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Strategic Perspectives on the Use of Virtual Reality within the Building Industries of Four Countries

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Abstract

This paper presents results from the first stage of an analysis of the use of virtual reality (VR) within the building industries of strategically selected countries, namely, China, Sweden, the UK and the US. The aims of the research are to assess VR usage and its benefits within the building industries of these countries and to identify perceived barriers to VR usage and ways of overcoming them. The countries selected offer a range of experience in the adoption of VR technologies and the paper provides an initial analysis of developments at an international level. Semi-structured interviews were conducted with senior professionals from each of six leading construction companies within each country. The findings included the rationale for the adoption of VR and the barriers to doing so, as well as some divergence between the respondents in their working definition of what visualization and, specifically, VR actually represents.

■ *Keywords* – Building industry; implementation strategy; international perspectives; interview survey; virtual reality

INTRODUCTION

The use of virtual reality (VR) within the construction industry is seen by many as holding great potential for increasing effectiveness as well as improving the democratization of the building process and urban planning. The aim of the present study was to assess VR usage and its benefits (accrued and potential) within the building industry in four strategically selected countries, namely, China, Sweden, the UK and the US. The study also aimed to identify the barriers to VR usage within the building industry and ways to overcome these barriers. This paper reports on the results obtained from semi-structured interviews with senior management.

VR IN THE CONSTRUCTION INDUSTRY

The concept of virtual reality was first articulated by Ivan Sutherland, describing the screen as a window through which to look into a virtual world (Sutherland, 1965). The big challenge for the computer graphics industry was to make the virtual world feel real. This involved looking and sounding real and responding to interaction in real time in the same way as the real world. Sutherland's vision became a goal for those wanting to adopt and develop this visionary technology for various disciplines and industries. In some of these, the use of VR has been very successful and is now well established. In 1999, at the 10th Institute of Electrical and Electronics Engineers (IEEE) Visualisation Conference (Vis, 1999) examples were given such as the use of flight simulators to train pilots, where, in some cases, the experience is very close to the real feeling.

To further these developments in the construction industry, a series of conferences and working groups, and committees that focus on information technology and communication (ITC) in the construction industry were established. Examples of these focused research gatherings are the International Conference

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on Construction Information Technology (INCITE) and the International Conference on Construction Applications of VR (CONVR), conferences held by the Council for Research and Innovation in Building and Construction, workshop W078 Information Technology for Construction, and the International Conference on Visualisation in Built and Rural Environments (BuiltViz) were organized by the IEEE. Researchers established that there are two very important requirements necessary to create an effective VR experience. One is to have adequate computing power and the second is to have an appropriate digital model that the VR experience is based on. These requirements have influenced the use of VR in the building industry.

When computer-aided design (CAD) was first introduced for architecture, engineering and construction in the 1980s, two types of systems emerged – 'entity-based' CAD, such as AutoCAD, and 'object-oriented' CAD, such as ArchiCad. Entity-based CAD used vector graphics such as lines, arcs, etc., whereas object-based CAD used parametric objects like walls, windows, etc. The entity-based CAD systems, and especially AutoCAD, saw the greatest uptake by industry as they produced something that the computer processors of the 1980s managed to handle (Tse *et al*, 2005). However, the way in which the actors in the building process communicated did not change; it was still done largely with 2D drawings. The only difference now was that the lines were drawn using a computer instead of pencil and paper.

To make a VR model from the earlier, entity-based CAD systems requires extra modelling hours and extra money to transform the 2D lines into 3D faces (Whyte *et al*, 2000). In order for the resulting model to be credible in terms of resolution and animation, software was needed that was good at handling this type of data in a computer-economic way: the computer had to produce animations of at least 20 frames per second. Additionally, to facilitate a better understanding, the existing surroundings of a proposed building often need to be modelled and this may require many modelling hours. All of these activities have made it difficult to implement VR technology in small projects with limited budgets using traditional CAD modelling software. In order to experience VR the way Sutherland envisioned it, it is necessary to have sophisticated equipment – for instance, a Cave environment where the viewer is surrounded by four to six displays and wears special stereo glasses – but this is only possible for projects with a generous budget. For more ordinary projects, the viewer has to be satisfied with looking at a model on a simple screen and without stereo effects. However, as commentators point out, this can still be more effective than communication using 2D drawings (see, for example, Mahoney, 1999 and Schwegler *et al*, 2000).

