.

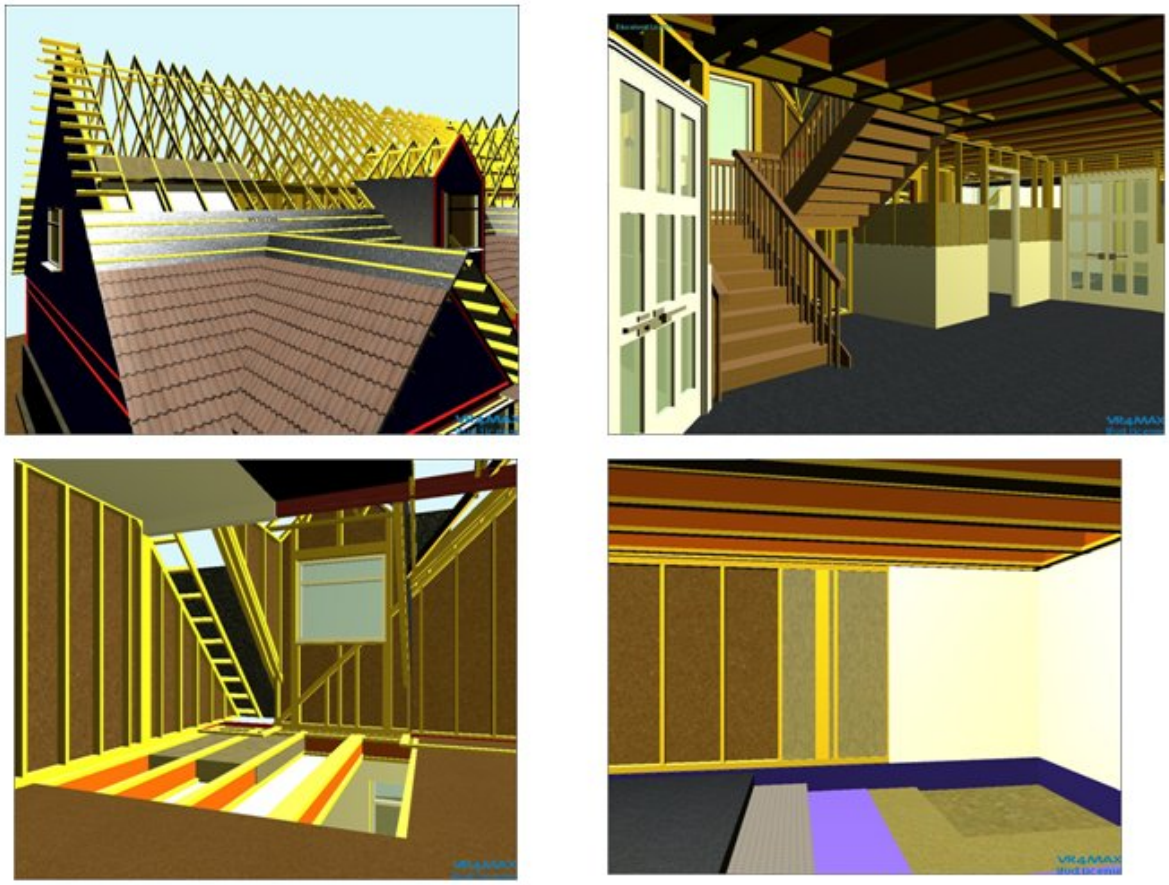

FIG. 8: Fully interactive VR model of timber frame house showing construction details. (Student: Peter Jones)

Fig. 9 shows the geometry, behaviours and simple screen menu for the timber frame house project. Fifteen behaviours were defined in this model to enable the user to select important views and camera paths in addition to interacting with the model.

