INDUSTRIAL APPLICATIONS OF VIRTUAL REALITY IN ARCHITECTURE AND CONSTRUCTION

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SUMMARY: *This paper reports on a study of industrial applications of virtual reality in USA and UK construction. A multiple case study approach is taken and eleven organizations that are lead users of the technology are studied. Their strategies and business drivers for the use of virtual reality are identified and emerging patterns of use are explored.*

The study finds early adopters focusing on the use of virtual reality for either systems integration, supporting the customer interface or developing new markets. The business drivers for implementing and using virtual reality include demonstrating technical competence, design review, simulating dynamic operation, co-ordinating detail design, scheduling construction and marketing. Those organizations using virtual reality in the architectural design and construction of the physical built environment sharply differentiate models created for professional use within the project team and supply chain and those for wider interactions. The size of their projects and the extent to which design is re-used may affect strategies for implementing and using virtual reality and the business benefits obtained.

In previous work, virtual reality is seen as a universal interface to all construction applications. However the findings of this study suggest a more complex story, with a range of strategies and business drivers potentially leading to competing design families.

KEYWORDS: *virtual reality, industrial applications, strategies, business drivers, technological families*

1. INTRODUCTION

There has been little empirical study of the use of virtual reality (VR) applications in architecture and construction. Academics collaborate with industry in the development of conceptual designs and prototypes (e.g. Aouad *et al.*, 1997b; Koo and Fischer, 2000) but the role of lead users and the emerging trends in usage have not previously been critically considered and empirically studied.

Construction is often perceived as a backward industry and the need for change is highlighted in government reports and initiatives (such as the Egan and Latham reports in the UK). Recent surveys of IT use have suggested an increase in computer literacy in the late 1990s and 2000s, with the majority of organizations now using some forms of IT and many business processes now completely computerised (Doherty, 1997; CICA, 1999; Rivard, 2000; Samuelson, 2002).

The 'pioneers' of virtual reality expected architecture to be a major application: walkthrough systems were developed (Brooks, 1986); Autodesk collaborated with the VR hardware company VPL (Hayward, 1993) and the trade press described potential applications (e.g. Evans, 1992). However, virtual reality is an emergent and unstable technology, which lacks a dominant design (Swann and Watts, 2002), and has had initially very slow diffusion into the sector (Bouchlaghem, *et al*. 1996).

Research on virtual reality in architecture and construction has been focused on developing and refining leading-edge tools. Researchers have developed software to improve construction scheduling (Fischer and Kunz, 1995b, 1995a; Op den Bosch and Baker, 1995; Retik, 1996); construction integration (Alshawi, 1995; Aouad *et al.*, 1997b); and design (Mandeville *et al.*, 1995; Kurmann *et al.*, 1997). Working within an analytic research paradigm, these researchers have sought to develop conceptual designs and prototypes with the ultimate goal of demonstrating improved performance by artefacts created in the research process.

Studies of wider technological innovation have focused on the empirical study of industrial use, arguing that early adopters or 'lead users' have a significant role to play in the introduction of new products and in their diffusion across communities of users (Rogers, 1962; Gardiner and Rothwell, 1985; von Hippel, 1988). According to von Hippel, lead users are those organizations which face needs that will be general in a market place – but face them months or years before the bulk of that marketplace encounters them and thus are positioned to benefit significantly by obtaining a solution to those needs. Lead users are active in the reinvention or re-innovation of new products, building upon early success but improving the next generation product with revised and refined features (Gardiner and Rothwell, 1985).

This paper reports on an empirical study of the lead users of virtual reality in construction. The aim is to explore the industrial applications of VR and the objectives are to:

- Identify the business drivers for the use of VR in the construction sector;
- Characterise the corporate strategies for the use of VR; and
- Establish whether VR can be described as a generic technology or whether different families of tools may emerge for different specialist activities.