The two types of CAD systems mentioned above started their development at approximately the same time (i.e. in the mid 1980s). By the late 1990s and the beginning of the 21st century, computers, and especially their graphic cards, had been much improved. It became possible to visualize object-oriented CAD in an acceptable way. In 2002, Autodesk bought the Revit Technology Corporation in order to develop a suite of programs based on parametric object-oriented CAD.

During the same period, the concept of using a building information model (BIM) was also introduced (Tse *et al*, 2005). A BIM is not only rich with geometric 3D data about the building, but has additional information that can be useful throughout the building's whole lifecycle. Examples of such information are strength values, isolation levels, acoustic values, etc. This additional information in computer models has made it possible to talk about 4D (3D+time/scheduling), 5D (4D+cost) and even nD modelling (involving other information properties, for example, the drying time of a concrete slab). Another bonus of using BIM is the possibility of viewing the model in real time. As Lee *et al* (2005) explain, 'nD modelling develops the concept of 4D modelling and aims to integrate an nth number of design dimensions into a holistic model, which would enable users to portray and visually project the building design over its complete lifecycle'. Only the future will reveal the extent of the 'n' in nD and this will become clearer when the building industry begins to discover and exploit the full extent of BIM potential.

According to a recent technical report by Gao and Fischer (2008), the use of 3D/4D models varies according to the business drivers, project stakeholders and project phases. They also emphasize that companies are starting to integrate 3D/4D models for more data-driven tasks such as the analysis of design options, supply chain management, cost estimating and change order management, facility management and establishment of owner requirements. Some recognition of the potential of BIM to offer a modelling solution to be used for VR purposes and make a significant contribution to real-time visualization has already taken place (Roupé and Johansson, 2005; Horne *et al*, 2005), but the uptake of BIM in practice is only just emerging. The 4D models currently used are not real-time visualizations enabling user interaction and navigation, but simply time-based models where the animations show changes over a given time period. Nonetheless, the visualization of BIM information is beginning to prove very effective for communication on the construction site (Staub-French and Khanzode, 2007).

New developments continue to take place in the field of urban planning. For example, work has been carried out at Chalmers Technical University with the aim of making it easier to model surroundings with the help of maps from the city authorities (Sunesson *et al*, 2008). BIM models can be placed in the city library environment without excessive expenditure on the modelling. These techniques have been used when planning the new library in Göteborg in Sweden. The use of VR made it possible to look at the building from many different perspectives and that was valuable for the participants in the evaluation jury, whose task it was to decide between different alternatives. It was considered that the evaluation was enhanced by this approach, as compared with more traditional methods, such as a static physical scale model or a film presentation (Sunesson *et al*, 2008). This collaborative exploration of design options and possibilities of improving the construction process by using real-time visualization has been noted in recent years (Cochrane, 1997; Retik, 1997; Gopinath and Messner, 2004; Bouchlaghem *et al*, 2005). Similar developments in virtual environments can be seen in a number of places in the world, e.g. in Germany (Döllner and Hagedorn, 2007) and Australia (Schevers *et al*, 2007).

RECENT RESEARCH

Although there is much hype in the media about the possibilities of VR, the extent to which it is used in practice in the building industry is not clear. A review of recent literature (e.g. Bouchlaghem *et al*, 2000; Calderon *et al*, 2000; Kim *et al*, 2001; Kähkonen, 2003; Bouchlaghem *et al*, 2005; Ganah *et al*, 2005; Naji, 2005; Woksepp *et al*, 2005; Westerdahl *et al*, 2006; Woksepp and Olofsson, 2006) shows there to be a lack of sufficient research, on an international level, investigating the use of VR technologies in the construction industry in different countries. In addition, in a study of the adoption of VR within construction processes, Fernandes *et al* (2006) identified the need to consider factors for VR technology adoption from a managerial and strategic level perspective. Whyte (2003) offered an empirical study of VR usage within the construction sector and identified a need to recognize divergent technological requirements of VR to meet distinctly different requirements.