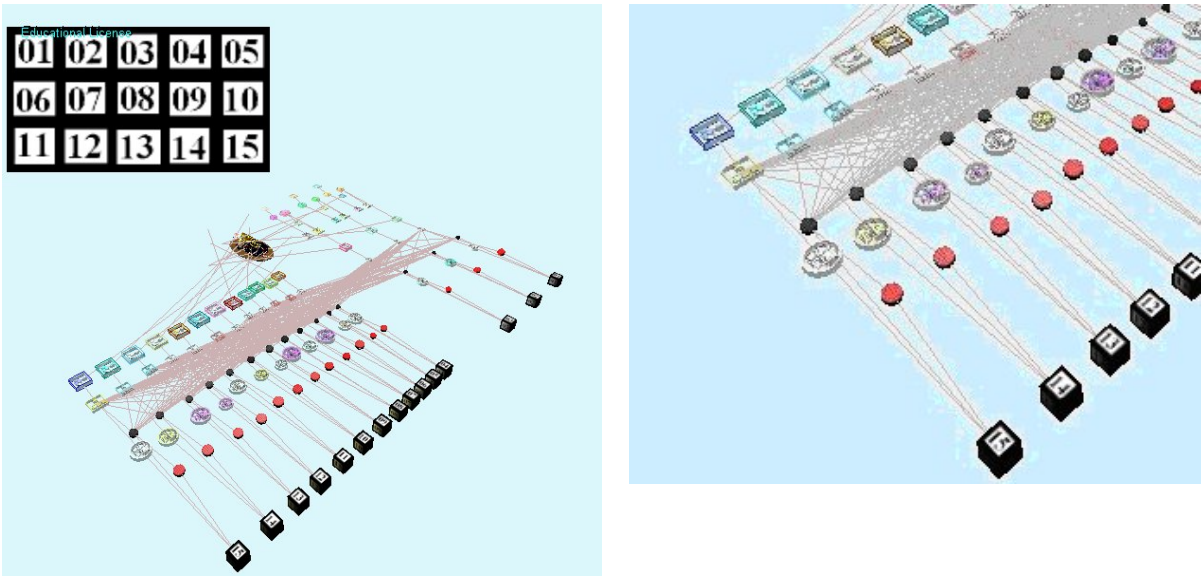

FIG. 9: Geometry and behaviours of design for a timber frame house (Student: Peter Jones)

4.3 Feedback

All students were requested to reflect on the effectiveness of their end results and submit this in written form. Additionally, 75% of the students had spent their previous year on professional placement and these students were organised to form a focus group so that information could be gained about their shared experience of applying VR to a design project. Focus groups can be useful after a programme has been completed to assess its impact and can be used as a method in their own right or as a complement to other methods (Morgan, 1988). The practical organisation of the focus group meeting was enabled by planning it to take place soon after the students had completed their VR model and presented it as part of their projects at the Design Project Critique, but prior to the start of their examination period. This ensured that all students attended and felt valued as experts in an emerging field. Those students who were less articulate in this group still had the opportunity to offer their reflective feedback in written form. Comments most often cited were:

- Beyond initial expectations – VR enabled flexible navigation and interaction with the model.
- Experienced a sense of space and feel for what the building would be like. Feelings of immersion were achieved by techniques such as:
    - doors opening on approach,
    - being able to follow the plane of the terrain when navigating through the model,
    - being able to avoid collision into walls, trees etc.
- Enabled programming of key presses, and design of screen menus, which facilitated presentation to other people and also operation by people of any technical ability.
- End result could be useful in highlighting areas of the model which required more work or part of the design that did not work very well.
- Improved speed of rendering of interactive model, although with less detail present than in 3dsMax animations.
- Credibility – the models had been based on accurate CAD data.

Their evaluations on reasons why the technology could be applied and integrated into professional practice were that VR could:

- Extend the traditional forms of representation.
- Improve communication for those people not familiar with interpreting 2D plans, sections and elevations. Avoid misunderstandings.
- Enable a client to not only see what his project would look like, but also to be able to interact with it.
- Facilitate the discussion of ideas and options prior to construction. The use of interactive technology in the initial stages of project design can enable issues concerning buildability to be highlighted early in the design process. Alternative surface textures, materials and colours can be explored by easy to use screen menus.
- Enable a client to see his project in the context of its surroundings.
- Enhance the image of a professional practice through using leading edge technology when submitting feasibility studies to clients.
- Attract funding and investment sources.

Other views that emerged from student feedback were in the areas of:

- Including the theory of VR should continue to be an integral part of the programme, and complement skill acquisition.
- Practicality - VR technology offering interactivity can now be run on personal computers, including laptops, typical of those in use in many offices.
- Productivity - The import / export facilities of commercially available software using familiar Windows interface enhances confidence and speed of productivity in creating interactive models.
- Generalisation - the technology could be used for many different applications. Students identified how it could be usefully employed by planning authorities considering a development proposal. They considered that it could be usefully applied for future development strategies by those responsible for the management of a site of buildings, say a hospital, government or private initiatives. They perceived its potential application for company marketing, client brief development and training.

Students reflected that linking VR to their professional practice project was very useful as they had a detailed understanding of the building to be modelled. They appreciated the importance of systematic file organisation and management and the ability to prioritise what level of detail was necessary to produce an appropriate representation. For their final presentation students presented their VR models alongside paper plans, sections, elevations and 2D renderings, supporting the view that VR, if used appropriately, supplements and extends other forms of traditional representation. The Design Project was assessed by a panel of two academic staff members plus two independent assessors from industry, with backgrounds in architectural design and technology. The independent assessors observed how the students attempted to integrate their VR models appropriately into the presentation of results. They encouraged continuation of this integration with more emphasis on using visualisation for communicating the interface between materials and related operational and maintenance issues.

5. FUTURE DEVELOPMENTS

The qualitative feedback from this case study has provided lessons which can be used in determining a correct integration methodology between two subject areas. The VR module and Design Project module were assessed separately to minimise the risk to students at this stage of investigation. Tutors noted that some students spent a longer time learning how to use the software, which affected their focus on design and choice of architectural technologies. Future integration for architectural technology will encourage the students to focus more on visualising the interface between various constructions and finishing materials. The development of further subject specific VR tutorial material and workshops will speed up the process of skill acquisition and enhance the appropriate application of the technology.