The work is informed by the firm-level analyses of technological innovation and the role of lead users conducted in the innovation studies research tradition (Rogers, 1962; Gardiner and Rothwell, 1985; von Hippel, 1986). However, in a process such as construction – which is characterised by fragmentation and diversity (Gann, 2000) – the concept of a typical user organization is insufficient. The construction process involves many disparate organizations working together on project-specific tasks (Gann, 2000). Organizations work across a range of projects, which vary in size from large projects to produce capital goods such as complex buildings and infrastructure to the relatively small, such as housing. Organizations also vary in the extent to which they re-use design across projects. Market success of any new technology depends on segmentation of users and markets (Estók, 2001) and it seems that further characterisation of users of virtual reality in architectural and construction is required.

2. METHOD

In this work, virtual reality is defined as a technology that provides an interactive, spatial, real-time medium. Virtual reality enables real-time viewing of, and interaction with, spatial information. Other words are used to describe use of the same or overlapping groups of technologies, and similar concepts include virtual environments, visualization, interactive 3D (i3D), digital prototypes, (urban or visual) simulation and 4D-CAD.

Rather than considering a cross-section of all companies, a multiple case study approach is taken to understand implementation and use of virtual reality in eleven organizations that are early adopters of virtual reality. The user companies studies included Kohn Pederson and Fox; Asymptote Architecture; Little and Associates (Skyscraper Digital); Disney Imagineering; Laing Construction; WS Atkins; and Bechtel. These organizations were identified as lead users through their participation in industry fora on virtual reality, or through virtual reality software suppliers' and other users' recommendations. Bechtel, for example, won the 2001 British Computer Society Award for its work using virtual reality on the Thameslink project. Collectively, the user organizations include architects, construction managers, contractors and consultant engineers and are located in the USA and the UK (as shown in Table 1).

Table 1: The types of user companies interviewed

	Type of company	Role of interviewee(s)	Location of interview (s)
1	Architect	Head of IT	UK
2	Architect	Partner	USA
3	Architect	CAD Manager	UK
4	Architect	Visualization Manager	USA
5	Major Real Estate Owner	Head of R&D; Visualization Specialist	USA
6	Housing Developer	Group CAD Manager	UK
7	Construction Contractor	Senior CAD Consultant; CAD Consultant	UK
8	Construction Contractor	Head of Integrated Design; Visualization Manager	UK
9	Consultant Engineer	R&D Engineer (UK); Project Leader (UK) Visualization Manager (USA); Visualization Specialist (USA)	USA & UK
10	Consultant Engineer	R&D Engineer; IT Manager	UK
11	Consultant Engineer	Visualization Manager (USA); Group Supervisor (USA); Visualization Manager (UK)	USA & UK

Empirical data was collected through semi-structured interviews with the user organisations (in 2000/01) and used in conjunction with supporting company documentation. Wherever possible, interviews were taped and transcribed, and in other cases extensive notes were taken. This work is also reported in Whyte (2002).

More cases were added to the study until the anomalous features discovered in the early cases could be satisfactorily explained. The early case studies with architects revealed particularly surprising results, so more architectural practices were studied than other organizations. The architects studied included a large established commercial practice, a multi-disciplinary design practice, an internationally award-winning young practice, and a regionally based mid-sized architectural practice. This range of practices was studied to ensure that the cases chosen were not anomalous or unrepresentative of lead users and to deepen understanding of the phenomena observed.

Detailed case studies with lead users are used rather than a wide survey, however the approach does have some limitations. The specific focus on the motivations of the early adopters of virtual reality leads to a pro-innovation bias in the work. The small sample size (though it includes major lead users of virtual reality) also means that the findings should be seen as preliminary. The phenomena being studied are dynamic and it is to be expected that organizational strategies and business drivers will develop as use of the technology becomes more established.

3. PATTERNS OF USE

The findings of each individual case study are summarised below in Table 2 and are explored in more detail in the following subsections. There was not one single approach to VR use across the different companies, but rather a set of related strategies, drivers and models. However, patterns of use are emerging and some commonalities exist.