SCOPE AND METHOD

The aims of the present research were to:

- assess VR usage, and the benefits of VR usage, within the building industry of four selected countries
- identify barriers of VR technology usage within the building industry of the four selected countries
- identify ways to overcome these barriers.

DEFINITION OF VR

Virtual reality is a term that is used frequently in the building industry, but which conveys different meanings to different people. Indeed, many different descriptions of VR can be found in the literature (e.g. Rheingold, 1991; Howard *et al*, 1995; Pimentel and Texixeria, 1995; Brooks, 1999; Bouchlaghem *et al*, 2000; Whyte, 2002; Burdea and Coiffet, 2003). According to Whyte (2002), 'the term "virtual reality" has become used to describe applications in which we can interact with spatial data in real-time'. However, other visualization methods, as Whyte (2002) points out, 'can describe the same or overlapping groups of technologies. These include: virtual environments, visualization, interactive 3D (i3D), digital prototypes, simulations, urban simulations, visual simulations and 4D-CAD.'

For the purpose of this survey it was agreed to record carefully respondents' own definitions and then follow this with an explanation of the definition used for this study. This research defines VR (in the building construction context) as 'real-time visualization of a computer-generated model of a built environment'. However, before describing or analysing the results of this survey it is necessary to distinguish the following categories.

NON-IMMERSIVE VR

This category comprises the development of three-dimensional modelling software, capable of running on desktop personal computers, enabling interaction with real-time computer-generated environments. However, the experience is one of viewing the scene as an observer, looking through a computer screen.

IMMERSIVE VR

This type of VR offers a psychological illusion of being immersed inside a computer-generated environment. Rather than viewing the scene as an observer from outside, the experience is one of being a participant within the scene. An immersive VR system offers a different environment from a simulated environment using traditional graphical user interfaces.

BUILDING INFORMATION MODELLING

The growth of BIM software provides a means to model accurately a built environment and is a significant innovation in the creation of computer-generated environments. BIM technology should be clearly distinguished and viewed as a technology that can produce the three-dimensional models required for the VR experience.

METHODOLOGY

This research is limited to the scope of VR activities in Europe (the UK and Sweden), the US and China and sets out to identify differences in the strategic approaches of VR implementation within the building industry for these countries. The UK and Sweden were selected because members of the research team were based in these countries and both had been active in implementing VR facilities and collaborating with the building industry. The US was selected because of its track record in utilizing VR for construction projects and China was selected because it is a relative newcomer in this field and has a different political structure. Each of the selected countries has several academic and commercial centres involved in VR research and development. The four countries were accessible geographically for the purposes of this study, accessible linguistically and were cooperative for research purposes.

BUILDING COMPANIES

Based on the available published statistics (Department of Trade and Industry, 2005; *Building*, 2006; McGraw Hill Construction, 2005; *New Civil Engineer*, 2005), the researchers identified the largest building companies in each of the study countries (China, Sweden, the UK and the US). The term 'building companies' was taken to include any organization with an involvement in general building (including non-residential building and housebuilding) or civil engineering contracting. The size of a company can be determined by a number of factors: for legal purposes, the European Union adopts a classification of size based on the number of employees, company turnover and company balance sheet; for statistical purposes, the number of employees and the level of annual turnover generally determine the size of an enterprise, and these statistics were adopted for this study. The top six companies in each country were selected and approached to discover their willingness to cooperate in the research. Table 1 shows the number of employees and annual turnover for each of the companies that responded in the four countries in this study.

For each co-operating company, a senior executive was identified as being in a position to offer a strategic overview of the use of IT within the organization and to grant authorization to proceed. A structured interview of one hour duration was held with this person, or another recommended senior manager. Table 2 shows the eventual list of responding companies and the personal profiles of the interviewees.