5.1 Model Development Challenges

Virtual Reality technologies, adding the components of *interactivity* and *immersion* to building models, are not yet widely used in the built environment due to the cost and time required to develop the models. The students who mastered the technology described in this paper had been given time to do so within the modular structure of an academic curriculum. Students commented that time and training would be necessary to implement VR into architectural practice. Specialist visualisers, either internal or external, are still often used when VR is required. The creation of a VR model is often based on the availability of traditional 2D and 3D CAD data which is them imported into software applications such as 3ds Max and Superscape. This involvement by third-party specialists adds to the production time and cost of VR models. However, recent advances in commercially available object oriented modelling software are offering new challenges to both working practice and educational establishments.

Interest in building information modelling technologies is resulting in emerging strategies for its adoption, subsequent evaluation, and potential for integration. The advent of parametric building information modelling software which considers massing elements and building elements (walls, columns, doors, windows etc.) rather than geometric lines, points, faces and surfaces (as in traditional CAD software) heralds a new way of working. Evidence is emerging that adoption of building information modelling software is resulting in productivity gains of 40-100% during the first year (Khemlani, 2004). Students and staff who are being introduced to such software, such as Autodesk Revit, are beginning to appreciate its capabilities and potential to be used throughout a project. Whilst the three-dimensional models currently created with such software may still be too detailed to be used as VR models, because the data is object-oriented it is easier to simplify or replace certain elements when used in a VR application (Roupé and Johansson, 2004). This could extend the *nature of interaction* within VR models from that of navigation and ability to decide *what* to look at, to that of intuitive modification of objects (facades, trees, roads etc) at run-time whilst viewing the model. This extension would lend support for the belief that VR can be successfully applied to the earlier stages of design (Leigh et al, 1996) and offer the user greater control over the virtual environment, as is the case with CALVIN – an immersive approach to applying Virtual Reality in architectural design. As building information modelling is further adopted into the design process, and a new generation of students emerge into practice with 3D modelling skills, the demand for a seamless integration between building information modelling and VR will increase. The established divisions between software are becoming less distinct as technologies blend into one another (Whyte, 2002).

5.2 Further Acceptance

Although the Virtual Environment was used initially only by students of architectural technology, it is already finding a wider role, with 390 students from across the School having currently been introduced to its capabilities. Academic staff, initially apprehensive about the supposed complexity of VR, are showing acceptance of a technology which employs the familiar Windows operating system, uses wireless, unthreatening peripherals, and is conveniently located in an accessible location. Staff concerns centre on the constant need for training, necessary to keep abreast of what advancing technologies can offer. The trajectory of training and retraining (Spiller, 1998) identified a decade ago is being seen by many as essential in order to take up the challenges afforded by VR.

5.3 Future Research

It is anticipated that future research will be able to report on applications of its integration by other built environment students as the facility will enable the exploration of possible benefits of VR across a wide range of projects. After a series of VR awareness events staff are suggesting VR applications which could aid their teaching and learning programmes. Future research will report on these and the methodology for their integration. A new generation of tools is emerging for the architectural design studio (Petric and Maver, 2003) and as students and staff gain more confidence in their use we should see more widespread and earlier application. Future research will also report on how VR is taught …….indeed, the state of the whole of the VR field may depend on how we teach it (Darken et al, 2004).

6. CONCLUSION

The approach outlined in this paper, in making VR more accessible in teaching and learning, is not claiming a significant break-through in terms of innovative computing achievement, but has been focused on selecting and implementing appropriate VR technologies alongside the integration of VR into the academic curriculum of built environment students. It has shown that:

- VR technologies must be selected first and foremost to be appropriate for the needs of the users.
- VR technology is becoming less technically demanding and cost prohibitive.
- Fairly sophisticated VR models can now be created by non-VR specialists using commercially available software.
- Increased student engagement in using VR will enhance design and construction knowledge and extend traditional communication techniques.
- The careful selection of VR systems may effect greater collaboration between AEC disciplines as visualisation develops to provide substantial integrative capability.

Whilst it may have been expected that computer-literate students would have mastered the technology, the study has shown that models of complex geometry and behaviours can now be created and applied to enhance the learning of built environment students. Samples of students work have been displayed at various times in the Virtual Environment and initial reaction by visitors from industry has been one of encouragement. The facility has been used to display students' work to external examiners, professional body accreditation panels and staff and students across the School and will hopefully encourage others in the pursuit of more widespread collaborative environments.

7. ACKNOWLEDGEMENTS

Undergraduate students on BSc Architectural Technology, final year, 2004-2005 for their valuable insight and constructive feedback. In particular thanks to Ryan Bird, Garry Bothwell, Andrew Forbes, Peter Jones and Rowena Rowell whose projects appear in this paper and who endeavoured to apply VR technology appropriately to their discipline.

Funding for the Virtual Environment has been provided Professor David Fleming, Dean of the School of the Built Environment, Northumbria University.

VR specialists Insite Environments and Virtalis for invaluable advice prior, during and post VR implementation. Philip Aitman, Northumbria University Zone IT, for technical support, and Estates Services, Northumbria University, for creating the space for the semi-immersive facility.

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