*Table 2**:** Summary of the business drivers and strategic focus found in the companies studied*

	Type of company	**Strategic focus of VR use**	**Business drivers**
1	Architect	Customer Interface	Marketing (low use)
2	Architect	New Markets	* – *(design of virtual space)*
3	Architect	Customer Interface	Design review, marketing (low use)
4	Architect	New Markets	* – *(Marketing, creation of city models for clients)*
5	Major Real Estate Owner	Systems Integration	Scheduling construction
6	Housing Developer	Customer Interface	Design review, marketing, demonstrating technical competence
7	Construction Contractor	Systems Integration	Co-ordination of detail design, demonstrating technical competence
8	Construction Contractor	Systems Integration	Co-ordination of detail design, marketing
9	Consultant Engineer	Systems Integration	Simulating dynamic operation, co-ordination of detail design, demonstration of technical competence and design review
10	Consultant Engineer	Systems Integration	Simulating dynamic operation, co-ordination of detail design
11	Consultant Engineer	Systems Integration	Simulating dynamic operation, design review

* *these companies are not using virtual reality in their processes for designing, producing and managing the built environment*

3.1 Strategic focus

The organizations using virtual reality in the architectural design and construction of the built environment make a major distinction between models created for professional uses within the project team and supply chain, and those for wider interactions:

1. Within the project team and supply chain, models are being created and used by consultant engineers, contractors, sub-contractors and suppliers. They may be used internally within one organization, or in conjunction with other professional organizations involved in the same project; and

2. Outside the project team, models are being used for wider interactions with end-users, clients, managers, funding institutions and planners. These models may be quite different from those used by professionals working on the project.

Those organizations with the largest investments in virtual reality were consultant engineers, contractors and real estate owners. These lead users were using virtual reality within the project team and supply chain and employing specialist modellers to create and maintain virtual reality models for systems integration. A wider group of organizations were using virtual reality for interactions with end-users, clients, managers, funding institutions and planners. Some organizations were focused on the use of virtual reality at the customer interface, whilst others were re-using models used for other purposes.

A surprising finding of the work is the low use of virtual reality amongst the architectural practices that are seen as lead users by their peers. On small unique projects architects and designers are not able to benefit from the economies of scope associated with re-using VR models. One architect argued that:

> *'If your client tells you to use it, then obviously you would do, but in terms of the business benefits of choosing to use it with a client, that is "all rubbish" – when you are with a client you are telling the client a story and the story is very carefully choreographed.'*

Reservations about the use of virtual reality in the design of the built environment included concern that virtual reality may limit the scope for designers to be creative and use their architectural imagination and concern that the medium does not provide the narrative structure required for external presentation of ideas. Two of the architectural practices that were studied were extremely enthusiastic about their use of virtual reality, but were found to be using to enter new markets outside their processes of design of the built environment. They were interested in design within a virtual or alternative reality and saw themselves exploring conceptions of space rather than more utilitarian issues associated with physical buildings.

Three different strategies for the use of VR can be characterised:

1. Systems integration – prototyping the product and simulating the processes of its construction and operation. Re-using the model at different stages of the process;
2. Customer interface – offering the customer a greater understanding of the design and a limited design choice from a palate of options. Re-using models across many different projects; and
3. New markets – using VR to diversify rather than to obtain business benefit in the building design process. Marketing expertise in spatial design and competing with web-designers, human-computer interaction experts and programmers in the design of new media 'places'.

3.2 Business drivers

The companies studied were asked about their motivation for using virtual reality in the architectural design and construction of the physical built environment.

Virtual reality is being used within the professional project team and supply chain, to visualize and manage increasingly complex engineering and design data. Models were most frequently used in this manner in construction contractors and consultant engineering companies, particularly on large and complex building and infrastructure projects such as railways, airports, shopping malls and theme parks.

The lead users do not see virtual reality as a subject of interest in itself. Instead they are concerned with reducing risk, increasing technological innovation and improving business processes. Visualization is seen as a means rather than an end. One manager said 'It's not about a pretty picture.'