INTERVIEW PROTOCOL AND CODING

The semi-structured interviews were audio-recorded and later transcribed and analysed. During the

TABLE 1 Details of responding companies in China, Sweden, the UK and US

COMPANY	NUMBER OF EMPLOYEES	ANNUAL TURNOVER	ANNUAL TURNOVER (£)
C1	23,000	$2116m	£1134m
C2	180,000	$11,092m	£5944m
C3	10,000	$1686m	£904m
C4	30,000	$3811m	£2042m
S1	200	£9.1bn	£9.1bn
S2	6445	SEK19,455m	£1638m
S3	20,000	SEK45bn	£3.79bn
S4	2200	SEK12,065m	£1016m
S5	12,000	£1.85bn	£1.85bn
S6	6500	SEK2891m	£243m
UK1	1400	£4171m	£4171m
UK2	9000	£4585m	£4585m
UK3	25,000	£2094m	£2094m
UK4	7500	£3361m	£3361m
UK5	1100	£1483m	£1483m
US1	17,134	$14.4bn	£7.71bn
US3	30,000	$13.2bn	£7.07bn
US4	2000	$2bn	£1.07bn

C = China; S = Sweden

TABLE 2 Personal profiles of the interviewees in the respective companies

COMPANY	INTERVIEWEE	EXPERIENCE (YEARS)	AGE
C1	General manager	16–19	42
C2	General engineer	20 and more	45
C3	Manager	20 and more	45
C4	Director of science and technology	11–15	42
S1	Department manager	20 and more	43
S2	Project manager – information technology	20 and more	53
S3	Industry researcher	6–10	36
S4	Quality director	20 or more	53
S5	Head of development and activity support	20 or more	59
S6	Strategist	16–19	61
UK1	Director of design	20 and more	55
UK2	ICT programme manager	11–15	39
UK3	Senior administrator	6–10	33
UK4	ITC, R&D project manager	20 and more	48
UK5	Business improvement leader	20 and more	57
US1	Vice president and chief information officer	1–5	n/a
US3	Corporate construction engineering manager	20 and more	57
US4	Senior vice president	20 and more	60

n/a Not available

transcription period, interviewees were assigned a code. These codes acknowledge their country of operation such as C for China, S for Sweden, UK for the UK and US for the US and are numbered in order to distinguish the companies in the same country such as C1, S2, UK4, etc.

RESULTS

FUNDAMENTAL CONCEPTION AND UNDERSTANDING OF VR

The results of the interviews revealed that the understanding of VR – as a term in general and as a concept and a tool in the building industry – differed widely. Numerous kinds of visualization techniques, from two-dimensional drawings to photomontage to three-dimensional models to building information modelling to virtual reality, are being used in the building sector. In line with the diversity of the definitions of VR in the research literature reviewed above, Table 3 shows the wide range of answers to the question 'How do you define virtual reality?' which was put to respondents in the survey.

The results in Table 3 show that there is not a common understanding of what virtual reality is and in which ways it may be useful for the construction sector. It seems that VR technology is frequently confused with, for example, 3D modelling and animations.

In fact, the results to the question 'What VR/ visualization programs do you use?' show that the respondent companies used a variety of visualization techniques other than VR technology: 75% used 3D modelling techniques on their projects and 63% used 2D techniques. Photomontage techniques are used by 38% of the companies and 38% of them liked to use hand-drawings and sketches in the early stages of their projects. These results are summarized in Figure 1.

VR USAGE

Although usage of VR technologies to some extent did differ between different companies, overall, after initial implementation barriers, companies are making use of VR technology. The technology is still classed as 'fairly new' and therefore in some cases VR is being used for small parts of the major workload (UK2). Similarly, although at present VR is not being used in many projects, communications with major clients indicate that this technology will be used in future projects from the start (S5).

In contrast to the above examples, some companies are making more use of VR technology. For example, company US3 uses this technology in 40% of all its projects and UK5 recently reviewed its workload to see what proportion of its building work uses VR technology and found out that 20–30% of live projects use VR in some form or another. From 'using simple VR applications in every project and using these VR models in early stages to creating

TABLE 3 VR definitions given by the interviewees in the study

'How do you define virtual reality?'
Nice 3D visualizations (S1)
A virtual picture of the reality (S2)
Virtual prototype of a future or existing construction with real-time interaction in 3D stereo (S3)
Experienced reality, a mirror of reality (S4)
High technology (S5)
Purely theoretical, three dimensions in something you can't touch; graphic presentation (S6)
Computer-generated image, a multi-dimensional and scale-less image (UK1)
Visually represent something on the screen (UK2)
Computer images, an impression of the end result (UK3)
Graphical fly-throughs, visualizations (UK4)
The technology that allows interaction with the simulated environment (UK5)
Real-time computer graphics, 3D drawings, building information technology (US1)
The ability to put scenarios in 3D in real time, 3D intelligent technology (US3)
One segment of technology classified by visualization media (US4)

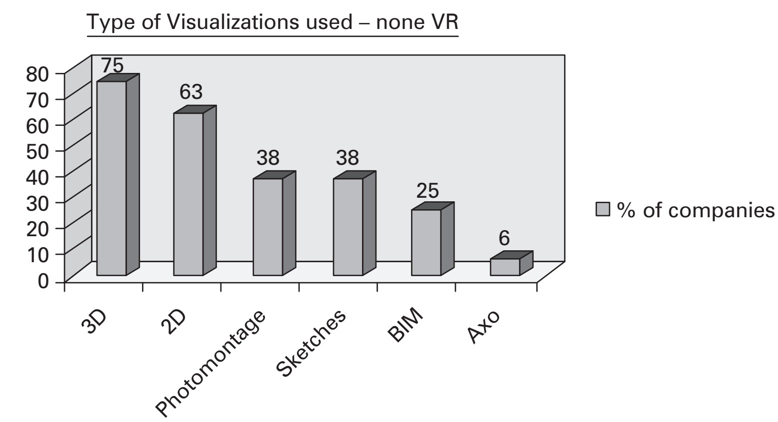

FIGURE 1 Use of visualization techniques other than VR

detailed VR models for later stages' (S2), the building industry is adapting itself to use this technology.

The research described above offers a picture of VR usage across the different countries, and responses to the question 'What proportion of your company building projects involves VR use?' are summarized in Table 4.

THE ROLE AND PERCEIVED BENEFITS OF VR IN THE BUILDING INDUSTRY

Kähkönen (2003) suggests the following abstraction levels for classifying and directing research and development in relation to VR:

- enabling technologies – the hardware and the software side of the technology that makes it possible to visualize
- applications – the way we use the VR technology in various activities
- process – the changing procedures that the building industry faces as a result of using this technology.

This categorization enables the identification of ways in which the building industry approaches VR technology. Furthermore, the research carried out by Bouchlaghem *et al* (2005) highlights 'ways in which visualization can assist AEC professionals to improve aspects of their work. During conceptual design, visualization can help designers work collaboratively and communicate ideas more efficiently.' Additionally, Bouchlaghem *et al* (2005) identify that 'visualization can bridge the gap between designers and site teams in facilitating the exchange of information for buildability problems'. Woksepp and Olofsson (2007) indicate that 'there is a need to improve the information flow at building sites and the present procedure of distributing information by means of 2D CAD drawings is ineffective'.

Our survey suggests that one of the perceived benefits of using VR technology is to improve communications between different parties involved in the building process. Accordingly, in different applications from design review to detailing to scheduling to marketing, etc., VR was considered to be a useful tool. For example, as a 'rapid means of transferring and translating information and improved communications' (UK1) and 'helping towards understanding of a project' (UK4) and 'decision process gets a lot quicker' (S2) were seen as some of the benefits that the building industry gains by using the technology.

Another desirable result of VR was the ability to see a prototype before construction begins. This use has also been identified in the research literature: 'By providing interactivity with the construction models, users can make changes and virtually test a proposed project by visualizing realistic simulation before construction actually happens' (Zhang *et al*, 2005).