The major business drivers for the use of virtual reality within the project team and supply chain are:

- simulating dynamic operation – One of the engineering consultancies using virtual reality for simulation of dynamic operation, had had an early interest in the use of virtual reality to understand people flow. The organization had experimented with off-the-shelf commercial VR programmes and having found that they did not do what they wanted, they decided to develop their own software. They have developed a PC-based programme to analyse fire egress and people flow and have been able to market and sell its specialist expertise in crowd simulation.
- **co-ordination of detail design** – A construction contractor interested in the co-ordination of detail design championed the idea of a single project model to manage all of the data relating to a project. This organization felt that construction contractors are being made increasingly

responsible for spatial co-ordination of detail design. Identifying errors and clashes early in the process was an important motivation for their use of virtual reality as they may be responsible for any rework that is necessary on site due to incompatibility problems.

- scheduling construction – Virtual reality is being used to improve the product and reduce waste in the process. One large organization that designs, builds, owns and operates a vast amount of real estate across the globe, felt that by investing capital they could save in construction costs.
- Virtual reality was also used for a range of tasks to support interactions with clients, managers and end-users. The major business drivers for these uses of virtual reality are:
- demonstrating technical competence - with clients before a project starts as a part of the proposal, competition entry or project bid. It is being used to show previous or proposed projects and to market the design skills of the organization. One consultant engineering organization found these models and visualizations useful when bidding for the construction of a new overseas facility.
- design review (and value engineering) - with clients and end-users on a number of complex project systems, such as airports and hospitals. It is seen as particularly important for value engineering, where costs need to be reduced and decisions need to be made about obtaining value for money without compromising design quality. One visualization specialist argued that clients make different choices when they can see the impact of their decisions. They often reject the least cost solution when they can visualize it, as they can see the quality difference between proposals.
- marketing (and client's marketing) - housing developers often have no known buyer at the start of the process. Being able to sell from plan is a major advantage as it reduces the risk of development and the housing developer has used virtual reality to get press coverage and sell from plan. One of the architects studied had worked with two major banks to develop models of their new headquarters. They were able to see what it was going to look like on the skyline, from different parts of downtown, the airport and the highway. As well as using the model for zoning board approvals, town hall meetings and to communicate the plans and get approvals, the banks have used the model to raise the profile of the development, obtaining television coverage on news bulletins.

3.3 Strategies, business drivers and technological requirements

The different strategies and business drivers suggest that lead users have different technological requirements for virtual reality tools. Table 3 summarizes the different business drivers associated with models created for professional use within the project team and supply chain and those created for interactions with clients, managers and end-users.

Table 3: Business drivers associated with models created for professional use within the project team and supply chain, and those created for interactions with clients, managers and end-users

Use within the professional project team	Interactions with non-professionals
Simulating dynamic operation	Demonstrating technical competence
Co-ordinating detail design	Design review (and value engineering)
Scheduling construction	Marketing (and client's marketing)

It was clear from the study that for different tasks, companies used different types of models and organised the use of virtual reality in different ways.

- For professional tasks, the model could be quite abstract, and the ability to interact with the model was more important than the quality of the images.
- For tasks that involve interaction with people who are not construction professionals, such as design review with clients, the quality of images and the ability to move through the model in real-time were more important.

These different uses were seen as distinct. However, organizations with a strategic focus on system integration were more likely to re-use models. On one project, a company created two separate VR models from the CAD data. One was used for design review (communication with non-professionals) and the other was used for co-ordination of detail design (professional use). The first model, for presentation of design, showed surface finishes and details; and the second, for improving co-ordination of design showed the HVAC, steel, floors and stairway design required for clash detection and engineering.

4. DISCUSSION

The different professional roles and responsibilities lead different players within the sector to use virtual reality in different ways. It is proposed that the extent of design re-use and size of projects may contribute to the formation of these diverse strategies. It appears that those with large unique projects are focusing on the use of VR for systems integration, whilst those with small projects with design re-use are using VR at the customer interface. Virtual reality was not found to be widely used on small unique projects and this could be due to the costs involved in obtaining software and creating and maintaining models.