TABLE 4 VR usage

COMPANY	WHAT PROPORTION OF YOUR COMPANY PROJECTS INVOLVES VR USE?
C1	100% computerization which includes VR
C2	100% computerization which includes VR
C3	100% computerization which includes VR
C4	100% computerization which includes VR
S1	Small percentage of the projects
S2	Small percentage in every project
S3	Small percentage of the projects
S4	15%
S5	Small percentage of the projects
S6	Small percentage of the projects
UK1	50%
UK2	Small percentage of the projects
UK3	Most of the projects
UK4	Most of the projects
UK5	20–30%
US1	No VR implementation yet
US3	40%
US4	1%

Thus, 'to be able to solve design problems before construction starts', the 'ability to solve collisions' (US4), 'prevent mistakes happening on site' (UK5) and 'being able to build correctly from the beginning and make the process more industrial' (S1) were believed to be influential for various applications. It is also perceived that the 'early visual representations can reduce later changes on site' (UK2) such as 'when everything is on the right place in the model then everything will be on the right place in reality as well' (S1).

Use of VR technologies inevitably will change the process of how the building industry works from the initial sketch to the work on the construction site. 'Testing the schedule and solving the issues beforehand' (US1) and the 'ability to prototype' (UK5) will enable users to 'reduce cost – especially the wrong cost' (S3). Due to easy prototyping, VR technologies 'minimize the risk of mistakes and make the process more effective' (S1) and this will lead to 'less complaints' (S2) at the end. At a corporate level, it is believed that use of this technology will 'add to the company's competitiveness and therefore there will be higher chances to get new contracts' (UK1).

STRATEGIES FOR IMPLEMENTING VR

Yang *et al* (2007) observed that the successful use of new technology was greater on larger infrastructure projects than for other project types, and that this should influence managers in deciding whether to invest in new technologies for given work functions. In the present study, the way the companies implemented VR technology differed widely. Nevertheless, it can be said that the companies perceived a direct correlation between successful projects and the technology they used. They believed that 'although the success rate is not entirely dependent on VR, the actual experience of VR exceeded their initial expectation on terms of success rate' (UK1).

Between the various countries, there are both similarities and differences in the timing, rationale and methods used for implementing VR technology. In China, for example, there has been a direct top-down approach set by the government, whose policy is to computerize 100% of the design process; the use of VR is an integral part of this policy. The effects are particularly evident in the case of the Beijing Olympics of 2008.

The results of a study by Yang *et al* (2007) indicate that technology was considered critical in assisting the execution of project work functions and may contribute significantly to project performance in terms of stakeholder success. Similarly, in our study, 'competition' and 'following the latest innovations' seem to be the main reasons for a switch to this technology. In addition, 'better communication requirements', 'better project co-ordination' and 'cutting labour costs' were given as drivers for the implementation of VR technology. Table 5 gives an overview of the implementation of VR in the countries surveyed.

It is noticeable that most of the companies, except for those in Sweden, had made a formal decision to apply these new technologies. When it comes to governmental input with regard to using ICT applications in the construction industry, it can be said that China's approach is more established than the other countries (Table 4). There are some other examples of governmental input, such as in the UK; the *Rethinking Construction Report* by Sir John Egan (Egan, 1998) suggests, 'there are enormous benefits to be gained, in terms of eliminating waste and rework for example, from using modern CAD technology to prototype buildings and by rapidly exchanging information on design changes'. Moreover, it advises that 'redesign should take place on computer, not on the construction site' (Egan, 1998).

The recent 'IT-barometer' survey conducted by Samuelson (2008) on the Swedish construction industry shows that overall IT usage focuses on support systems and not on more advanced techniques that can change the business. Nevertheless, the priority of the planned IT investments for virtual reality in the Swedish construction industry has risen since 2000.