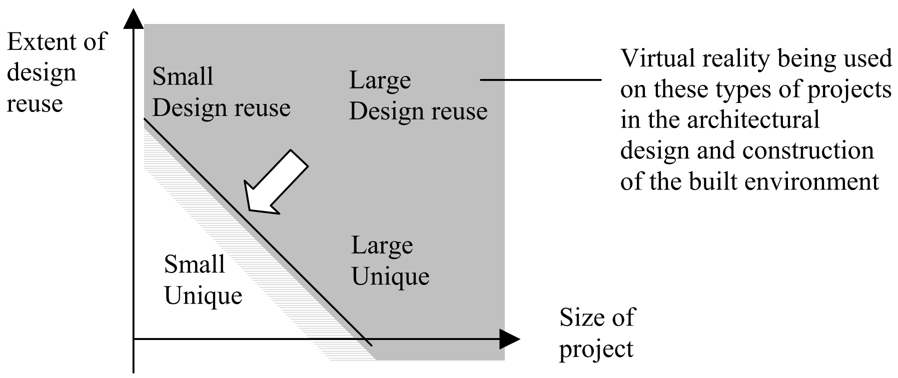

FIG. 1: The extent of design re-use and the size of the project

Companies that work on large complex projects have major business drivers for the use of virtual reality within the project team and supply chain. On these large complex projects, professionals, such as consultant engineers and construction managers, are using virtual reality to visualise and understand engineering problems and hence to reduce risk and uncertainty. Many of these firms are interested in virtual reality as an integrated interface (Aouad *et al.*, 1997a; Issa, 1999). Budgets for hardware and software may be relatively large and there may be a greater investment of time in model building. Modelling and visualization staff may be seconded to work on the project full-time and models may become a focus for design and a repository of design knowledge. These models may be returned to over an extended period and used for integration of different subsystems and design checking.

Companies that work on small projects have gained benefit from using virtual reality at the customer interface when they have been able to reduce the resource input by re-using models on many projects. Virtual reality has been used successfully on such small projects, though budgets for hardware and software are low and few hours can be invested in model building on individual projects. Less functionality is required and a library of forms approach to model creation is suitable.

Suppliers begin to develop and customise VR applications to the needs of construction sector users; as competitors begin to use VR and as regulators and customers begin to demand or expect the use of VR. As the cost of hardware, software and modelling time associated with the use of VR fall, the cost effectiveness of using VR on small unique projects (such as those designed by architects) may increase (as shown by the arrow in Figure 1).

5. CONCLUSIONS

Though architectural applications of virtual reality have been discussed for more than ten years, industrial application is still in its early stages. There is not one typical user of virtual reality in the construction sector. Early adopters have different strategies and business drivers for implementing and using virtual reality in their businesses. Strategies can be characterised as systems integration; supporting the customer interface; and exploiting new market opportunities. It is consultant engineers, construction contractors and real estate owners rather than architects that have made the largest investment in virtual reality for the architectural design and construction of the built environment.

Virtual reality is being used by groups of professionals working together in the project team, and also by building professionals working with clients, managers and end-users. Major business drivers identified by lead users are: demonstrating technical competence; design review; simulating dynamic operation; co-ordinating detail design; scheduling construction; and marketing. The approach that different organizations take may be affected by the extent of design re-use between projects and the size of the projects on which they work.

These findings suggest that lead users within architecture and construction have different priorities for the technological development of the virtual reality tools that they use. Though the focus in much of the academic literature is on the longer-term integration of packages that will be usable by everyone, different business drivers and corporate strategies suggest that one generic technology will not satisfy all user groups, but that overlapping families of technological solutions may be developed. Further work is required to test the conclusions of this work and to further explore the emerging patterns of use in construction and across other sectors of the economy.

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