BARRIERS TO IMPLEMENTING VR

Yang *et al* (2007) observed that 'the construction industry has been criticized for its slow adoption of emerging technologies. However, it is believed that in recent years this trend has been changing.' With the development of technologies in recent years, construction companies, in what is an extremely competitive industry, are constantly searching for established technologies that present a benefit to them. 'Implementing problems of these new technologies have always been the main barrier in adopting them, however while in the past the main problem was cost, it is now more organizational and human issues that stand in the way of taking full advantage of the benefits that can be realized' (Bouchlaghem *et al*, 2005). Similarly, a 4D implementation research study carried out by Dawood and Sikka (2007) points out these human issues as 'lack of awareness, lack of sufficient IT skilled people and resistance to change by general contractors'. It is believed that construction companies were uncertain about the competitive advantages and benefits of using innovative technologies. Equally, research in this field 'continues to support the idea that cultural [people] issues are a major barrier to IT implementation in AEC industry' (Davis and Songer, 2008). 'Helping people to understand this cultural change' (UK2) was one of the basic barriers that companies faced. Additionally, since the 'customers are not asking for virtual reality' (S1), justifying this change both financially and culturally is a big challenge. Accordingly, the interviews carried out show that at the early stages of VR implementation, companies came across various barriers such as 'budget constraints caused by lack of understanding of the technology and time-consuming ways of creating VR models' (UK1) and 'time to learn the technology and the distinct existing process of producing projects created difficulties' (UK5). Furthermore, in early implementations, finding a suitable project and courageous project manager who would agree to use this new technology (UK4) was described as one of the initial barriers.

Additionally, introduction of a new technology comes with its own implementation difficulties, which sometimes can be seen as barriers. For instance, instead of learning additional skills in order to get 'a better feeling of depth in a construction model, the VR software should enable users to utilize the model simply by using it as if it is a computer game' (S1). Moreover, deciding which software to take on is one of the most important tasks of introducing a new technology. The 'chosen one' should be reliable, cost effective, easy to train on, easy to use, etc. Hence 'not having industry standard software in USA' (US1) was seen as one of the main barriers. Similarly, European companies were concerned about not having industry standards (S6).

TABLE 5 Implementation of VR in the countries surveyed

	STRATEGY OF IMPLEMENTING VR			
COMPANIES	WHEN	WHY	HOW	FORMAL DECISION
C1	1996	In 1996, the government produced a policy that the design process should be 100% computerized. Their argument was that the procedure of design should keep pace with international developments. Various software and technology are used to carry out this policy and VR is one of them		Yes
C2	1997			Yes
C3	1996			Yes
C4	n/a			Yes
S1	1995	To help customers who have difficulties with reading 2D drawings	In-house	Yes For ADT[1]
S2	1995	To get a better understanding of the building process, and to get better help in controlling the project drawings and models	In the beginning in-house but since 1997 out-sourced	No
S3	2000	To test the technology and future benefits	Pilot studies and some 'real-life' projects – mostly out-sourced	No
S4	2002	Initially it was considered that VR would be useful	Out-sourced	No
S5	2003	Reduce errors, solve logistic problems, test construction virtually	Out sourced	No
S6	1995	To understand projects better	Out sourced	No
UK1	1995	Needed to communicate better with people who struggled to understand the conventional means of communication in design	Initially out-sourced	Yes
UK2	2002	Unique coordination between different disciplines	Driven from CAD, Navisworks	Yes
UK3	n/a	Local office believes that this would be a regional decision to choose the appropriate technology		n/a
UK4	1990s	To keep ahead of the competition, follows the latest innovations	Initially out-sourced, now in-house	No, came from bottom-up
UK5	1996	Company vision to have forward thinking and follow the developments in the industry	In-house	Yes
US1	Company does not use VR at the moment. They have a five-year plan to change their core IT systems like accounting software, management software, emailing system, etc.			
US3	1986	To cut cost on labour. Believed that they would not have spent time	Client driven	Yes
US4	n/a	BIM is used for visualization and they saw this as an important movement in the construction industry	In-house by mapping out an implementation programme	Yes for BIM

n/a Not available

1 Autodesk Architectural Desktop

Furthermore, 'the implementation of this new technology and going into profit with it can be slow' (S2) can be seen as one of the big barriers.

METHODS OF OVERCOMING THE BARRIERS

Apart from cost and software/technology-related concerns, barriers to implementing VR technology centred on organizational and human-related issues. To overcome this type of barrier one company 'has required all new jobs to implement VR in all their projects' (US3). They believe that the decision whether to use VR technologies or not is no longer an option within their company. It is also believed that 'the construction companies do not have resources to do all the research needed to implement VR technologies. Having a direct relationship with the outside groups, such as educational facilities, software companies, and construction- and software-related societies, is beneficial to the construction companies. These outside groups can do the research and convince the construction companies to use this new technology' (US3). Additionally, one of the major contributors towards the advance of VR into mainstream building activities was thought to be 'having these outside groups and construction companies getting together and creating standards that will underline legal issues concerning roles and responsibilities of the development of a VR model' (US4).

Advanced developments on digital technologies can help implementation processes and enable more feasible work on site. 'A better and faster wireless technology would enable the engineers to use tablet PCs and perform their work on site' (US3).

In order to advance VR usage into mainstream building activities, a VR model needs to be accepted as an accountable source of information. The more information fed into the model, the better the overall understanding of the model (UK1). This leads to the combination of technologies for different purposes during the construction process.

CONCLUSIONS

The consistent advancement in computer-processing capabilities coupled with the decreasing costs of graphics cards is likely to result in a change of perception of the potential of virtual reality for the building industry.

This study has identified improved communication between different parties, increased project understanding and speed of decision making, and the production of an interactive prototype as key benefits of VR integration. Collision detection, reduction of mistakes and changes in the construction process, and hence cutting costs, were also recognized as key issues. The degree of business competition that VR implementation can offer a company, identified by Fernandes *et al* (2006), was also recognized.

This study has also provided an insight into the perceived barriers to, and enablers of, the technology from those with a strategic perspective. Key barriers have been identified as implementation issues and uncertainties regarding the benefits of VR and the competitive advantages the technology can offer. Barriers at an organizational level have been identified as lack of awareness of what VR can offer to a company, time required to create the 3D models and lack of time for training. The need to have a suitable project and 'champion' to further VR integration was also identified. Since 'successful adaptation of new technologies depends on careful consideration of organizational and business issues' (Bouchlaghem *et al*, 2005), raising awareness of the new technology and transferring information regarding how this technology would be a benefit to the construction industry should be a focal point for the methods of overcoming barriers.

In addition, the study also identified that companies are overcoming the barriers by using simple VR techniques in every project. It is likely that as building information modelling becomes more recognized in the industry, and uptake is increased, the availability of computer models to be used for VR worlds will also increase. Brandon *et al* (2005) describe the construction industry 'as an industry that requires vast stores of interdisciplinary knowledge; that needs visual imagining of finished product and simulation of performance because the cost of physical prototyping is just too prohibitive'. In their study, they try to pinpoint when and how the IT applications in general will be widespread and conventional in the construction industry. As with any change, much research in this area (Egan, 1998; Koskela *et al*, 2003; Davis and Songer, 2008) indicates that for a sustainable change, initially the culture (people)-related issues need to be resolved and, as Egan (1998) points out, 'technology should be applied as a tool to support the cultural and process improvements'.

During this first stage of research it has not been possible to do a more rigorous analysis country-by-country without 'harder data'. For example, Table 4 presents an interesting observation on the variability of VR uptake between the countries in the study: Chinese companies claim 100% take up, although this remains to be carefully substantiated; take up in Sweden is small but consistent across respondents; the UK displays slightly higher take up; and the US shows most variation with take up ranging from zero to 40%.

FURTHER RESEARCH

Being fairly novel in its approach and cross-sectional in nature, the research naturally invites further work. The results from this study are from an ongoing project that will eventually include comparable data from India and a more rigorous country-by-country analysis: these findings will be presented for publication in due course. The countries were selected for study partly strategically (in that they were likely to offer examples of a variety of levels of uptake of VR) and partly because of their accessibility to the research team; similar studies in other countries would yield interesting comparison. The same considerations were present in the choice of respondents *within* the chosen countries, in that they represent some of the 'biggest players' in those countries' building industries: it is highly probable that smaller organizations would produce an entirely different perspective. However, the present study can offer a feasible basis from which to proceed with such work. The results may also usefully be compared with similar data from other industries in order to identify methods of best practice. Finally, although it is likely that many of these findings are locally or situationally determined, some may be transferable as 'best practice' to the building industries of the world.

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